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IMPROVED TECHNIQUES FOR EXPLORATION OF GROUNDWATER DEPOSITS FOR CONDITIONS OF RURAL AREAS OF THE MANGYSTAU PENINSULA

Purpose. Development of an innovative methodology for exploring groundwater deposits for the conditions of rural areas of the Mangystau Peninsula, which will allow finding sources of groundwater with acceptable mineralization with a minimum number of drilled wells.

Methodology. The assigned tasks were solved using a comprehensive research method, which includes a review and synthesis of literary sources; patent market research; study of geological and hydrogeological conditions of the work area; critical analysis of existing methods for exploration of groundwater deposits; studying and summarizing previously conducted exploration work in the area and developing recommendations for improving exploration methods.

Findings. The reasons for the insufficient use of groundwater reserves on the Mangystau Peninsula have been established. A highly effective method for exploring groundwater deposits has been developed, taking into account the specific features of the Mangystau Peninsula – vast sparsely populated areas and the chaotic location of aquifers with acceptable mineralization. Reducing the number of wells drilled is achieved by searching and identifying the boundaries of the aquifer using successive cycles with a moving center, which allows you to systematically explore the area and find the best aquifers.

Originality. For the first time, a methodology for exploring groundwater deposits has been proposed, the main provisions of which are as follows: exploration wells are drilled with a small diameter, and only wells that have uncovered horizons with acceptable mineralization are subject to expansion; wells are drilled using a combined grid, combining the capabilities of radial and regular grids; the centers of the first cycle of the exploration grid are existing water intakes containing water with acceptable mineralization; from such centers, drilling is carried out along a radial grid of six wells; when a horizon with acceptable mineralization is discovered, the discovered well becomes the center of the second cycle of a radial grid of six wells, at least three of which have already been drilled in the previous cycle. Further exploration continues with subsequent cycles with the goal of constructing wells with acceptable flow rate and mineralization.

Practical value. The implementation of the developed methodology is of great practical importance for the further development of oil and gas production, industrial production and agriculture of the Mangystau Peninsula, as well as social significance for meeting the needs of the growing population of the region for high-quality water for drinking and household water supply. The use of the developed methodology makes it possible to reduce the number of useless wells, minimizing exploration costs.

Keywords: *groundwater, exploration methodology, well grid, Mangystau Peninsula*

Introduction. A significant portion of Kazakhstan's territory, including the central, southern, and western regions, falls within desert and semi-desert zones characterized by scarce precipitation. Since 2003, the country has been implementing the "Drinking Water" program, aimed at fully providing potable water to more than 7,000 settlements. Water supply systems were to be connected to 174 villages, as well as 86 cities and urban-type settlements. The program's works lasted for 8 years, and a budget of 195 billion tenge was allocated for its implementation. After the program's completion, the work continued under the "Ak-Bulak" program (2011–2020) [1]. According to this program, by 2020, 85 % of Kazakhstan's rural population and 100 % of the urban population were to be supplied with quality drinking water from centralized water supply systems. A total of 1.3 trillion tenge was planned to be allocated for the program's implementation.

However, for various reasons, the realization of these programs was not fully achieved. The water supply issues in many areas remained unresolved.

The Mangystau Peninsula, located in the western part of Kazakhstan, possesses unique natural and geographical conditions that significantly affect the availability of water resources. Given the limited surface water sources, groundwater becomes the main source of water supply for the population and various sectors of the economy. The Mangystau Peninsula is characterized by an arid climate with low precipitation and high summer temperatures [2]. These climatic conditions create significant challenges for the accumulation of surface water resources. Most of the precipitation evaporates before reaching the aquifers, leading to a shortage of water in open water bodies and rivers. Under these conditions, groundwater becomes the only reliable source of water supply.

The intensive economic development of the region, including oil and gas extraction, industrial production, and agriculture, requires significant volumes of water. Water is used not only for technological processes but also for the domestic needs of workers in these industries. Without a sustainable water supply source, economic development may be hindered, emphasizing the necessity of groundwater exploration and assessment.

The population growth on the Mangystau Peninsula demands an increase in water supply volumes for domestic and sanitary needs. A water shortage can lead to a deterioration in the quality of life, increased illness rates, and a decline in public health. Providing the population with sufficient quantities of quality drinking water is an important social priority.

Sustainable use of groundwater contributes to the preservation of the region's ecological balance. Groundwater exploration allows for the identification and protection of aquifers, preventing their over-exploitation and contamination. This is especially crucial in arid climates where ecosystems are vulnerable and require water resources to support their existence.

Modern groundwater exploration technologies allow for more precise and efficient identification of aquifers, as well as determining their volumes and quality. The integration of geophysical, hydrogeological, and geoinformation technologies enables the creation of more accurate models of groundwater resources and the development of strategies for their rational use. This opens new opportunities for the region's sustainable water supply.

Currently, the demand for drinking water on the peninsula amounts to 149 thousand m^3 per day, with a deficit of 51 thousand m^3 [3]. By 2025, the demand is projected to reach approximately 260 thousand m^3, and if no radical measures are taken to improve the situation, the deficit will range from 100 to 110 thousand m^3 [4].

Addressing this issue faces serious challenges. The peninsula lacks a river network. Water for the regional capital, Aktau, is obtained through seawater desalination. There are water pipelines, one of which supplies water from the Amu Darya River, and the other from the mouth of the Volga River. However, these facilities do not fully meet the region's water needs, which raises the critical issue of utilizing groundwater.

Previous exploratory work has identified several aquifers [5]. The most important criterion for their use is mineralization. For freshwater, the mineralization level does not exceed 1–2 g/L (drinking water), and for brackish water, it is no higher than 5 g/L (used for irrigation and livestock) [6].

Groundwater exploration on the Mangystau Peninsula is essential for ensuring the region's sustainable economic, social, and environmental development. The region's climatic conditions, economic development, population growth, and environmental demands make groundwater the primary and most reliable source of water supply. Modern technologies enable efficient exploration and assessment of groundwater resources, contributing to the rational and sustainable use of the region's water resources.

Literature review. The groundwater system at key locations of the Jianghan Plain for the study on optimizing the groundwater monitoring network based on the groundwater flow system classification in Hubei Province was analyzed in the work [7]. The adopted dynamic groundwater mapping method provided a geological basis for the installation of groundwater monitoring wells. A quantitative assessment of water level interpolation accuracy for evaluating the monitoring network density was carried out using the Kriging interpolation method. As a result of the study, the monitoring well network was expanded from 77 to 107. The optimized monitoring network in the study area can help obtain scientific and comprehensive information on groundwater dynamics.

In the study [8], conducted in a pilot area in central Italy, several factors, such as hydrogeological conditions, groundwater vulnerability, as well as natural and anthropogenic pollution levels, were analyzed and used in designing a network tailored to the monitoring objectives, specifically, the study of groundwater quality evolution related to natural conditions as well as pollution processes occurring in the area. A geographic information system (GIS) was used as the basis for evaluating the network density, and water supply points were ranked based on several factors, including discharges, actual pollution levels, maintenance conditions, and accessibility for periodic sampling to select the most suitable points for the network. It was found that the GIS procedure, such as point distance analysis (PDA), is technically faster and simpler to perform than other procedures used for these purposes. The applied GIS procedures made it possible to select the required number of water supply points (50 out of 121 candidates) from the initial set, evaluating the most reliable ones and the corresponding network density.

The dynamic groundwater mapping method based on GIS development was used to optimize the distribution of positions for a dynamic monitoring network in the Ordos Basin [9]. The aim of the optimization was to observe the regional dynamics of groundwater with a reduced number of observation wells. The optimization also considered the distribution of vegetation, which is closely related to groundwater. The method identified and evaluated the positions of 28 new observation wells to optimize the existing groundwater monitoring network.

In the article [10], the existing closed water monitoring networks in the plain area of Hohhot (Mongolia) were selected as the research target, and the standard deviation of estimation error was adopted as a parameter for evaluating the rationality of the monitoring networks. Using the ArcGIS geo-statistical module, interpolation of the studied points was performed with the Kriging interpolation model to obtain a contour line of the estimation error's standard deviation. The results showed that the standard deviation of the water level monitoring error changed from 0.47–4.44 (before optimization) to 0.5–0.8 (after optimization, except for the area near the southwestern boundary of the study region). Thus, the overall standard deviation of the estimation error significantly decreased.

The study [11] demonstrates a reliable and transferable groundwater monitoring network (GMN) design structure for poorly studied statistically homogeneous depth to groundwater (DTW) to facilitate appropriate, long-term, cost-effective, and regional groundwater monitoring. The natural homogeneity of DTW data on a regional scale was explored for grouping observation wells into 18 strictly structured clusters/layers using the optimal number of clusters (k = 18), which corresponded to the highest average silhouette score of 0.72, and the K-means clustering algorithm. Clustered observation wells were used to evaluate cluster random sampling (CRS) and stratified random sampling (SRS) for GMN design. Sampling methods were assessed to reveal the spatial variability of DTW across the study region through spatial modeling with adequate accuracy using inverse distance weighting (IDW) interpolation tools. A GMN with 540 wells was designed, corresponding to 70 % sampling under SRS for accurate, cost-effective, and long-term groundwater monitoring. As a result, the number of observation wells was reduced by 30 %.

The article [12] presents a new approach combining the gamma test and a monitoring priority map for the optimal design of a groundwater monitoring network (GMN), taking into account the cumulative impact of industrial activity, human activities, and natural factors on groundwater quality. The proposed method was successfully applied to create an optimal groundwater salinity monitoring network on Kish Island in the Persian Gulf. The optimal number of monitoring wells was determined using data analysis through the gamma test method. A practical algorithm for determining the optimal placement of monitoring wells was then presented. According to the results, the optimal number of monitoring wells is 110, and their locations are evenly distributed across the island.

The article [13] proposes a method for optimal monitoring network design to obtain groundwater level data with high spatial significance at low costs. It utilizes the reduction of estimation error variance obtained using a static Kalman filter as the optimization criterion while simultaneously evaluating optimal routes to solve the traveling salesman problem. It was tested on a network of 49 wells in the Calera aquifer in Zacatecas, Mexico. The study area was divided into three zones, with one working day (8 hours) allocated for visiting each zone at an average speed of 40 km/h and a sampling time of 0.5 hours. The proposed method resulted in an optimal network of 26 wells, while 21 wells would need to be monitored if optimal routing is disregarded. The average standard error when using the original 49-well network was 35.01 m, with 38.35 m error for the 21 wells (without optimal routing) and 38.36 m for the 26 wells selected by the proposed method. However, the latter yielded estimates closer to those obtained from the 49 wells. Following this proposal allows for the collection of more field data, thereby reducing costs.

The study [14] proposes a method for optimizing a quantitative groundwater monitoring network by selecting the optimal number of sampling wells and determining their optimal locations to reduce the costs and time of groundwater assessment. Data from 110 observation wells on the Neyshabur Plain in Iran, covering the period from 1986 to 2016, were analyzed. The combined "Selection-Kriging" method was used for analyzing the data, and a Pareto diagram was constructed to determine the optimal number and location of wells in two scenarios. The first scenario involved determining the optimal location of wells among existing wells, while the second scenario focused on identifying the optimal placement of wells for groundwater level monitoring across the entire plain. To limit the search space, the maximum and minimum number of monitoring wells was set at 30 and 85, respectively. The results showed that the selected method accurately ensured the appropriate placement of wells. In the first scenario, RMSE values for the number of wells ranged from 0.71 to 2.34 m, which are acceptable. In the second scenario, RMSE values ranged from 1.04 to 2.89 m, which are suitable in accordance with the task's objective. Additionally, the spatial distribution of the selected wells in most locations was also uniform in the second scenario, demonstrating the method's high accuracy.

Unsolved aspects of the problem. The analysis conducted has shown that the issue of designing a network of wells for the exploration and monitoring of groundwater is a relevant problem being addressed by specialists worldwide. However, despite the existence of various methods for exploring deposits, they do not yield sustainable and stable results in the conditions of the Mangystau Peninsula. This can be explained by the following factors:

1. The extensive arid territories of the peninsula require drilling a large number of exploratory wells according to existing methodologies, which in turn leads to high costs and makes exploration activities unprofitable.

2. The chaotic distribution of areas with acceptable mineralization necessitates the use of high-resolution grids, which is also economically unfeasible.

Thus, the **purpose of the article** is to develop an improved method for exploring groundwater deposits suitable for the rural areas of the Mangystau Peninsula, which will allow for the identification of groundwater sources with acceptable mineralization while minimizing the number of drilled wells.

Objectives of the work are:

1. To analyze the reasons for the low utilization of explored groundwater reserves in the Mangystau Peninsula area.

2. To study the characteristics of shallow aquifers and consider their potential for supplying water to rural areas of the peninsula.

3. To develop an effective method for exploring shallow aquifers to establish locations for prospective wells for subsequent transfer to local enterprises.

4. To examine the features of using the proposed methodology through examples.

Methodology. The tasks set forth were addressed using a comprehensive research method that includes reviewing and summarizing literary sources; conducting patent and market research; studying the geological and hydrogeological conditions of the work area; critically analyzing existing methodologies for exploring groundwater deposits; examining and summarizing previously conducted exploratory works in the area; and developing recommendations for improving the exploration methodology.

Results. ***Ways to ensure groundwater supply for rural regions of the peninsula***. The difficulties in addressing the water supply problem for rural settlements are related to their large number and the vast territories they occupy. Cost reductions can be achieved by utilizing aquifers located close to the surface, which are relatively widespread on the peninsula [15].

The aquifer of Quaternary deposits is found in the southeastern and northwestern parts of the region [16]. Water is located in sands with a grain size of 0.05–0.25 mm and a filtration coefficient of about 5 m/day. The thickness of the aquifer layers ranges from 5 to 24 m, with a depth of occurrence of 7–12 m. The static level is 3–7 m. The discharge of drilled wells ranges from 0.5 to 2.1 L/s with a lowering of 3–4 m. The mineralization at some sampling points may be 2–3 g/L, while in neighboring areas, it can reach up to 50–70 g/L.

The complex of middle-upper Pliocene deposits is widespread in the southeastern part of the region [17]. The water-bearing rocks are encountered at depths of up to 18 m, with a thickness ranging from 5 to 11 m. They consist of fractured limestones and medium- to fine-grained sands, with a filtration coefficient of 5 m/day. The static level varies from 3 to 10 m depending on the surface level and depth of the layer. Freshwater predominates, with mineralization ranging from 0.2 to 1 g/L. The flow rate of drilled wells is between 0.5 and 0.6 L/s with drawdowns of 0.5 to 1 m.

The complex of middle-upper Miocene deposits is widely distributed throughout the peninsula and is encountered in several dug wells at depths ranging from 6 to 12 m [18]. These are predominantly unconfined waters. The aquifer is represented by fractured limestones and marls. The flow rate measured in one of the dug wells was 0.2 L/s with a drawdown of 0.8 m. The mineralization of the water was 1.6 g/L. No data is available for other dug wells, nor for drilled wells.

The Maastrichtian aquifer is distributed throughout the region [19]. It is represented by fractured chalk layers. The depth of the roof in the northern part is about 10 m, while in the southern part, it reaches up to 60 m. Accordingly, the static level varies from 5 to 20 m. The flow rate from drilled wells does not exceed 1 L/s with drawdowns of 5 to 20 m. Depending on the location of the extraction point, the waters can be fresh, brackish, or saline.

The aquifer complex of Albian-Cenomanian deposits is widespread in the northeastern part of the region [20]. The waters are located in layers of heterogeneous sands with a filtration coefficient of about 6 m/day. The thickness of the layers ranges from 5 to 65 m. In the north, the depth encountered by dug wells is 5–10 m, while to the southeast, the depth increases to reach 200 m. In this direction, the static pressure also increases, and the static level can reach 54 m above the ground surface. The flow rates of the wells increase along with the pressure, ranging from 3 to 6 L/s in the north and reaching 45 L/s in the south. In the northern part, the mineralization ranges from 2 to 4 g/L, while in the south, it increases to 8.6 g/L.

The study of the aforementioned aquifers varies, but overall, it is recognized as insufficient [2]. Information regarding the number of wells on which the final figures are based is lacking. For the middle-upper Miocene aquifer, there is no information on drilled wells at all, and the data provided is based on the study of a single dug well.

A significant issue is that even after the completion of exploration work, the results are utilized to an unsatisfactory degree. For instance, at the Samskoye field in 1969, the established groundwater reserves were utilized only by 18 %. By 2009, groundwater extraction in this area had ceased entirely [20].

Water extraction wells on the peninsula were primarily drilled using the UGB-50 lightweight drilling rig. The maximum recommended diameter for these wells is only 150 mm, which limits their flow rate. This flow rate is defined as [21]

$$Q = UL\pi D, \tag{1}$$

where L is the length of the water-collecting part of the well (in meters); D is the diameter of the water-collecting part (in meters); U is the allowable inflow velocity (in m/h). The latter is defined as [22]

$$U = 2.71\sqrt[3]{K_F}, \tag{2}$$

where K_F is the filtration coefficient of the aquifer (in m/day).

From formula (1), it is evident that the flow rate is directly proportional to the diameter of the well. Clearly, with the low filtration coefficients typical of the peninsula, wells drilled using rotary drilling, which generally do not exceed 200 mm in diameter, do not provide satisfactory flow rates. This is likely a significant reason for the low level of utilization of the established groundwater reserves.

It is advisable to use impact-cable drilling rigs like the UKS 22M, which have a final casing diameter of 324 mm [23]. This should increase the flow rates of the wells by more than twice compared to the UGB-50 installations due to the increase in the diameter of the water-collecting part.

In global practice, the technology for constructing water extraction wells with a final diameter of up to 1.5 m or more is used [24]. At such diameters, the power of most modern drilling rigs is relatively small, ranging from 30 to 60 kW, which is related to the use of low rotor rotation frequencies (6–16 RPM).

The complexity of providing groundwater for rural regions, besides their vastness, also lies in the close and random arrangement of areas with acceptable and unacceptably high mineralization in the promising aquifers in the region [2]. Exploration of such horizons requires drilling wells on a grid with exceptionally high resolution, which is economically unfeasible.

Methodologies for designing well grids for groundwater deposits. The design of well grids for exploring groundwater deposits involves several methodologies, each with its own characteristics and applied according to specific conditions and research objectives. Let us examine the main methodologies in more detail.

The regular (linear) grid is one of the simplest and most common methodologies. In this case, the wells are arranged in a regular pattern, such as in a square or rectangular grid. This method is convenient for planning and implementation, as it ensures uniform coverage of the area and allows for easy interpretation of the obtained data [25]. However, it may not take into account the specific geological and hydrogeological conditions of the region, which can lead to some wells being located in non-aquifer zones while there may be insufficient wells in promising areas. Moreover, in the arid conditions of the Mangystau Peninsula, such a grid does not provide the results required for a significant increase in the practical utilization of existing aquifers. Factors such as the vast territory and chaotic arrangement of zones with varying mineralization of groundwater necessitate the use of exploration grids with very high resolution, which requires drilling a huge number of exploratory wells and investing substantial funds.

The ***radial grid*** involves arranging wells radially from a central point, which is usually located at the center of the proposed deposit. This method is convenient for localized studies, as it allows for a focus on the central part of the deposit. However, the radial grid limits area coverage and may miss peripheral aquifers.

The ***stepped grid*** combines large grids for extensive areas with smaller grids for detailed study of promising sites. This approach allows for efficient resource utilization by directing them toward a thorough examination of prospective areas. Additionally, the stepped grid provides flexibility in planning and allows for adjustments during the work process. However, this method is complex in design and implementation, requiring additional time and resource investments.

The ***adaptive grid*** is a method where the well grid is adjusted based on preliminary data and current drilling results. This approach offers high accuracy and adaptability to real conditions while optimizing costs by reducing the number of unpromising wells. However, the method requires constant data analysis and plan adjustments, which can be challenging to implement without specialized software.

The ***geostatistical grid*** employs geostatistical methods for optimal well placement based on spatial analysis and modeling. This approach ensures high accuracy and scientific justification, as it takes into account the spatial variability of aquifers. However, the geostatistical grid requires complex analysis and specialized software, leading to high initial research and modeling costs.

The ***combined grid*** integrates various methodologies to create an optimal well network. This approach allows for maximum adaptation to geological and hydrogeological conditions while optimizing costs and time for exploration. However, the combined grid is complex in design and implementation, requiring a comprehensive approach and expertise in various methodologies.

The choice of methodology for designing a well grid for groundwater exploration depends on numerous factors. Among these, geological conditions play a crucial role, including the type and structure of the rocks, as well as the depth of the aquifers. Hydrogeological conditions, such as the presence and distribution of aquifers, their productivity, and water quality, also significantly influence the selection of methodology. Furthermore, it is essential to consider the research objectives, including scale and detail, as well as the required data accuracy. Finally, available financial and technical resources, along with the time allotted for the work, play a decisive role in making the decision regarding the methodology.

Under ideal conditions, the optimal approach is often to use a combined methodology, which allows for the adaptation of well planning to the specific conditions of the studied area, ensuring the most comprehensive and accurate examination of groundwater resources. This approach combines the advantages of various methodologies and minimizes their drawbacks, providing high efficiency and precision in exploration.

In the developed methodology, a positive result is achieved by creating a method for searching and determining the boundaries of the aquifer through the use of sequential cycles with the movement of the center. This allows for a systematic investigation of the territory and the identification of the best aquifers. Selecting the best wells based on water quality and yield ensures a more reliable water supply. The methodology enables a reduction in the number of unproductive wells, thereby minimizing exploration costs.

The developed methodology is based on utilizing the existing water intake facilities in the area for a detailed study of the adjacent sections of the corresponding aquifers. These water intakes may be represented by wells drilled as a result of previously conducted exploratory work. Overall, the number of such wells is insufficient, and for some aquifers, exploratory wells have not been drilled at all; the results presented in reports have been obtained using dug wells of the local population. The proposed methodology can also rely on these dug wells.

The movement from existing water intakes to find other acceptable water intakes is carried out according to a scheme based on the theory of experimental design [26]. An example of such movement is illustrated in Fig. 1.

Exploratory work includes the following stages:

1. Selection of the starting point. An existing water intake in the area is chosen, for example, dug well 1 (Fig. 1), which has acceptable water quality. It is taken as the starting (central) point for drilling exploratory wells.

2. Selection of the distance between exploratory wells. This parameter is a key factor in designing the well placement grid. When choosing the distance between water intake wells in the exploratory network, a number of factors must be considered that directly affect the effectiveness of exploration and the quality of the obtained data. First and foremost, the geological structure of the research area plays an important role. The heterogeneity of the rocks, the presence of fractured zones, and the variability of the aquifers may require closer spacing of wells to adequately cover the entire studied area. Hydrogeological conditions, including the productivity of the aquifer, its thickness, and filtration properties, must also be taken into account. In areas with low productivity or complex hydrogeological conditions, the distance between wells may be reduced to ensure a more accurate determination of the boundaries of the aquifers.

Another important factor is the degree of study of the area. In previously unexplored areas, it is preferable to choose a denser network of wells to gather as much information as possible about the groundwater and refine the geological and hydrogeological models. In places where preliminary data already exist, the distance between wells can be increased, as there is the possibility of adjusting the drilling plan based on existing data.

The quality of groundwater and its mineralization must also be taken into account. If significant variations in water quality are observed in the area, the distance between wells should be reduced to accurately identify zones with acceptable mineralization.

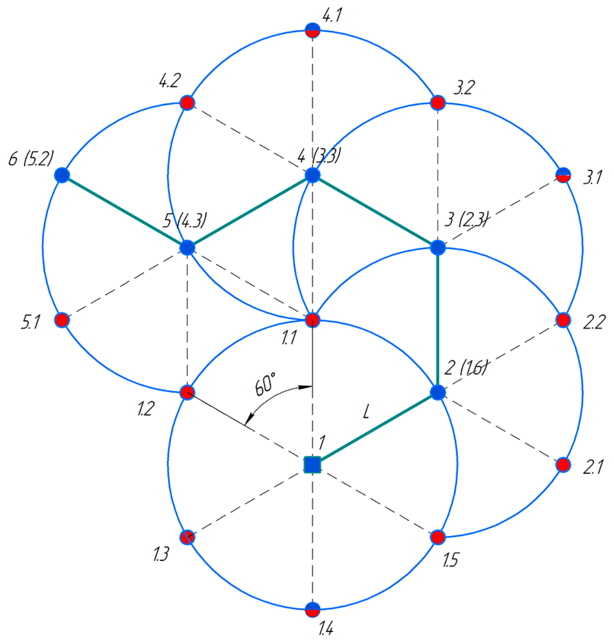

Fig. 1. Sequence of drilling exploratory wells for rural water supply according to the developed methodology:

1 – dug well; 1.1–1.5 – wells of the first cycle; 2 (1.6) – well of the first cycle, meeting all requirements for yield and mineralization, which becomes the central well of the second cycle; 2.1, 2.2, 3.1, 3.2, 4.1, 4.2, 5.1 – wells of the second, third, fourth, and fifth cycles, respectively (wells not meeting yield and mineralization requirements are marked in red); 3 (2.3), 4 (3.3), 5 (4.3), 6 (5.2) – wells of the second, third, fourth, and fifth cycles, respectively, meeting all requirements for yield and mineralization, becoming central wells of the third, fourth, fifth, and sixth cycles, respectively (marked in blue); 1.4, 3.1, and 4.1 – wells partially meeting the requirements for yield and mineralization (marked with a combination of red and blue); L – distance between wells. The color indicates the sequence of identifying prospective wells

Technical and economic constraints also play a role in determining the spacing of wells. Too close a spacing can significantly increase exploration costs, while too sparse spacing may lead to the omission of prospective areas or insufficient study of the aquifer. Furthermore, ecological and social factors, such as potential impacts on existing water sources or the surrounding environment, may limit the selection of optimal spacing.

Finally, the ability to interpret the obtained data and apply mathematical modeling methods for assessing groundwater must also be considered. The greater the distance between wells, the higher the likelihood of needing to employ more complex modeling methods to accurately describe the aquifers. Thus, the choice of well spacing is a compromise between geological, hydrogeological, technical, and economic requirements, as well as the need to obtain the most accurate data for assessing water resources.

3. Initial well location scheme. The chosen distance is maintained both between all wells located around the central point and between the wells and this point. Under this condition, six wells are drilled around a circle with a dug well at its center, with the angle between the radii on which neighboring wells are located equal to 60°.

4. Well Parameters. The wells are drilled with the minimum diameter sufficient for sampling. The depth of the wells is comparable to that of the original water intake and takes into account the angle of inclination of the aquifer. A well is considered prospective if the mineralization for drinking water does not exceed 1.5 g/L, and for agricultural purposes, it does not exceed 5 g/L [27]. A prospective well is expanded and handed over for operation. Its minimally acceptable yield is calculated based on the specified minimum yield after expansion (1).

5. The initial (first) cycle consists of drilling six small-diameter wells. If more than one prospective well is obtained, the well with the best results is selected for further work (in Fig. 1, this is well *2* (1.6)). Other prospective wells (in cycle 1, this is well *1.4* in Fig. 1) remain in reserve.

Bringing the prospective well into operation. The prospective exploratory wells designated for expansion serve as pilot wells during their enlargement. The presence of a pilot well facilitates the expansion process and reduces the required time. Drilling the pilot well and its subsequent expansion are carried out with different drilling rigs: specifically, a light rotary rig and a special rig designed for large-diameter wells. Wells that do not meet the established criteria are decommissioned (in the first cycle, these are wells *1.1, 1.2, 1.3,* and *1.5* in Fig. 1).

The second cycle of exploratory work has its center at the most successful well from the first cycle. As in the first cycle, six exploratory wells will be located around the central well; however, due to the adopted geometric scheme, it is actually necessary to drill only three new wells (wells *2.1, 2.2, 2.3* in Fig. 1), as the other three have already been drilled during the first cycle.

All subsequent cycles (third to sixth in Fig. 1) are built around the best point from the preceding cycle. If the trajectory shifts towards previously discovered progressive points (the fifth cycle in Fig. 1), the number of necessary new wells may decrease from the usual three to two.

If no prospective wells are discovered as a result of the current cycle, subsequent cycles may be conducted based on reserve wells (for example, *1.4, 3.1* and *4.1* in Fig. 1). In the absence of reserve wells, a positive result may be achieved by reducing the established distance between wells.

Since the aquifers being utilized are located at shallow depths, drilling pilot wells and their subsequent expansion take a relatively short time.

Example of using the proposed methodology. The parameters presented in the table represent average values for the Maastricht horizon based on the parameters mentioned above. According to the proposed method, the well should initially be drilled with a diameter of 132 mm, which is sufficient for conducting logging operations and test pumping [28].

Before reaching the productive zone, the well passes through a layer of aquitards, which also underlie this zone. The layer of highly mineralized groundwater is covered by a guiding pipe with a diameter of 146 mm during the drilling of the pilot well.

In Figure 2, Stage I, the well is shown during logging operations.

In Stage II, the operation of using a detonating cord is shown, which is performed when a significant increase in yield is necessary. In aquifers composed of fractured rock, this will increase the quantity, length, and opening of fractures [29].

In Stage III, the process of expanding the well to its final diameter is shown. A three-bladed spud bit is used, consisting of a bit body and blades, with the bit body serving as a guiding element [30]. Minimum rotation frequencies are applied. The flushing is carried out with technical water, which significantly reduces clogging and helps increase yield. The need for drilling fluid corresponds to a sharp increase in the volume of broken rock; however, in local conditions, it is reduced due to low absorption caused by the low filtration coefficient.

In stage IV, the design of the well is shown after the installation of the filter column and the creation of the gravel pack. Above the pack, the annular space is filled with sealing cement, which is separated from the gravel pack by a buffer layer of sand. After the cement hardens, the well is sealed to the surface with clay.

Thus, the developed methodology differs from the existing ones by combining the use of small-diameter drilling with the subsequent enlargement of wells that identify aquifers with acceptable mineralization, as well as employing a combined drilling grid that includes elements of both radial and regular schemes. An important distinction is also the use of existing water extraction points as centers for the first cycle of drilling and the multi-cycle nature of the exploration with a gradual shift of the center of the radial grid towards productive wells.

These differences provide several advantages. First, the methodology significantly reduces costs at the initial stage of exploration by using small-diameter wells and minimizing the number of non-productive wells. Second, the combined drilling grid allows for more flexible consideration of the geological and hydrogeological characteristics of the area, which enhances the accuracy and efficiency of the exploration. Finally, the sequential multi-cycle approach to exploration ensures a systematic and targeted study of the aquifers, facilitating a more accurate determination of their boundaries and the selection of the best wells based on water quality and discharge.

Conclusions.

1. The underground water reserves in the Mangystau Peninsula are insufficiently utilized for the following reasons:

- the exploration grids require drilling a large number of wells;
- due to complex hydrogeological conditions and the chaotic distribution of areas with acceptable mineralization, only a small number of wells tap into horizons with water suitable for drinking water supply;
- the need to drill many wells leads to the use of small diameters for the water intake section, so even wells that have tapped horizons with water meeting the mineralization requirements do not meet the discharge requirements.

2. The methodology for exploring groundwater deposits has been improved, with the main provisions being as follows:

- exploratory wells are drilled with a small diameter, and only those wells that tap into horizons with acceptable mineralization are subject to enlargement;
- wells are drilled according to a combined grid that integrates the possibilities of radial and regular grids;
- existing water extraction points containing water with acceptable mineralization serve as the centers for the first cycle of the exploratory grid;
- from these centers, drilling is carried out according to a radial grid consisting of six wells;
- when a horizon with acceptable mineralization is discovered, the well that tapped it becomes the center for the second cycle of the radial grid of six wells, with a minimum of three already drilled in the previous cycle;
- the exploration then continues with subsequent cycles aimed at constructing wells with acceptable discharge and mineralization.

3. The improved methodology takes into account the patterns of productivity distribution and mineralization of groundwater. This allows for more accurate consideration of the geological and hydrogeological characteristics of the area.

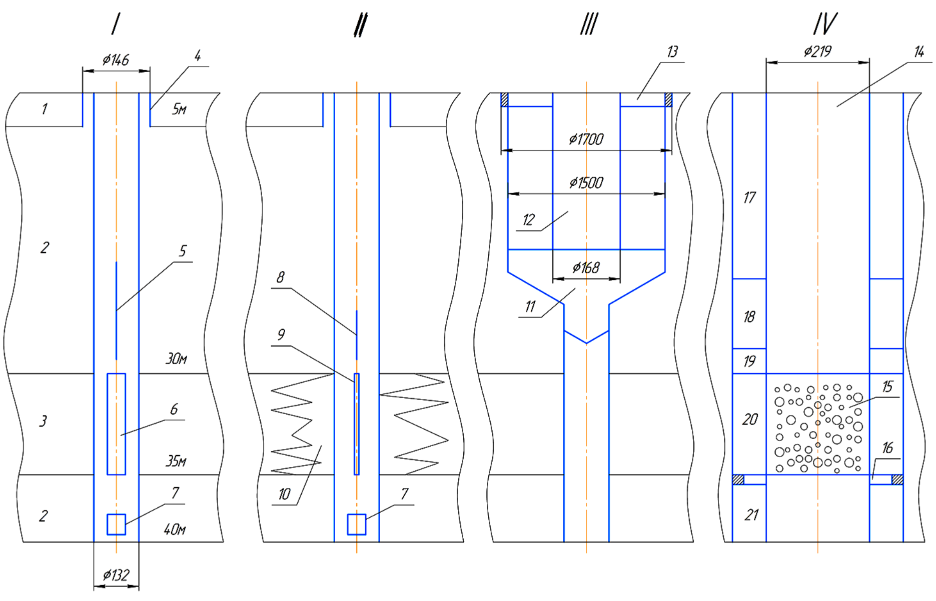

Fig. 2. Stages of creating a water intake well:

I – logging of the pilot well; II – detonation of the detonating cord; III – well expansion; IV – final well design; 1 – aquifer layer; 2 – aquitard; 3 – productive zone; 4 – guiding pipe; 5 – logging cable; 6 – probe; 7 – weight; 8 – cable; 9 – torpedo; 10 – blast impact zone; 11 – bit; 12 – drill string; 13 – concrete ring; 14 – filter column; 15 – filter; 16 – centralizer; 17 – clay cementing; 18 – cementing; 19 – buffer sand layer; 20 – gravel backfill; 21 – settling tank

Table

Parameters of a typical water extraction well

Parameter	Value
Depth of the water table, m	30
Depth of the bottom of the aquifer, m	35
Rock type of the aquifer	Fractured chalk
Coefficient of permeability, m/day	5
Rock type of aquitards, m	Marl
Height of pressure from the top of the aquifer, m	20
Depth of the well, m	40
Diameter of the well, mm	132* and 1,500
Well discharge, L/s	0.44* and 5
Drawdown, m	9
Cementing interval, m	28–30
Clay sealing interval, m	0–28 m
Outer diameter of drill pipes, mm	73* and 168
Inner diameter of drill pipes, mm	59* and 154
Outer diameter of the filter column, mm	219
Inner diameter of the filter column, mm	205
Type of filter	Wire wrap, gravel packing

* *Parameters for the pilot well*

4. The choice of distance between water extraction wells in the exploratory grid must consider geological and hydrogeological conditions, the degree of study of the area, the quality of underground water, as well as technical and economic constraints. The optimal distance between wells should be such as to ensure sufficient data accuracy and rational resource use during exploration.

5. The developed methodology allows for a reduction in the number of non-productive wells, minimizing exploration costs. This is achieved by identifying and defining the boundaries of the aquifer through the use of sequential cycles with a shifting center, which enables systematic exploration of the territory and the identification of the best aquifers. The selection of the best wells based on water quality and discharge ensures more reliable water supply.

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Удосконалена методика розвідки родовищ підземних вод для умов сільських районів півострова Мангістау

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Мета. Розробка інноваційної методики розвідки родовищ підземних вод для умов сільських районів півострова Мангістау, що дозволить знаходити джерела підземних вод із прийнятною мінералізацією з мінімальною кількістю свердловин.

Методика. Поставлені завдання вирішувалися комплексним методом дослідження, що включає огляд та узагальнення літературних джерел; патентно-кон'юнктурні дослідження; вивчення геологічних і гідрогеологічних умов району робіт; критичний аналіз існуючих методик розвідки родовищ підземних вод; вивчення та узагальнення раніше проведених розвідувальних робіт на площі й розробка рекомендацій щодо удосконалення методики розвідки.

Результати. Встановлені причини недостатнього використання запасів підземних вод на півострові Мангістау. Розроблена високоефективна методика розвідки родовищ підземних вод, що враховує специфічні особливості півострова Мангістау – великі малозаселені райони й хаотичне розташування водоносних горизонтів із прийнятною мінералізацією. Скорочення кількості бурових свердловин досягається за рахунок пошуку й визначення меж водоносного горизонту шляхом використання послідовних циклів із переміщенням центру, що дозволяє систематично досліджувати територію та знаходити кращі водоносні горизонти.

Наукова новизна. Уперше запропонована методика розвідки родовищ підземних вод, основні положення якої полягають у наступному: розвідувальні свердловини буряться малим діаметром, а розширенню підлягають тільки свердловини, що розкрили горизонти з прийнятною мінералізацією; буріння свердловин здійснюється по комбінованій сітці, що поєднує можливості радіальної та регулярної сіток; центрами першого циклу розвідувальної сітки є наявні водозабори, що містять воду з прийнятною мінералізацією; із таких центрів буріння здійснюється по радіальній сітці із шести свердловин; при виявленні горизонту з прийнятною мінералізацією свердловина, що розкрила, стає центром другого циклу радіальної сітки з шести свердловин, мінімум три з яких уже пробурені на попередньому циклі. Далі розвідка продовжується з наступними циклами з метою будівництва свердловин із прийнятним дебітом і мінералізацією.

Практична значимість. Упровадження розробленої методики має велике практичне значення для подальшого розвитку нафтогазовидобутку, промислового виробництва й сільського господарства півострова Мангістау, а також соціальне значення для задоволення потреб населення регіону в якісній воді для питного й господарського водопостачання. Застосування розробленої методики дозволяє скоротити кількість марних свердловин, мінімізуючи витрати на розвідку.

Ключові слова: *підземні води, методика розвідки, сітка свердловин, півострів Мангістау*

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