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ANNOTATION

Dissertation for the degree of Doctor of Philosophy (PhD) in the specialty

6D075500 - Hydrogeology and Engineering Geology

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Topic: **"Studies of colmatization processes on experimental systems of artificial groundwater recharge in South-Eastern Kazakhstan".**

The problem of growing deficit of water resources in the world, including the arid zone in Kazakhstan, caused by global climate warming and aggravated by long distances to natural sources of good quality water, requires the combined use of surface and groundwater from local aquifers to supply the local population with quality drinking water.

The new State Water Resources Management Program envisages measures to reduce the expected water resources deficit through modernization and development of infrastructure, efficient use of water resources, including large-scale implementation of artificial groundwater recharge systems (hereinafter referred to as AWRRS).

When solving the problems of decentralized economic and drinking water supply of remote rural settlements, pasture watering, oasis irrigation areas, more and more interest is shown to the method of IWDWR, the essence of which is to transfer surface water into groundwater by infiltration or injection into the aquifer.

With the help of special infiltration facilities, IWRM as the most important tool of water resources management is applied also as an effective method to combat aquifer depletion in hydrogeological and water management practice and to prevent reduction of water supply to consumers.

Application of artificial groundwater recharge methods can be effective only under condition of obtaining positive characteristics of soil and ground parameters of aeration zone and productive aquifers in the processes of infiltration and colmatization, which are one of the determining indicators for ensuring productivity and duration of infiltration basins in a given regime.

Despite the importance of the problem under consideration, there are currently no methodological guidelines that would cover the hydrogeological basis for artificial recharge of fresh groundwater.

Meanwhile, artificial groundwater recharge, or pumping, can be an effective way to solve this problem. In the process of recharge, groundwater reserves are regulated, allowing to obtain the required amount of groundwater later. Besides, in arid conditions it is the only way to preserve the aquifer from depletion, to increase its storage capacity and to expand the area of the aquifer distribution with natural self-purification of water, which will allow to meet the needs of the population in drinking water. At the same time, the research concept should be based on the existing theoretical and technological approaches to this problem in the world practice.

One of the actual studies, determining the future effective operation of infiltration structures, is to identify the features of hydrodynamics of the filtration process. In modern science this issue is debatable and requires in-depth study.

Theoretical analysis of groundwater movement under infiltration basins, trenches, canals ("open" infiltration structures in artificial recharge systems) is based on the classical theory of saturated flows. At the same time, in many cases the forecast of infiltration structures yield is not justified, and the forecast of groundwater surface level is not justified either. The reason for this is usually considered to be insufficiently complete consideration of factors affecting the nature of filtration under the basins These factors primarily include the formation of a weakly permeable silty film at the bottom of the basin, its compressibility, colmatization of the upper part of the filtering layer, temperature difference between groundwater and filtering water, etc.

The river valleys of South-Eastern Kazakhstan are a promising region of practical importance for improving water supply to rural settlements and remote pasture areas, where the presence of an open groundwater mirror and the absence of overlying water bearing sediments make the method of free infiltration most effective. They are confined to areas composed of Quaternary alluvial sediments mainly of modern and upper Quaternary age.

The deficit of water resources in the south-east of Kazakhstan, aggravated by long distances to natural sources of good quality water, requires the combined use of surface and groundwater from local aquifers to supply the local population with quality drinking water. It is argued that one of the relevant studies determining the future effective operation of infiltration structures is to identify the features of hydrodynamics of the filtration process.

Taking into account the prospects for the creation of IWWPI installations for their further practical use in South-East Kazakhstan, the need for comprehensive field studies on the study of infiltration and colmatization processes at the experimental sites becomes obvious.

In this regard, the **main purpose and direction of research** were focused on the issues of studying the main factors affecting the processes of colmatization in the bases of infiltration basins, as well as the basic determinants of the prospects and effectiveness of the IWRWR systems at the stages of feasibility study and subsequent working one-stage design. In this case, the following basic and determining criteria are used in the work:

- the presence of a potential consumer of stored water at the WUIWUI sites. Such consumers are those rural settlements where residents use either imported water for drinking water supply, pasture watering and oasis irrigation or when available surface sources do not meet sanitary-epidemiological requirements;

- availability of water-bearing layers (horizons) with sufficient potential to accept an appropriate volume of stored groundwater reserves, of the required quality and in the required quantity;

- the possibility of using the selected IWRM site as a model site for dissemination of the obtained data to similar areas for further implementation and utilization of the research results;

- possibility of organizing experimental works at the site;
- cost and other technical and economic indicators.

The research methodology was determined by the set goals and objectives, and the study of parameters in the composition of research and study of colmatization processes was based on the existing in the world practice modern technological approaches to this problem.

The hypothesis of scientific research was formulated as an assumption of comprehensive study of such a problematic and little-studied issue as the infiltration process in the presence of a colmatizing layer, when during infiltration the characteristics, parameters and conditions of this process can change. It was assumed that the degree of studying the main parameters of the colmatization process as a result of integrated scientific research will determine the correctness and serve as a reliable and real basis for future projects of infiltration basins in the integrated use of water resources under conditions of their increasing scarcity and global climate change.

In this connection, the **main objectives of the present work** were to develop the organization of representative research plots, methods of complex field studies in infiltration mini-basins within the river valleys of Aksu, Lepsy and Koksu, accepted as typical for the territory of South-Eastern Kazakhstan, which is most in need of improving water supply to rural settlements and remote pasture massifs.

When organizing the sites, poorly studied and insignificant types and volumes of scientific and applied research on the territory of South-East Kazakhstan in the field of hydrogeology, engineering geology were taken into account, therefore, large-scale comprehensive studies to obtain reliable in-situ characteristics and parameters were set and organized in the **list of priority tasks.** Detailed assessment of water-physical, hydrodynamic and filtration properties of cover sediments and upper aquifer layers was added to these studies.

Availability of a guaranteed source of groundwater recharge is one of the important factors determining the scheme and efficiency of infiltration facilities, including the formation and influence of colmatization processes in the bases of infiltration basins on the whole system. Of the physical indicators, turbidity is the most important. In case the turbidity of water is higher than normal, its use can lead to a serious problem and cause colmatization of sediments in the bottom of infiltration basins, even in spite of special water treatment to reduce turbidity to MAC (5 to 20 mg/dm^3).

In this regard, the **list of priority tasks in the work** includes the **study and subsequent** quantitative and qualitative assessment of anthropogenic changes in river flow of the main rivers as a source of field studies of colmatization processes in the bases of infiltration basins in the design of IWRM systems with the use of a database on average monthly and average annual water discharge for the entire period of systematic observations up to 2014 inclusive, supplemented and adjusted to the hydrological observations conducted by the author in those years.

For arid conditions of South-Eastern Kazakhstan the leading role is played by mechanical colmatization, caused by the transfer of physical weathering products by river runoff and, especially, by flood waters. Therefore, in the dissertation work the

primary importance is given to carrying out full-scale studies of turbidity values of surface waters of rivers on representative and experimental sites of Southeast Kazakhstan to study colmatization and assess its impact on the processes of colmatization when used as a source of artificial replenishment of groundwater reserves.

Defensible statements in the performance of this research work:

- study of the processes of filtering layer colmatization, rates of silt layer and film formation at the bottom of the basin and their influence on the filtration capacity of the basins. Quantitative assessment of the degree of siltation of infiltration structures;
- identification of possible changes of boundary conditions in time and degree of hydraulic connection of surface and ground waters - groundwater level separation from the infiltration basin at its silting up and change of the underpinned filtration regime by sprinkling;
- methods and equipment for field studies of the IFB permeability depending on the granulometric composition and degree of homogeneity of the filter layer;
- study of siltation and colmatization rates under the influence of physico-chemical and biological processes and justification of periodicity and methods and types of restoration works;
- forecast of surface water quality used for infiltration basin filling and groundwater withdrawal under conditions of artificial recharge; systematic control over the efficiency of water used for recharge.
- justification of optimal groundwater exploitation regimes at the water intake taking into account natural and disturbed hydrodynamic and hydrochemical regimes of surface and groundwater at the intake site;
- assessment of the variability of artificial replenishment efficiency over time and justification of measures to improve it;
- development of specific recommendations to prevent, mitigate or apply preventive measures to colmatization processes.

The relevance of scientific and full-scale experimental studies lies in the fact that they allowed to substantiate the features and perform a long-term forecast of hydrodynamics of infiltration processes and deep colmatization, which in the first place predetermines the future effective operation of infiltration structures. In modern science this issue is debatable and requires in-depth study.

To solve the forecasting tasks the development and creation of numerical models of geofiltration and mass transfer was performed, i.e. system models of colmatization processes were built on the basis of actual initial data obtained as a result of long-term experimental studies and long-term forecast of colmatization of the filtering medium in the cover and alluvial sediments of the plain part of the water basins of the rivers of South-Eastern Kazakhstan. For this purpose the program complexes Visual MODFLOW Pro and HYDRUS-1D were applied, often used in researches by foreign and domestic scientists and specialists.

The use of the program complex "Visual MODFLOW Pro" allowed to substantiate hydrodynamic and water-balance characteristics as well as to make a long-term

forecast of groundwater level reductions in the network of water intake wells located on pasture massifs within the representative area.

The following tasks were accomplished in the modeling process:

- A numerical model of groundwater filtration in the upper unconfined aquifer was created and calibrated, taking into account the main hydrogeological and reclamation conditions of the research area;
- peculiarities of the formation of balance components of groundwater flow during 2018-2020 have been performed and scientifically substantiated under the conditions of global climate change;
- forecast estimation of changes in groundwater table depth and balance components of groundwater flow under conditions of water withdrawal from wells located at watering points.

Experimental studies of infiltration rate, specific water yield of infiltration surfaces and study of colmatization processes were conducted at each of the four Aksu sites and one each in Lepsa and Karatal-Koksu regions of South-East Kazakhstan separately and differentiated depending on the water content of the hydrological year in the period from 2017 to 2020 using **methods** based on the assumptions of steady and unsteady filtration regime.

Scientific novelty consists in the fact that in order to obtain the necessary parameters for research of colmatization processes in open infiltration basins under the IWWPI an **innovative and unified approach of** simulation of natural conditions of water infiltration up to full saturation of the tested capacity of rocks of cover sediments and dynamics of infiltration flow formation into the upper layers of water-saturated sediments of the first from the surface unconfined aquifer at close groundwater table at the created water table was **chosen.**

Large-scale field and laboratory studies on detailed study of colmatization processes on constructed and equipped physical models of mini-basins with infrastructure of water intake and drip structures, imitating optimal for conditions of South-East Kazakhstan system of IWWTP were carried out **with attraction of software modeling and modern tools and innovative methods and technologies of digitalization.**

The scientific and practical significance of the performed research was that for the first time the priority was given to full-scale field and laboratory works, the results of which served as a primary characterization of the fundamental parameters of formation and physical activity of colmatization processes.

In the course of experiments, in addition to measurements of water flow rate, the turbidity of supplied water, thickness of muddy sediment, volume mass of muddy sediment skeleton, which are initial parameters for calculations of water filtration under colmatization conditions, were determined.

The experiments were carried out taking into account the actual value of the main river flow, which starts annually in March and ends in late October at different water availability of the hydrological year: from 25 to 75% of water availability, in connection with which the total duration of the infiltration period under the use of artificial groundwater recharge systems was annually about 8 months during four years.

For the first time in the practice of hydrological works, full-scale studies of instantaneous values of turbidity of surface waters of rivers were carried out by the photometric method - point measurements using a portable turbidity meter when taking water samples and control laboratory analyses by the weight method.

Such large-scale and long-term experiments in the domestic practice of research in Kazakhstan **were carried out for the first time**, the **results of which allowed to** finally identify both the nature of the change in the rate of infiltration, and its transition through certain control values, conditionally serving as a quantitative benchmark for assessing the terms of the filter cycle, and exclude the element of chance in identifying the probabilistic-statistical nature of the change in the rate of infiltration both by area and depth.

In addition, fillings were made in the aeration zone soils and bedrock of the upper part of undivided modern and Upper Quaternary alluvial-proluvial sediments located at different distances from river channels and differing in lithological and granulometric composition, water permeability parameters and depth from the ground surface.

Field pilot infiltration studies **allowed to identify for the first time the** infiltration capacity of the aeration zone; to establish the regularities of colmatization development; to determine the parameters of infiltration structures for the IWWTP; to estimate the exploitable groundwater reserves taking into account their artificial recharge; to forecast changes in groundwater quality. **This allowed to give more objective and more large-scale and detailed characterization of** water **infiltration processes** and actual colmatization through the aeration zone soils and underlying sediments of the upper part of the aquifer prospective for the IWWTP, which finally served as a real possibility to unify the obtained data for similar rivers of South-Eastern Kazakhstan.

Data from field and laboratory studies of the hydrochemical regime of surface and groundwater were used to substantiate the created geofiltration models.

Thus, the created one-dimensional model of moisture transfer in the zone of incomplete saturation at the Aksu experimental site and calculations of balance components of moisture transfer of two variants using the HYDRUS-1D program made it possible to

- estimate the volume of water entering the unsaturated zone of the soil profile;
- characterize the flow rate of water filtered into the aquifer from the infiltration basin;
- evaluate the accuracy and reliability of the created model by comparing them with the field experiment data.
- quantitatively evaluate the most important hydrophysical functions of soils composing the soil profile: dependence of moisture and saturation coefficient on hydrostatic head;
- analyze balance components of infiltration flow in the zone of incomplete saturation and calculate the volume of filtered water, which will be further supplied to replenish groundwater reserves of the underlying aquifer.

- to substantiate that at creation of infiltration basins opening sandy sediments, formation of colmatation layer due to settling of suspended particles of surface waters of Aksu river will not significantly affect the infiltration process.

The created geofiltration model of groundwater of the upper unconfined aquifer of undivided modern and upper Quaternary sediments at the Aksu experimental site using the program complex "Visual MODFLOW Pro" made it **possible:**

- to study the main parameters characterizing the process of groundwater filtration for the characteristic lithological section for the conditions of the experimental site on the Aksu River;
- evaluate balance components of groundwater flow in the zone of full saturation and the role of Aksu River surface runoff in groundwater formation within the experimental site in the interfluve of Aksu and Akozek rivers;
- to give forecast estimation of operational water withdrawal availability under the given scheme of designed watering points location;
- assess the prospect of artificial maintenance of the required water level in water intake wells using infiltration basins.

Degree of implementation and cost-effectiveness.

The performed large-scale research of scientific and applied character on the study of colmatization processes on physical and mathematical models of representative and experimental sites of IWWRM undoubtedly confirmed the justifiability and full compliance with the **truth of the** put forward and **formulated hypothesis of scientific research;** reasonably indicate a **sufficiently high degree of their scientific and technical potential** as a reasoned tool for the introduction of small-scale IWWRM systems in all identical regions of the arid zone of the Republic of Uzbekistan.

Field experimental studies allowed to evaluate infiltration and colmatization processes using a comprehensive set of field experiments, monitoring and laboratory studies for typical soil profiles in the southeastern region of Kazakhstan. Infiltration tests using original mini-basins, simulating in miniature the IWRM system optimal for this region, allowed to study the processes of water runoff in different soil profiles under the mini-basin and the creation of a clogging layer under local natural conditions.

Particle size analysis of soil samples allowed to reliably determine the mechanical composition of all major soil types - loams, sandy loams and sands that make up the upper part of the soil profile in areas of potential infiltration basin construction. Based on sets of infiltration tests, values of soil hydraulic coefficients were found for the saturated state over the entire soil profile from the soil surface to the upper unconfined aquifer.

Four-year monitoring observations allowed to substantiate the level regime and chemical composition of groundwater in the upper unconfined aquifer, changes in turbidity of surface water of the Aksu, Lepsy and Koksu rivers in the annual section and depending on the water content of the year as a potential source of water for infiltration basins.

The obtained positive results of field studies can serve as a factual basis for design, as well as can be recommended and accepted as design indicators both at the stage of

feasibility study and at the stage of detailed design of artificial groundwater recharge systems without additional labor-intensive and costly survey work, and the approved methodology of their implementation will be useful in conducting similar studies in other regions.

Recommendations of the created models can be further used as an automated permanent mathematical tool by water and agriculture authorities not only on the territory of research works of scientific-applied nature, but also by economic entities when performing operational operational water management settings under conditions of growing water resources deficit and glabal climate warming.

Global warming, reduction of river flow, some causes of negative impact as a result of increasing anthropogenic load cannot but have a direct or indirect impact on the composition and concentration of polluting ingredients in river water, which is projected as the only source of WWTP. On the basis of scientific and laboratory innovative research practical recommendations on the use of river runoff as a source for the installation of IWRWTP, long-term forecast of environmental indicators of groundwater under artificial replenishment, taking into account the processes of mixing and self-purification during infiltration. High efficiency of using surface infiltration basins for artificial groundwater recharge is shown.

It should be emphasized that these studies were aimed at developing the necessary measurements and methods applicable to local conditions, and more objective and more extensive and detailed characterization of water infiltration processes and actual colmatization were the initial field information for the implementation of the relevant part of the project "Assessment of fresh groundwater resources as the main source and long-term reserve of sustainable drinking water supply for the population of the Republic of Kazakhstan" funded by the Komi Republic of Kazakhstan

Some provisions of the dissertation work and the **results of scientific - research work** were approved in international and republican scientific conferences and were reported at a number of scientific-practical conferences, regional seminars and at round tables of public organizations, employees of the agrarian sector of the Ministry of Agriculture of the RK and scientists of the Republic with the participation of a number of international organizations (UNESCO, UNDP) and representatives of donor companies working in Kazakhstan in the field of agriculture.

Thus, the main provisions defended in the dissertation work on environmentally safe technologies for integrated management of water sources aimed at the most efficient use of local surface and groundwater resources were considered and approved at seminars organized in 2018-2020 by the Akimat of Enbekshi-Kazakh district of Almaty region for heads of farms on the initiative of the Public Fund "Farmer of Kazakhstan" and the Republican Association of Agricultural Cooperatives "AgroSoyuz of Kazakhstan".

The author expresses special gratitude to rural Akimats for the opportunity to conduct research on the territory of South-East Kazakhstan, for allocated areas for the arrangement of infiltration mini-pools and organization of complex experimental sites, for providing practical assistance in conducting field experiments.

The author would like to personally note and thank Dr. Shakibayev I.I., Head of the Zonal Hydrogeological and Ameliorative Center of the Ministry of Agriculture of the Republic of Kazakhstan and his specialists for providing equipment and practical and methodical assistance in laboratory measurements and field experiments, as well as Chernykh A.L., General Director of "GISS" LLP and his employees for providing technical assistance in installing and equipping observation piezometers at the experimental site.

According to the results of the performed research works 8 articles were published and 3 reports were made, 2 of which were published in international editions included in the database of Scopus and Thomson Reuters, and 3 articles in scientific editions recommended by the Committee for Supervision and Attestation of the Ministry of Education and Science of the Republic of Kazakhstan.

One article: M.K.Absametov, E.Zh.Murtazin, V.V.Kulagin, A.T.Makyzhanova, A.Zh. Ismagulova "Infiltration and colmatation dynamics on physical models study by infiltration basins at artificial groundwater recharge" has passed all procedures, approved and accepted for publication in the journal "Water Conservation and Management (WCM), included in the database of companies Scopus, Malaysia.

Two articles are prepared for printing in 2022 upon completion of desktop processing of the final results of field studies and modeling of colmatization processes, and sent for expert review to foreign publishers included in the database of Scopus and Thomson Reuters.

Personal contribution of the author. It consists in setting up and conducting experiments and research, generalizing and interpreting the results obtained, writing articles.

Publications. The results of the work are reflected in 8 scientific papers, including: Scientific articles indexed by Scopus database.

Structure and scope of the thesis. The dissertation consists of a thesis, literature review, description of objects, research methods, results of research experiments and discussion, conclusion and a list of used sources of 155 names.

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