LEC Journal 2022, 4(1): 28-32
ISSN: 2565-5205 (print)

Research Article

RESEARCH BY GEOPHYSICAL METHODS OF HYDRAULIC STRUCTURES OF WATER MANAGEMENT PURPOSE

[1]Iryna Chushkina, [2]Nataliia Maksymova, [2]Dmytro Pikarenia, [3]Olga Orlinska*

[1]Department of civil engineering, construction technologies and environmental protection) Dnipro State Agrarian and Economic University, Dnipro, Ukraine

[2]Department of ecology and environmental economics, Technical University "Metinvest Polytechnic", Mariupol, Ukraine

[3]Department of civil engineering, construction technologies and environmental protection), Dnipro State Agrarian and Economic University, Dnipro, Ukraine

***Corresponding author email:** Orlinska.o.v@dsau.dp.ua*

ABSTRACT

Yield growth in the Southern Steppe is impossible without irrigation with the introduction of mineral and organic fertilizers, so the repair, restoration, and construction of new irrigation networks are one of the main tasks of regional and district water management. For the repair of water management networks, regulation of pools of irrigation systems it is necessary to use inexpensive effective methods of the establishment of their technical condition. Such methods are geophysical, which allow to identify the areas of filtration, flooding, violations of protective screens in the control pools of irrigation systems. The necessity of localization of areas of filtration water losses to concentrate repair and restoration works in the most disturbed zones is scientifically substantiated, which will significantly reduce the cost of time and money and increase the overall efficiency of the structure

Keywords-technical condition of hydraulic structures, geophysical methods, method of pulsed electromagnetic field of the Earth, method of vertical electrical sounding, filtration losses, flooding)

INTRODUCTION

Prolonged operation of irrigation control pools and lack of proper care have led to a deterioration in their technical condition, which is primarily manifested in significant losses of water for filtration. At the current level of operation, losses can exceed 35% or more, and the world and domestic experience show that the filtration flow affects the strength and stability of the soils of such structures and leads to accidents in more than 30% of cases. Since it is impossible to repair these structures at the same time, there is a need to identify and locate areas of the most intense water loss. Violation of the ground part of the structures, as a rule, has obvious manifestations of deformation of the anti–filtration coating or suffusion. However, a significant part of the structures may lose the filtration strength and stability of the soil embankment or be in the initial stages of formation of such areas and have no external signs of the manifestation of these processes. It is more difficult to detect underground filtration routes and structural violations of building elements. The issue of diagnostics of the technical condition of soil hydraulic structures of the class of consequences (responsibility) SS1 and especially the regulating basins of irrigation systems, with the help of non–destructive methods, is given insufficient attention today.

This emphasizes the urgency of finding and implementing new methods of a comprehensive assessment of technical condition and detection of hidden filtration zones in the body of canals and control basins of the Armed Forces. That will allow location and timely repair of the site, hence, extended life of the facility and prevention of groundwater levels in the surrounding areas.

According to VBN B.2.4–33–2.3–03–2000 "Regulation of riverbeds. Design standards for the detection of areas of concentrated filtration", is expected to determine the areas of increased filtration in the structures of regulatory basins using a set of geophysical methods, which include the following: vertical electric sounding (VES), micro–electric sounding (MES), electro profiling (EP), natural field method (PP). It should be noted that these methods have a significant estimated cost, time of fieldwork, the ambiguity of interpretation, which limits their application. Unfortunately, these methods do not allow to fully determine the filtration zones, to assess individual indicators and the technical condition of the control basins in general. Thus, today the improvement of existing and introduction of new methods of a comprehensive assessment of the technical condition of regulatory basins is an urgent scientific and practical task.

CHARACTERISTIC OF THE OBJECTS AND THE RESEARCH METHODS

The following geophysical methods were used in the work: field research to establish filtration zones by the natural pulsed electromagnetic field of the Earth (NPEMFE) and vertical electric sounding (VES).

The NPEMFE method refers to "quality", proposed according to DBN A.2.1–1–2014 "Engineering surveys for construction" to identify filtration paths in the body of dams and dams, as well as the establishment of deformation zones of linear structures and to assess the stress–strain state of buildings and buildings, etc.

Method of the natural pulsed electromagnetic field of the Earth. This method is relatively new and has been used to solve engineering and geological problems since the 80s of the last century [1–7]. Consider this method in detail. A pulsed electromagnetic field consists of three sources: external – solar radiation and cosmic fields; internal, that caused by geological processes under or directly on the day surface; man–made – various kinds of industrial and domestic radiation. The frequency range of such an integrated pulsed field is from the first hertz to mega– and even gigahertz.

The natural pulsed electromagnetic field generated by internal sources has been studied in geology. Electrokinetic phenomena in permeable porous media which include rocks, attracted the attention of geophysicists, causing primarily interest in such problems as pre–and post–seismic electromagnetic phenomena, electromagnetic precursors of earthquakes [3]. There are many known processes and phenomes as a result of or during which there is electromagnetic radiation or electromagnetic emission (both terms are used). One of them is the piezoelectric effect of minerals and rocks. The piezoelectric effect in rocks containing minerals exhibiting such effects is the basis for the development of a new direct geophysical method for searching for quartz veins and pegmatites [2, 4]. A.A. Vorobyov [1] began to explore a field called NPEMFE. Then it was continued by V.N. Salomatin [6] with colleagues and students. Similar work is underway in Russia and Ukraine, Germany, Israel [7]. One of the particular interests is the practical use of the parameters of electromagnetic signals (EMS) arising during mechanoelectrical transformations to control changes in the stress–strain state of dielectric structures, rocks, and concrete to predict their durability, strength, and geodynamic manifestations. The first studies in this direction indicated that the EMS parameters and characteristics of electromagnetic emission (EME) depend on the strength of rocks. Later it was shown that the characteristics of EME depend not only on strength, but also on structural and textural features, moisture content, and mineral composition [5]. Another powerful source is the tectonic stresses of the rock mass, especially at the level of pressures that precede the formation of cracks and gaps. The third significant source is various electrical and electrochemical processes in rock massifs (changes in the electric double layer, electron emission during the motion of solutions, chemical transformations of minerals and rocks). Other sources are much less studied, or their contribution is rather limited. In the first place, you can put the dynamics and direction of tectonic stresses in the earth's crust. The result is an abrupt burst of electromagnetic radiation, which is called the pulse of the electromagnetic field. It is characterized by a sharp increase in the amplitude and energy of radiation and a very short (milliseconds and microseconds) time of manifestation. The frequency of pulses of NPEMFE from the first hertz to 20 kilohertz, this field NPEMFE differs from atmospheric and man–made sources. In the field of NPEMFE, there is no periodicity characteristic of man–made emitters, which serves to separate these sources. Experimental studies by various authors have shown that the number, energy, and amplitude of NPEMFE pulses increase under the pressure of crystalline rocks and reach a maximum before the onset of brittle deformations. As soon as the phase of destruction (formation of cracks) comes, the number of pulses sharply decreases up to zero, and then slightly increases to a certain level at which it remains. When the load continues, the phenomenon is repeated. If the formation of cracks does not occur, the total level of the NIEMFE field in the stressed array is higher than in the surrounding rocks. At the tensile forces, the mechanism of formation of impulses is similar. Recent studies of plastic rocks (clays and loams) conducted by our group have shown the identity of processes with crystalline rocks, although the overall level of NPEMFE was slightly lower [8, 12–13].

Electromagnetic radiation propagates in solid rocks at considerable distances from the source, while its amplitude and energy vary quite weakly. If there is a site of soaking of rocks or a zone of emptiness (flooded and dry cracks, etc.) on the way of propagation of electromagnetic radiation, the intensity of radiation decreases very sharply, and dissipates or is absorbed in a powerful zone.

The most effective method is used to assess the possibility of landslides. Research is conducted on the network in the profile–plane version, the denser the network, the better the information. Based on the results, maps of field characteristics are compiled and analyzed. Our group uses the value of the flux density of pulses NPEMFE, which is the number of pulses per unit time. Other researchers use the amplitude and energy of the pulses. Many do not specify which indicator is embedded in the maps. The interpretation is based on the features of the NPEMFE field and consists of the selection of areas (zones) with the maximum pulse flux density, which is regarded as the maximum stress state of the rock mass. Here are the highest tensile stresses that can lead to shear separation. NPEMFE method is used to study the subsidence of structures. Around the correctly constructed structure, the field of NPEMFE is characterized by an increased level in comparison with surrounding breeds and a certain monotony (blurring). If there is an area of a sharp decrease in level, it can be regarded as the beginning of soil soaking. During planar studies by the NPEMFE method, a network of cracks that are in the mode of compression (high level of the field) and stretching (low level) is quite clearly distinguished on the maps. Flooded cracks have the lowest level of the NPEMFE field. Their cross–section can serve as a basis for laying a well on water. The main advantages of the NPEMFE method are its high productivity in comparison with other electrical reconnaissance methods. Yes, the measurement time takes the first seconds; more is spent on transitions between points. Building and interpreting maps also take a reasonable amount of time. Thus, using the method of NPEMFE it is possible to allocate interesting sites on which to put other more expensive and labor–consuming methods. Of the disadvantages should be noted the complexity of its application to assess the depth of anomalous objects.

The application of the method to determine the technical condition of agricultural hydraulic structures (GTS) is based on the following pattern: electromagnetic pulses generated by all rocks, including loose soils, are extinguished in areas of excessive flooding and filtration. Field survey is performed by the device "SIMEIZ" (Fig. 1–2) on three antennas, one oriented vertically down, and two horizontally in the directions south–north, west–east. Observation points are recorded by a GPS navigator. Field survey in the control pools was carried out on a square grid: the distance between the profiles and observation points is 2 m.

Fig. 1. Antennas in working condition

Fig. 2. Appearance of the device "SIMEIZ"

NPEMFE pulses generated by the soil mass or other materials are captured by three antennas and transmitted to the device. The data is written to a flash drive. According to the research on the program, "Surfer–8" maps of the flux density of the magnetic component of NPEMFE are constructed and interpretation is carried out.

The main advantages of this method in comparison with other electrical reconnaissance methods are: simplicity and speed of fieldwork; shooting can be performed both on free and built–up areas; observations are successfully conducted in the conditions of plain and mountainous terrain.

The VES method refers to "quantitative" geophysical methods and is recommended in the standard VBN B.2.4–33–2.3–03–2000 "Regulation of riverbeds. Design standards for the detection of areas of concentrated filtration. The method of vertical electric sounding allows to investigate changes of a geological section on depth; set the groundwater level; watertight position.

It is well known, and its theoretical foundations are given in [9, 10]. A four–electrode symmetrical AMNB unit with supply A and B and measuring or receiving M and N electrodes was used for research [9]. Metal pins, which are driven into the ground, were used as electrodes. Steel–copper wires and cables were used for the installation of supply and receiving lines. The electrodes were located on one straight line in relation to the center of the installation 0. During fieldwork in Belarus, the size of the spacing of the supply electrodes did not exceed 60 m. Measurements were performed by electric reconnaissance mine equipment SHERS–5M with the following parameters: distances AB – 3, 4, 5, 6, 9, 15, 40 m; the distance between the MN distances was 1m and 3m when shooting at subjects (Fig. 3–4).

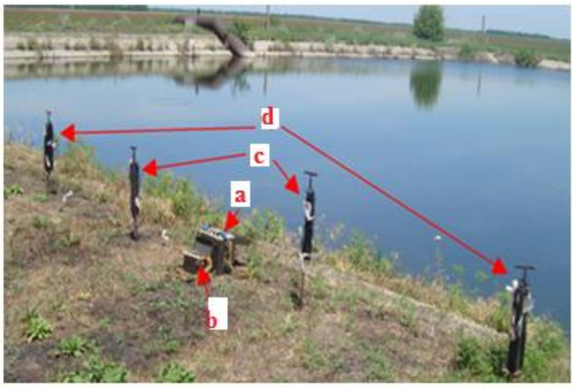

Fig. 3. Methods of field research by the VES method a – current generator; b – meter; c–d – electrodes: i – measuring, g – feeding

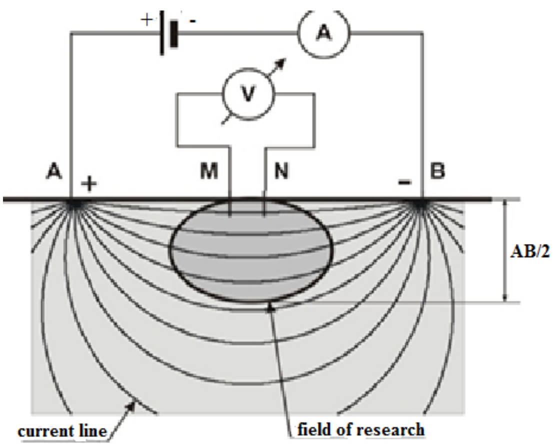

Fig. 4. Diagram of the location of the receiving and supply electrodes in field studies by the VES method

The VES method is more labor–intense than the NPEMFE, therefore the research by this method was carried out at 2–3 observation points at each site to establish the groundwater level and depth to the water resistance, which is necessary for the calculation of filtration losses. Interpretation of the VES research results was performed according to the IPI2Win.

The NPEMFE method in combination with the VES method makes it possible to significantly increase the amount of information, increase economic efficiency and reduce labor costs during the localization of areas of latent increased filtration in the body of regulatory basins and irrigation systems.

THE RESEARCH OUTCOMES

The calendar plan of works at the first stage provided the performance of field research on the establishment by geophysical methods of a technical condition of 5 regulating basins.

The NPEMFE survey was performed in the profile version with a distance between profiles of 2 m, between observation points on the profile of 2 m in two stages. Measurements were performed in daylight in clear weather and light wind. During the analysis of field survey data, the geological and tectonic structure, and hydrogeological features of the study area were considered. Interpretation of NPEMFE data was carried out under the guidance of Dr., Prof. Orlinska O.V.

At the first stage, measurements of the NPEMFE parameters were carried out on filled regulating basins. The observation profiles ran parallel to the dams of the basin. There were five profiles, but depending on the shooting conditions, decreased to 3–4 or increased to six. The profiles were arranged in the following sequence: the first – at the foot of the outer slope, the second – in the central part of the slope, the third – on the outer edge of the embankment, the fourth – in the center of the embankment, the fifth – on the inner edge of the embankment.

In the second stage, when the control basins are emptied, the survey of NPEMFE will be carried out not only onboard but on the bottom of the basins. According to the results of NPEMFE research and vertical electric sensing of VES, filtration zones were determined and water losses from the regulating basins of RB–1 of Vasylivka irrigation system in Orikhove village, RB–1 of Petrovsky irrigation system of 32 km of Dnipropetrovsk–Zaporizhzhya system, RB–2 were calculated. Near the village Lyubimovka, RB–1 Solonyano–Tomakivska irrigation system, near the village First of May, RB–2 Solonyano–Tomakivska irrigation system, near the village Malosaccharine. Consider the results of the research on the example of the largest of the 5 regulatory basins – RB–2 Solonyano–Tomakivka irrigation network near the village Malozacharine.

NPEMFE survey was performed in the profile version with a distance between the profiles of 2 m, between the observation points on the profile of 2 m. The parameters of NIEMFE were measured when the water–filled regulating basin. Each side of the Republic of Belarus was studied separately. Observation profiles were laid parallel to the axis of the board of the regulating basins, their number was 5 profiles, sometimes, depending on the shooting conditions, decreased to 3. The profiles are arranged in the following sequence: the first – at the foot of the outer slope, the second – in the central part of the slope, the third – on the outer edge of the embankment, the fourth – in the center of the embankment, the fifth – on the inner edge of the embankment. The volume of work in the observation of NPEMFE was: the number of profiles NPEMFE – 19, the length of one profile – 140 m, the total length of the profiles – 2660 m, the number of observation points NPEMFE – 1097 points. NPEMFE observations were performed using the device MIEMP–14/4 (series "SIMEIZ") with the simultaneous use of three antennas, oriented in azimuths north–south, west–east and vertically down at a distance of 15–20 cm from the ground. The antennas were attached to a wooden pole with adhesive tape; special attention was paid to their isolation from each other. The recording was performed with the following parameters of the device, the same for all three antennas: sampling frequency – 50 kHz, measurement duration – 0.2 s, signal gain – 10 V / mV, discrimination level – 5 mV, measurement mode – simultaneous. The map of the location of observation points is shown in Fig.5.

The VES works were carried out in a point version within the filtration zones through the sides of the basin selected according to the NPEMFE data. A total of 5 points were worked out, their position and numbers are shown in Fig.6. The SHERS–5M equipment with the following parameters of spacing AB – 3, 4,5, 6, 9, 15 m was used; spacing MN – 1, 3 m.

According to the field research of NPEMFE with the help of the program "Surfer–8" maps–schemes of pulse flux density (number of pulses per unit time, usually per second) of the magnetic component of NPEMFE on three antennas oriented in the directions north–south, west–east and vertically.

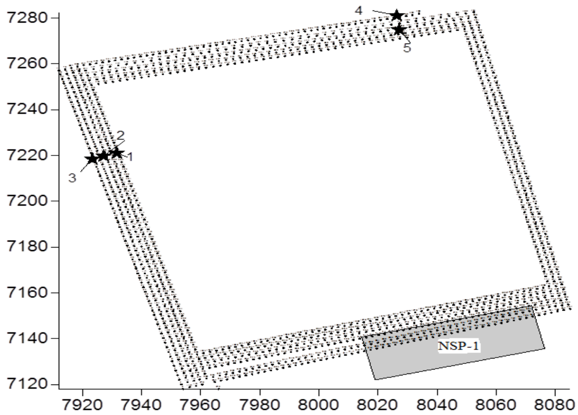

Fig. 5. Map of the actual material of the flux density survey of the magnetic component of the pulsed electromagnetic field of the Earth filled with water RB–2 Solonyano–Tomakivska irrigation system near the village. Malozakharyne, Dnipropetrovsk region. Asterisk – the point of vertical electrical sounding and its number. Coordinate scale metric, conditional. NSP – 1 – pumping station

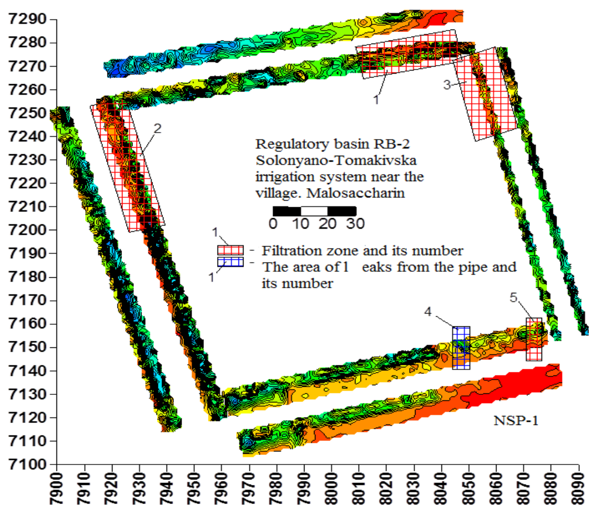

Fig. 6. Map–scheme of the flux density of the magnetic component of the pulsed electromagnetic field of the Earth of the control basin RB–2 Solonyano – Tomakivska irrigation system near the village. Low–saccharin according to horizontal antennas oriented along the sides (inner contour) and across the sides (outer fragments) of the basin

The interpretation of the map–schemes is based on the standard method of geophysical data processing and the assumption that the flooded areas of the sides of the basins and the bottom in the field NPEMFE should correspond to areas of weakly differentiated, "blurred" field with low pulse flux density. On the contrary, areas with high values of pulse flux density indicate a relatively normal technical condition of the soils that are placed on the sides of the regulating basins. According to the survey NPEMFE managed to establish the planar distribution of the filtration zones (Fig. 6). Zones № 1–3, 5 correspond to the zones of water filtration through the slopes of the regulating basin. Visually, in some places, they spatially coincide with the areas of violation of the coating in the bowl of the regulating basin. The fourth flood zone is caused by water leaks from pipes from GNS–1 and NSP–1.

Processing and interpretation of the results of measuring the electrical resistivity of rocks by the VES method was performed using the IPI2Win program. This program is designed for automatic and semi–automatic (interactive) interpretation of data of various modifications of vertical electrical soundings, including traditional installations and is intended for use on personal computers. It is assumed that the user of the program is a specialist who aims to interpret both a satisfactory selection of curves and the solution of a geological problem. Focus on geological results is a distinctive feature of IPI2Win compared to common programs for automatic solution of the inverse problem.

Particular attention is paid to interactive interpretation. The approach to interpretation implemented in IPI2Win is based on the choice of the concept of geological structure of the profile and allows the best use of a priori information in complex geological situations. To calculate the filtration losses from the regulating basin in a homogeneous soil with pressure less filtration flow, the formula V.V. Vedernikov [11]. According to this formula, the specific filtration losses per 1 m of the length of the filtration zone are determined:

$$q = C_p \cdot (B + A \cdot h_0) \cdot \left(1 + \frac{h_0 + h_k}{Y}\right), \qquad (1)$$

where: q – specific seepage losses per 1 m of the length of the seepage zone; Cp – permeability coefficient in the slope, m/day (for loess loam Cp = 0.1 m/day, for loamy clay Cp = 0.03 m/day) [14]; B – length from the beginning of the slope to a point with a constant groundwater level, m (according to field research data taking into account VES); A – coefficient of the lateral spreading of the seepage stream (A = 1.7 m) [11]; h_0 – depth of water in the retention basin, m (h_0 = 3.0 m) (according to field research); h_k – height of capillary rise of ground water, m (h_k = 3.0 m) [14]; Y – depth to the impervious stratum, m (according to the VES).

The main elements involved in the calculations are shown in Fig. 7

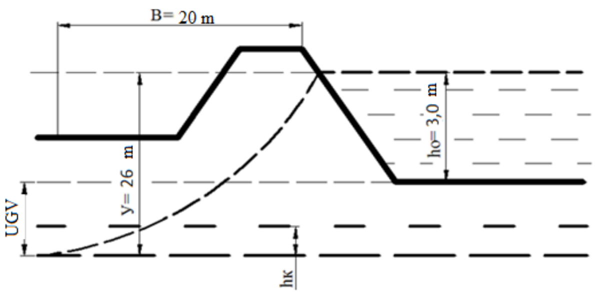

Fig. 7. Scheme of calculation of specific filtration losses from regulating basin

Based on the above results of field and analytical studies performed for all RB revealed their unsatisfactory technical condition. Filtration losses from them cause the rise of groundwater in the areas adjacent to the buildings and can lead to their subsequent flooding (Table 1).

TABLE I. GENERAL CHARACTERISTICS OF FILTRATION LOSSES ON THE STUDIED OBJECTS

Object of study	Volume of the research object, m^3	Total length of filtration zones, m	Filtration volume per day, m^2/day	Filtration costs per month, m^3/month
RB–1 Petrovskaya IS	15400	73	2,18	4774
RB–2 Petrovskaya IS	9600	53	1,97	3132
RB–1 Solonyano–Tomakivska IS	18500	36	3,31	2495
RB–2 Solonyano–Tomakivska IS	53800	131	3,41	13413
RB–1 Vyshchetarasivska IS	10000	62	2,12	3911

SYMBOLS: RB–1 of Vasylivka irrigation system, RB–2 of Vasylivka irrigation system in the village of Walnut; RB–1 of Petrovsky irrigation system 32 km of the Dnipro–Zaporizhzhya highway, near the village of Dnipro; RB–2 Petrovsky irrigation system near the village. Lyubimovka; RB–1 STIS – RB–1 of Solonyano–Tomakivska irrigation system near the village of Pershe Travnya; RB–2 STIS – RB–2 Solonyano–Tomakivska irrigation system near the village. Malosaccharin.

Calculations have shown that depending on the technical condition of the regulating basin, as well as the chosen calculation method, these losses per month can be from 15 to 30% of the volume of water pumped into the basin

CONCLUSIONS

The expediency and proved the possibility of applying a set of geophysical methods NIEMFE and VES to identify the development of hidden areas of water loss for filtration in the initial stages by reducing labor costs and labor costs compared to existing methods. This will improve approaches to assessing water losses during the operation of regulatory basins of irrigation systems. On the example of a typical control basin with a size of 120 × 120 m, field research by a team of 4 people is performed for 6 hours with the possibility of removing areas of disturbed condition and filtering water into nature.

The technical condition of regulating structures on irrigation systems in Dnipropetrovs’k region is estimated. The number of detected zones of water filtration from structures varies in basin from 1 to 4. It is established that the control basins of irrigation systems have different parameters of areas of damage and defects. The volume of filtration water losses in the regulatory basins is about 30%.

According to field research and analytical calculations, it is established that depending on the design parameters of transporting and regulating structures and modes of their operation, the loss of water for filtration from 50 to 55 cubic meters per month per 1 linear meter of the structure length, while plots the amount of water loss for filtration reaches 103 cubic meters per month per 1 linear meter. In monetary terms, at an average water cost of 0.25 cents per cubic meter, water losses in one typical regulatory basin of 100 × 100 m amount to on them is about 3000 euros per month, and for the entire irrigation period 15,000 euros. On average, the cost of such field analytical studies of the technical condition of the regulatory basin is about 1,800 euros, and 5 basins – 7,125 euros. Therefore, such research work will pay off in the amount of 7125 euros / 15000 = 0.5. That is, the work will pay off in a year. The calculation of the payback is approximate, as it does not include the cost of repair work in the identified areas. It is economically more profitable to carry out repair work not on the entire structure, but only on its damaged areas, which are revealed as a result of performing a complex of geophysical methods. The based on the obtained indicators of the technical condition of the regulatory basins, which are subject to repair and restoration works, the rational use of funds will be ensured and the overall efficiency of the regulatory basin will be increased by reducing water losses for filtration

RECOMMENDATIONS

For operative diagnosis of a technical condition and timely detection of sites of losses of water on a filtration from regulating basins of irrigation systems at initial stages it is recommended:

1) A combination of fast and low–cost geophysical methods of the Earth's natural pulsed electromagnetic field and vertical electric sounding;

2) Use of the method of quantitative assessment of water losses for filtration, taking into account the design parameters of the objects and the identified violations of their technical condition.

REFERENCES

[1] Vorobiev A.A., Vorobiev, G.A., Vorobiev, G.A. (1971) Pulse breakdown and destruction of dielectrics and rocks. Tomsk: Tomsk Publishing House. University. 225 p.

[2] Parkhomenko E. I. (1968). Phenomena of electrification in rocks. M.: Nauka, 255 p.

[3] Sobolev GA, V.M Demin (1980). Mechanoelectric phenomena in the Earth. M.: Science. 2015 p.

[4] Yakovitskaya G.E. (2007). Development of a method and measuring tools for diagnosing critical states of rocks on the basis of electromagnetic emission: author's ref. diss. at the request of scientists. Degrees of Dr. tech. Science: special. 25.00.20 "Geomechanics, destruction of rocks, mine aerogas dynamics and mining thermophysics". Novosibirsk. 45 p.

[5] Bespalko A.A., Yavorovich L.V., Fedotov P.I. (2008). Relationship between the parameters of electromagnetic signals and the electrical characteristics of rocks under acoustic and quasi–static effects. Notifications. Issue 7, №1, 146 p.

[6] Salomatin V.N. (2009). Many years of experience in applying the EIEMPZ method in solving a set of problems in Ukraine. Team. tr. International. Scientific conf. Formation and development of scientific research in higher education, dedicated to. 100th anniversary of his birth. prof. A.A. Vorobyova, Tomsk Polytechnic. un–t. Vol.2. Tomsk. pp. 384–391.

[7] Pikarenya D.S., Orlinskaya O.V. (2009). Experience in applying the method of the natural pulsed electromagnetic field of the Earth (NPEMFE) to solve engineering–geological and geological problems. Dnepropetrovsk: SWIDLER Publishing House. 120 p.

[8] Chushkina I.V., Pikarenia D. S., Orlinska O. V., Maksymova N. M. (2019). Experimental substantiation of the NPEMFE geophysical method to solve engineering and geological problems., Bulletin of VN Karazin Kharkiv National University. Series “Geology. Geography. Ecology”. Issue. 51. pp. 109–123

[9] Zhdanov M.S. (1986). Electrical Intelligence. M.: Nedra. 316 p.

[10] [10] Yakubovsky Y.V., Renard I.V. (1991). Electrical Intelligence. M.: Nedra. 358 p.

[11] Zheleznyakov, Yu. A., Ivanov P.L. (1983). Hydraulic structures. Designer's Guide. Ibad–zade. M.: Stroyizdat. 543p.

[12] Musa Abubakar Tadda, Amimul Ahsan, Monzur Imteaz, Abubakar Shitu, Umar Abdulbaki Danhassan and Aliyu Idris Muhammad. Operation and Maintenance of Hydraulic Structures (2020).

[13] Olasunkanmi N.K., Aina A., Olatunji S. and Bawalla M. Seepage Investigation on an Existing Dam using Integrated Geophysical Methods. Journal of Environment and Earth Science. (2018), pp. 6–16.

[14] Ruban S.A., Shinkarevsky M.A. (2005). Hydrogeological assessments and forecasts of the groundwater regime of Ukraine.