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GEOPHYSICAL STUDIES IN THE SEARCH FOR FRESH WATER IN THE TERRITORY OF THE FOLDED DONBAS

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The results of a geophysical survey aimed at identifying promising areas in territories with a significant influence of man-made factors are considered in the article. In recent years, the search for underground water and near-surface water in the eastern part of Ukraine has become a complex state problem. The analysis of the geological and hydrogeological situation, particularly the hydrogeological parameters of wells drilled for water in Folded Donbas, showed that a significant percentage of them have a low flow rate. To address this issue, preliminary studies were conducted to identify geological structures favorable for the accumulation of drinking water using electroresearch methods, including modifications of vertical electrical sounding, electroprofiling, and the natural field of the Earth. These methods enabled more accurate determination of the locations for drilling drinking water wells, thereby increasing the likelihood of successful drilling outcomes.

The comprehensive set of geophysical works conducted in these territories, determined by both the geological structure of Folded Donbas and man-made factors (such as the worked-out areas of mine fields, significant density of residential and industrial communication networks, and other anthropogenic elements), allowed for the development of a research and interpretation methodology that can be applied to similar tasks. The application of these methods enhances the accuracy of locating drinking water wells and improves the chances of successful drilling results. The results of geophysical research at the Shovkova site in the Luhansk region are presented as an example.

Drilled exploratory wells confirmed the presence of aquifers with standard quality drinking water, validating the selected method for assessing site prospects. The method is effective for marking water wells drilling sites. The findings and the developed interpretation method are proposed for use in future work on preparing wells for drinking water within the basin of formation-block pressure waters of the Donetsk-Don Basin of Folded Donbas.

Key words: Eastern Ukraine, Folded Donbas, underground waters, geophysical research, interpretation, well.

Introduction. After the end of the war in eastern Ukraine, there will be an urgent need to provide the population and its economic needs with fresh (drinking) water. Surface and near-surface waters will be contaminated with various toxic chemical elements as a result of the impact of explosive substances on the territory [9; 11; 18]. Providing drinking water to a large area is a challenging task even at the state level. Therefore, the authors considered geophysical research materials as a case study for subsequent use to identify optimal criteria for underground water

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searches in the Luhansk and Donetsk regions (Fig. 1). The area of geophysical research belongs to the Folded Donbas and consists of a thick layer of sedimentary rocks from the Paleozoic, Mesozoic, and Cenozoic eras [17]. These territories are situated within the basin of layer-block pressure waters of the Donetsk-Don Basin [10; 14]. The proposed set of studies for locating underground water in the liberated Donetsk and Luhansk regions will significantly reduce exploration costs, even with limited funding.

Statement of the Problem. Providing the population of Ukraine with high-quality drinking water is a socially significant issue, as drinking water is a critical determinant of citizens' health and the ecological and epidemiological safety of human life [2; 4; 8; 11; 13; 16; 18]. This task becomes especially crucial in eastern Ukraine, where hostilities have led to the contamination of surface and near-surface waters with various chemical toxicants [4; 9; 11].

Analysis of Research. Geophysical research began in the 1970s with the "Dnipro-geofizika" and "Kyivgeology" trusts [5; 6]. During this period, a set of geophysical studies was developed and implemented in hydrogeological works, introducing new approaches in interpreting geophysical materials to assess detected water anomalies. Such interpretation significantly improved the quality of exploratory hydrogeological works within the Ukrainian Shield.

The proposed rational complex of geophysical research included profile and planar surveys using Vertical Electrical Sounding (VES) method and detailed seismic research using the Correlation Method of Refracted Waves (CMRW). These studies showed that geophysical methods are useful for a wide range of tasks [7; 9], such as:

– detection and tracing of fractured and tectonically weakened zones in crystalline rocks;

– identification of paleodepressions on the surface of the crystalline foundation;

– determination of the stratigraphic section of sedimentary deposits and weathering crust;

– more accurate assessment of the filtration properties of rocks with the selection of zones with predominant distribution of various rocks based on their permeability.

Complex geophysical studies significantly reduce the scope and financial cost of further hydrogeological studies when selecting promising areas and preparing wells for water supply.

Goal. To develop an optimal research complex for locating underground water in the liberated Donetsk and Luhansk regions, based on previous findings, and to reduce the cost of groundwater exploration under limited funding.

Geophysical Studies of Aquifers in the Donetsk Hydrogeological Province. The geological structure determines the peculiarities of the area's hydrological state, associated with two types of reservoirs. Therefore, geophysical research plays a critical role in searching for potable underground water under these conditions [17]. In the upper structural layer – comprising sediments – the pore type of the reservoir predominates. Another source of water supply in Folded Donbas is underground water of the fractured type. The development of fracturing in dislocated rocks is characterized by considerable heterogeneity and anisotropy. The degree of fracturing significantly impacts the water enrichment of rocks.

Under such conditions, terrestrial geophysical research methods are crucial for justifying site selection. These methods are conducted in the initial exploration and reconnaissance stages and aim to study the hypsometry of the water-enriched horizons' roofs, qualitatively assess the section's permeability, and identify and trace fractured and tectonically weakened zones, which are promising for groundwater searches.

Experience shows that not all hydrogeological wells yield water. Therefore, it is necessary to identify geological, hydrological, and geophysical factors that, along with increased rock permeability, play an important role in evaluating their water content prospects [1; 5; 6].

The area of geophysical research lies in the Folded Donbas zone and comprises a thick layer of sedimentary rocks from the Paleozoic, Mesozoic, and Cenozoic periods. Administratively, it is located in the Luhansk region.

In hydrogeological zoning, Ukraine is divided into two hydrogeological provinces: platform and geosynclinal folded [14]. Within these provinces, subprovinces are distinguished, such as the East European and Scythian subprovinces, which structurally coincide with the East European platform and the Scythian plate; and the Eastern Carpathians and Mountain Crimea, which adjoin these folded systems.

Within the East European hydrogeological subprovince, the Donetsk and Ukrainian Shield hydrogeological regions are distinguished (Fig. 1).

Hydrogeological Conditions. The hydrogeological conditions of the work area, located within the Donetsk Folded Region (Fig. 1), are influenced by the geological structure of Folded Donbas and man-made factors (such as the worked-out areas of mine fields and the significant density of residential and industrial communication networks).

Groundwater within the near-surface Carboniferous aquifers is concentrated in Quaternary and Carboniferous deposits – loess loams, sands, and pebble-gravel rocks, compacted sandstones, sandy and sandy-clay shales, karst, and compacted limestones.

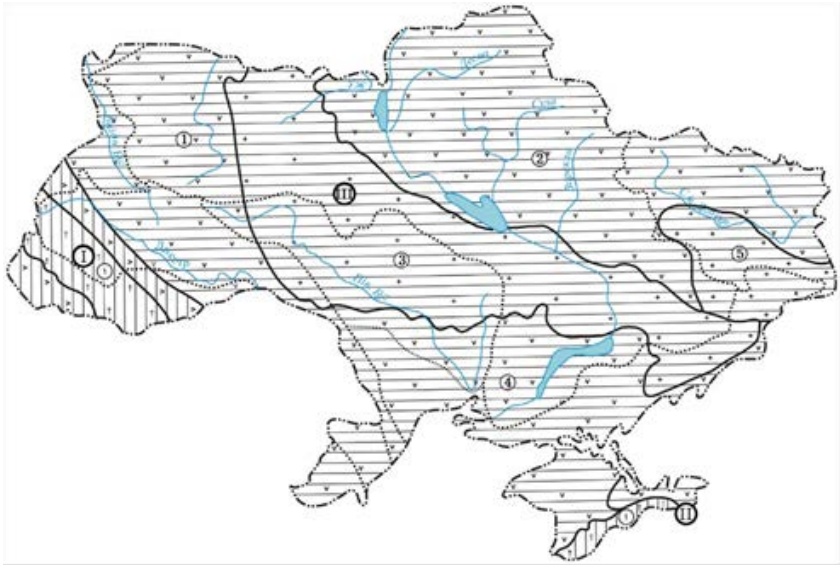

Fig. 1. Scheme of hydrogeological zoning of the territory of Ukraine (groundwater basins)

Legend. I – Hydrogeological province of the folded region of the Ukrainian Carpathians; II – Hydrogeological province of the folded region of Mountain Crimea; III – East European hydrogeological subprovince: 1. Volyn-Podilsky artesian basin; 2. Dnipro-Donetsk artesian basin; 3. Area of fractured waters of the Ukrainian Shield; 4. Black Sea artesian basin; 5. Hydrogeological province of the Donetsk folded region

Loams and clayey-gravelly eluvial-deluvial sediments mainly represent quaternary sediments of watersheds, which are weak and practically waterless. Alluvial aquifers are recharged by atmospheric precipitation, partly due to the unloading of carbon aquifers, filtration from local ponds, reservoirs, and surface drains, especially during the flood period.

The quality of water in an alluvial aquifer is largely determined by the quality of its source waters [14]. According to the chemical compound, the waters of alluvial Quaternary deposits are mainly hydrocarbonate-sulfate and sulfate-hydrocarbonate in anions and multicomponent in cations.

The mineralization of groundwater ranges from 0,3 to 3,6 g/dm³ and depends on the water exchange rate. The freshest groundwater is associated with areas of rapid water exchange, with proximity to feeding zones and discharge through sources into open drains. Increased mineralization of groundwater is observed in areas with limited water exchange, with large distances between the supply and drainage areas, in semi-closed hydrogeological structures, and in areas where atmospheric and underground (including mine waters) water supply mix.

Aquifers of coal deposits from the Serpukhov, Bashkir, and Moscow layers are associated with loosened sandstones, sandy clay shales, and, rarely, limestones. Under normal conditions, sandstone deposits are low-porosity and weakly permeable. A significant improvement in the filtration properties of Carboniferous rocks is observed in the near-surface weathering zone, the crushing zones of tectonic disturbances, in the axial parts of the folds, and in the areas of subsidence that occurred after the working of the coal seams.

The aquifer of the weathering zone of coal deposits is a product of chemical and physical weathering of sandstones, sandy and clay shales, and limestones.

The total thickness of the weathering zone depends on the lithological composition of the rocks and the degree of their metamorphism and ranges from the first meters to 20–40 m.

The waters of the weathered zone are both pressure water and gravity water, which is determined by the ratio of the absolute elevations of the areas, their feeding due to atmospheric precipitation and areas of drainage through streams and rivers, the presence of local geological factors affecting their horizontal movement.

The head varies from 0 to 60–70 m, there are mostly gravity water [14]. Flow rates of wells are from units to 20 l/sec., flows of sources 0,3–5,0 l/sec. with predominant filtration coefficients prevail at the level of 0,05 m/day, but in some areas they can be up to 180 m/day. The capacity of the aquifer varies from the first meters to 25–30 m.

Formation-type aquifers in decompressed sandstones are controlled by the structural factor and the strength of the formations themselves.

Separate aquifers are water-saturated crushing zones of discontinuous tectonic disturbances of significant amplitude and extension [1]. Mostly, they are localized in narrow (first tens of meters) strips, with a significant power and length of the water saturation zone.

Considering the significantly high degree of metamorphism of coal rocks in the open part of Donbas, the general conditions of water exchange and replenishment of underground water reserves are unfavorable, which is confirmed by the data of hydrogeological indicators of wells drilled for drinking water in Folded Donbas.

The area of the Folded Donbas is a complex regional man-made and geological structure. The depth of man-made water accumulation of coal deposits reaches 350 m, including the zone of active water exchange and the zone of gradual attenuation of open fracturing.

Sandstones and sandy shale, in some places sandy – clay shale, mainly represent aquifers in these areas. Hydrogeological parameters in the research areas differ significantly, depending on the lithological composition of the rocks, the degree of fracture, as well as the depth of the aquifers.

The analysis of the geological and hydrogeological situation, in particular the hydrogeological parameters of the wells drilled for water in the Folded Donbas, showed that a significant percentage of them have a low flow rate. This indicates the need for preliminary research and study of geological structures favorable for the accumulation of drinking water, by

geophysical, in particular, electrical exploration methods and the use of the obtained data to more accurately determine the locations of wells for drinking water and increase the probability of positive drilling results [3; 7; 12; 15].

Physical properties of rocks. The main parameters of electrical properties of rocks [3; 7] are specific electrical resistance ($\rho_п$) and induced polarizability (η), which are most widely used in geophysical studies to assess the hydrogeological parameters of the geological section in the Folded Donbas. Specific electrical resistance is a universal parameter characterizing the geological environment of the work area, therefore, its study was given the greatest attention during previous geophysical studies.

Specific electrical resistance. Within the Carboniferous formations, parameter generalization was carried out separately for sandstones, clayey, siltstone-clay shales, carbonized rocks and for coal in the C_2^3 coal-bearing formation (Smolyaninov Formation).

Clay, siltstone-clay shales in the formations are determined by a small specific resistance, the average values of which vary from 25 Ohm·m in the C_2^3 formation to 54 Ohm·m in the C_1^4 formation (Kalmius Formation).

Sandstones are characterized by a higher specific electrical resistance compared to clay rocks. Thus, the average value of ρp for sandstones in the C_2^3 formation is 13–40 Ohm·m, and in the C_1^4 formation – 92 Ohm·m.

Rocks enriched in organic matter (carbon) are characterized by low average values of $\rho_п$, which vary from 19 Ohm·m in the C_2^2 formation (Mospin Formation) to 9 Ohm·m in the C_1^4 formation. The gradual increase in the value of ρ_p of clay and silty clay shales from younger to older rocks occurs due to the increase in the degree of metamorphism of these rocks.

The specific electrical resistance of water-bearing sand-clay deposits can vary from 10 to 500 Ohm·m. Water-resistant rocks are characterized by low specific resistance and are represented by clay shales and clays.

Polarization properties of rocks. The average values of polarizability of clay rocks vary from 1,6% in the C_2^2 formation to 2,7% in the C_1^4 formation. The polarizability of sandstones varies from 2% in the C_2^2 formation to 3,1% in the C_1^4 formation. Clay and sand-clay shales are characterized by high polarizability values from 2 to 43,0%, enriched with carbon. Average values of polarizability for these rocks vary from 5,7% in the C_2^2 formation to 20,2% in the C_1^4 formation.

The polarizability of clay and sand-clay shale depends on the content of sulfide mineralization and varies from 2 to 22%. The average value is 6,8%.

The polarizability of rocks in the geological section of the district increases from younger (C_2^2 suite) to more ancient (C_1^4 suite) rocks. The presence of aquifers in the section is marked by an increase in polarizability values.

Methods and techniques of field work. The method of VES in the modification of induced polarization (VEZ-VP) allows solving the problems of dismembering the geoelectric section and studying the filtration properties of rocks, determining the level of groundwater – by establishing correlational dependencies between geophysical and hydrogeological parameters.

Profile works were carried out by the VEZ-VP method on all search areas of the works in a 200x50m grid using a symmetrical four-electrode installation A^1 MN B with 12 spreaders AB/2=3; 4.5; 6; 9; 15; 25; 40; 65; 100; 150; 200; 250 m, which made it possible to better differentiate the rocks by lithological composition.

Parametric works by the VEZ-VP method were performed at 4 observation points located on the search areas along 4 azimuths.

The VPF device was used as the measuring equipment at the frequency selected based on the results of experimental observations.

Verification drilling of wells. After the completion of ground geophysical research at the prospective prospecting area of Shovkova, two wells with a depth of 50 m and 60 m were drilled, respectively, with parametric pumping and water sampling for chemical analysis.

Geophysical studies in boreholes. The purpose of geophysical research in wells was as follows:

– lithological segmentation of rock strata;
– determination of the level of exposure dose power (EDP) of gamma radiation of rocks;
– determination of water-saturated horizons;
– determination of water level, flow and mineralization of water in wells.

In the wells on the site, a standard complex of logging was performed, which included electrical logging (gradient and potential probes, PS), gamma logging (GC), cavernometry to solve the first two tasks. In order to identify aquifers, determine the water level in the wells, discharge and mineralization, thermometry (during descent and ascent of the device) and resistivity measurement in the excitation mode were performed.

Results of geophysical research. The Shovkova area (Figs. 2, 3) is located within the development of middle Carboniferous rocks, represented by deposits of the Carboniferous

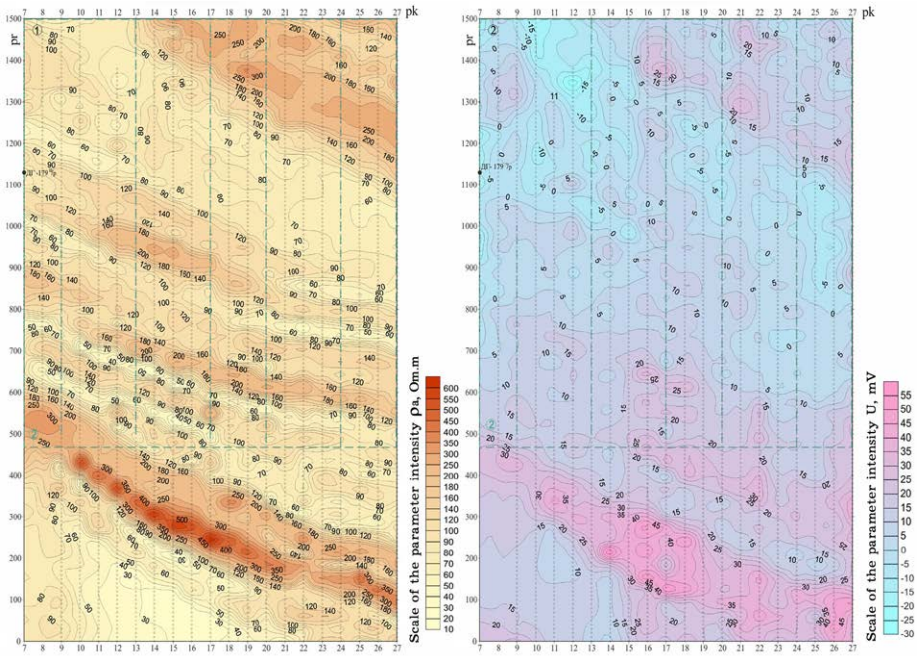

Fig. 2. Results of geophysical research at the Shovkova prospecting site: a – map of imaginary resistance ρ_u according to the results of electroprofiling; b – a map of the natural field

Conventional designations: 1 – distribution zones of mainly sandy rocks identified by the results of electroprofiling; 2 – absorption zones according to the results of research by the PP method; 3 – zones selected according to the data of VEZ-VP: a – with a relatively high value of ρ_u – sandstones (100–300 Ohm·m); b – with a relatively high value of φ_{vp} – moistened rocks– (−1,4 ÷ −2,0°); 4 – tectonic disturbances; 5 – daytime relief horizons and their value in m; 6 – a well recommended for verification drilling for drinking water and its number; 7 – profiles and pickets of geophysical observations: 1 profile number; 200 – picket number

Smolyaniniv Formation (C_2^3). In terms of lithology, it is a layering of sandstones, siltstones, and limestones [7; 10]. Aquifers are associated with fractured rocks – sandstones, which are drained by springs in the upper reaches of the streams and are tributaries of the Luhanchyk and Sukha rivers.

Investigations by the VEZ-VP method on the site were carried out on profiles 5, 8, 11. Low-resistivity rocks were found on the sections ρ_y in the upper part of the section, which

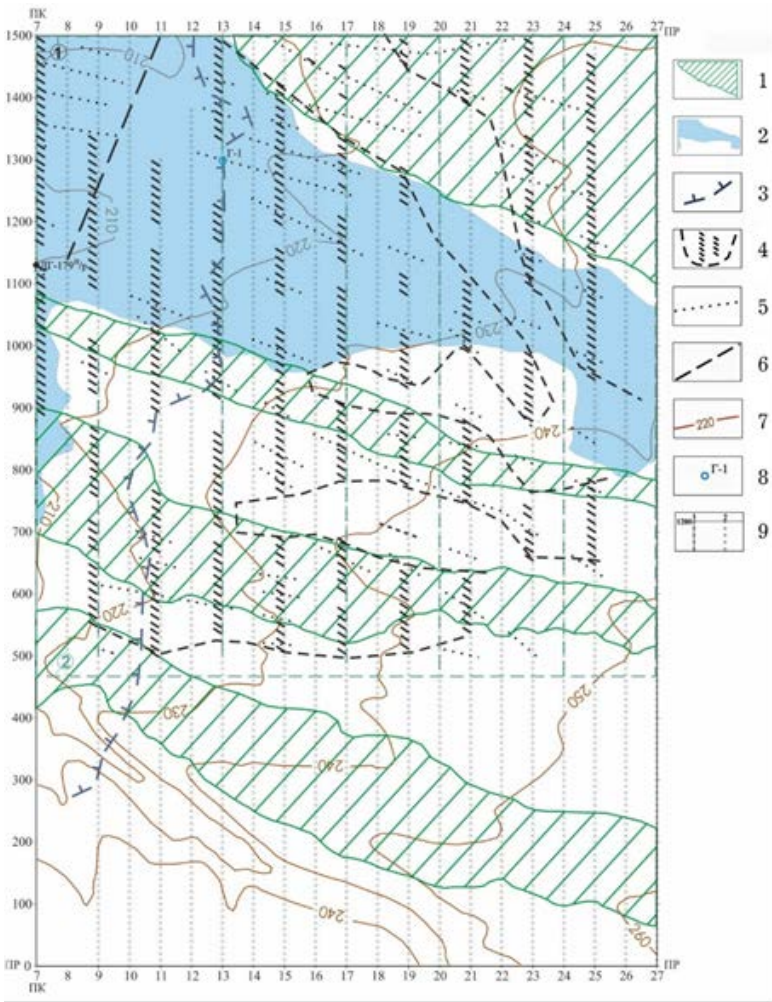

Fig. 3. Map of complex interpretation of geophysical data at the Shovkova search site

Conventional designations: 1 – distribution zones of mainly sandy rocks, selected based on the results of electroprofiling; 2 – absorption zones according to the results of research by the PP method; 3 – zones of reduced values of PP tension; 4 – near-surface water-saturated zones according to the results of studies by the PP method; 5 – axes of subvertical weakened water-saturated zones according to the results of studies by the RAP method; 6 – Tectonic disturbances according to geological data; 7 – daytime relief horizons and their values, in m; 8 – the well is recommended for verification drilling for drinking water, 9 – profiles and research pickets

may indicate their near-surface hydration. The results of geophysical research at the Shovkov prospecting site are shown in fig. 2-a, 2-b.

On the map of imaginary resistance, which was compiled based on the results of research using the method of electroprofiling (EP) (Fig. 2-a), two high-resistivity zones are distinguished – in the northern and southern parts of the site, with resistance values of 90–220 Ohm·m, which corresponds to rocks of predominantly sandy composition. The character of the field, ρp, is not significantly differentiated and indicates the probable presence of a tectonic disturbance in the submeridional direction and may serve as a favorable factor for the accumulation of moisture.

Anomalous values of the parameter $\varphi_{вп}$ −2,2 ÷ −2,6 are observed on profile 11, pickets (700–950). According to the ratio of the imaginary resistance parameters $\rho_{у}$ and $\varphi_{вп}$, two promising zones are distinguished on the sections compiled based on the results of research by the VEZ-VP method. To confirm the obtained data, it was recommended to drill wells on profile 5, picket 350 and on profile 11, picket 800 (Fig. 3).

The map of the natural field at the work site (Fig. 2b) turned out to be uninformative. The natural field has only positive values and is not characterized by significant differentiation. The highest intensity of anomalies (6–8 mV) is noted in the northern part of the site and probably corresponds to the zone of rock hydration in the area of the gully.

Features of the obtained materials are reflected on the map of complex interpretation, which was compiled for the site, despite the different level of their informativeness. The complex maps (Fig. 3) show the parameters, the ratio of which indicates the presence of areas of water-saturated rocks:

– distribution zones of moistened and decompressed rocks, selected according to the results of electroprofiling;
– leakage zones based on the results of works by the natural field method;
– near-surface water-saturated zones according to the results of studies by the PP method;
– axes of subvertical weakened water-saturated zones;
– recommended places for drilling wells;
– position of exploration wells in search areas;
– tectonic disturbances according to geological data.

A general analysis of geological data and geophysical materials obtained in the course of research at the site showed that the hydrogeological situation is quite favorable for the localization of groundwater, but this situation was not clearly reflected in the geophysical fields. This fact must be taken into account when conducting further work on the search for groundwater.

Conclusions. The considered complex of geophysical works was used for the first time to solve the problems of searching for fresh underground water in the territories determined both by the geological structure of Folded Donbas and by the influence of man-made factors (worked out areas of mine fields, significant density of residential and industrial communication networks and other anthropogenic components). Therefore, attention was focused on the development of a set of research and interpretation methods, which could be used in the future to solve similar problems.

The analysis of the geological and hydrogeological situation, in particular the hydrogeological parameters of wells drilled for water in Folded Donbas, showed that a significant percentage of them have a small flow rate. This indicates the need for preliminary research and study of geological structures, favorable for the accumulation of drinking water, by geophysical, in particular, electro-reconnaissance methods and the use of the obtained data to more accurately determine the locations of fresh water wells and increase the probability of positive drilling results.

The exploratory wells drilled on the Shovkova site helped to establish the presence of aquifers of drinking water of standard quality, to confirm the correctness of the selected method of assessing the prospects of the sites.

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ГЕОФІЗИЧНІ ДОСЛІДЖЕННЯ ПРИ ПОШУКАХ ПРІСНИХ ВОД НА ТЕРИТОРІЇ СКЛАДЧАСТОГО ДОНБАСУ

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У статті розглянуті результати геофізичної зйомки з метою виявлення перспективних ділянок на пошуки підземних вод на територіях зі значним впливом техногенних чинників. Протягом останніх років вона існує як складна державна проблема для східної частини України. Аналіз геолого-гідрогеологічної ситуації, зокрема гідрогеологічних показників свердловин, пробурених на воду у Складчастому Донбасі, показав, що значний їх відсоток має невеликий дебіт. Для розв'язання цього питання були проведені попередні дослідження на вивчення геологічних структур, сприятливих для акумуляції питних вод електророзвідувальними методами в модифікаціях вертикального електричного зондування, електропрофілювання та природного поля Землі. Їх використання дозволило більш точного визначити місця закладання свердловин на питну воду та збільшення вірогідності позитивних результатів буріння.

Розглянутий комплекс геофізичних робіт на територіях, зумовлених як особливостями геологічної будови Складчастого Донбасу, так і впливом техногенних чинників (відпрацьовані ділянки шахтних полів, значна щільність житлових і промислових комунікаційних мереж та інших антропогенних складників), дозволив розробити методику досліджень та інтерпретації, яка може надалі використовуватись для вирішення таких завдань. Її використання дозволяє більш точно визначати місця закладання свердловин на питну воду та збільшити вірогідності позитивних результатів буріння. Як приклад наведені результати геофізичних досліджень на ділянці Шовкова в Луганської області.

Пробурені розвідувальні свердловини встановили наявність водоносних горизонтів питних вод кондиційної якості та підтвердили правильність вибраної методики оцінювання перспективності ділянок. Розроблений метод ефективний для розмітки місць буріння на воду. Отримані результати та розроблену методику інтерпретації пропонується використати у подальшій роботі з підготовки точок закладення свердловин на питну воду в межах басейну пластово-блокових напірних вод Донецько-Донського басейну Складчастого Донбасу.

Ключові слова: Східна Україна, Складчастий Донбас, підземні води, геофізичні дослідження, інтерпретація, свердловина.