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Cite as: AIP Conference Proceedings **2676**, 060002 (2022); https://doi.org/10.1063/5.0109330

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Features Of Water Seepage From The Retention Basins Of Irrigation Systems With Different Geological Structures

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Abstract. Topical applied and scientific problem concerning the evaluation of technical condition of retention basins of irrigation systems has been highlighted. The expediency of comprehensive use of geophysical methods of the natural pulsed electromagnetic field of the Earth as well as vertical electrical sounding to identify deformation zones of agricultural hydraulic structures and seepage techniques has been considered making it possible to determine parameters of the disturbed areas. It has been demonstrated that geological (inclusive of tectonic and hydrogeological) features of territorial structure and development are the factor of unsatisfactory technical condition of agricultural hydraulic systems of land-reclamation schemes turned out to be understudied during their design and construction. Localization of zones of water seepage losses to concentrate repair and restoration works within the most disturbed areas will help reduce significantly time and costs while improving the total efficiency of a hydraulic system operation. Hence, the measure emphasizes expediency of further use of the system of geophysical methods.

Keywords**:** Technical condition of hydraulic structures, Geophysical methods, Method of natural pulsed electromagnetic field of the Earth, Method of vertical electrical sounding, Seepage losses, Flooding

INTRODUCTION

During the last decade, the problem of fresh water management has become urgent since the natural resource is especially valuable. Agriculture is among its largest consumers. The major water share is spent on irrigation. For the purpose, within the territory of Ukraine (among other things, *Pivdenny Step* is meant), the branched irrigation system was developed more than fifty years ago. The system consists of water supply, accumulation, and distribution components. Due to long-term operation, nonavailable overhaul (resulting from different reasons), and the limited investment to support its relevant technical condition, quite expected partial or even complete destruction of certain assemblies and components has taken place. Accumulation objects (i.e. retention basins and principal

Industrial, Mechanical and Electrical Engineering
AIP Conf. Proc. 2676, 060002-1–060002-10; https://doi.org/10.1063/5.0109330
Published by AIP Publishing. 978-0-7354-4207-8/$30.00

channels) turned out to be the most sensitive elements. The abovementioned factored into waterproofing defects and significant water losses through underground seepage [1]. In addition to economic loss, such multiyear seepage has resulted in the environmental problems being flooding, soil salinization, increase in underground water mineralization etc. Moreover, that also stipulates the increased water intake from the surface water bodies (among other things, the Dnieper River is meant) with long-term sequences, i.e. breakdown of a hydrological regime, changes in ecological systems of the river and the Black Sea, and deterioration of human life due to qualitative fresh water deficit. Hence, surface water management and its rational use is the urgent problem of both country and humanity.

Efficient use of water and, hence, decrease in seepage losses are the priority tendencies of water management improvement in Ukraine where 'Irrigation and Drainage System for the Period up to 2030 [2] Strategy has been developed. According to the Strategy, irrigation continuation and progress is one of the priority tasks of Ukrainian–European Union Association Agreement and Water Framework Directive 2000/60/EU of 23 October 2000 'On the Determination of Frameworks of Activities of the Communities in the Field of Water Policy'. Relying upon the abovementioned, it becomes quite important to evaluate technical condition of irrigation systems without which it is impossible to implement the 'Strategy…'.

REVIEW OF THE EARLIER STUDIES

Retention basins of irrigation systems have been built according to the standard projects; structurally, they are of a cut and fill shape. Laterally, they are four-squares; their wall parameters vary from 50 to 100 m; and their average depth is from 4 to 6 m. The structures have been built of local soil materials using clay and plastic clay. Reinforced concrete slabs were applied for internal lining. The basins are required to accumulate water inflowing from water intake of the surface water bodies and redistribute it to irrigation areas. Hence, during the irrigation season, lasting for 6 - 7 months, the basins become completely filled and emptied for several dozen times. The abovementioned creates alternating dynamic loads on the waterproof coating. During winter, the basins (with few exceptions) are waterless which also effects negatively the protective water-proof barrier. Thus, covering removal takes place. Repair is required since water seepage starts in the certain areas of surrounding space. The areas are divided into obvious, identified with no specific facilities since they are seen using the naked eye, and hidden areas, identified with the help of special analysis. That is why, the hidden areas are the greatest problem since their spatial position and parameters are uncertain. Consequently, nobody knows what should be repaired and how it should be done. Moreover, budgeting and long-term activities are required to study them but they are performed sporadically due to lack of funds.

Scientists and researchers from different world countries considered problems of safe operation and evaluation of state of hydraulic structures for instance [3-15].

Currently, regulations recommend bunch of methods in Ukraine to analyze technical condition of retention basins [16-18].

Geophysical methods (namely, electrical sounding, seismic profiling, georadar profiling etc.) are among them. However, their application is still limited since they are considered as economically unprofitable and labour-intensive while requiring involvement of highly qualified personnel of proper specialization. Partially, it is quite a reasonable idea. Nevertheless, there is an alternative to implement cheap, informative, and quick at work geophysical methods. For instance, method of natural pulsed electromagnetic field of the Earth (NPEMFE) and method of vertical electrical sounding (VES) are meant.

In our publications, we considered repeatedly theoretical background and methods to apply the NPEMFE and VES system for hydraulic structures – among other things, for retention basins, principal irrigation channels, and engineering and geological as well as geological surveys [19]. Note for the research purposes that physical content of NPEMFE method is based upon generation of pulse electromagnetic radiation by rocks or loose artificial materials experiencing mechanical compression or tension. In the context of case one, increase of electromagnetic pulses takes place; in the context of case two, sharp decrease happens resulting from absorption providing that rock continuity is disturbed and shear fractures or cleavage fractures are formed. If the fractures are overflooded then absorption continues increasing. Consequently, absorption of electromagnetic pulses means availability of fractures and their probable water intrusion. The abovementioned is represented by relevant maps making it possible to identify the hidden seepage areas. The VES method, being classical geophysical electrical survey technique, determines depth of the areas; in this context, physical principles of the method need not any detailed consideration.

According to the data, health diagnostics of retention basins of irrigation systems using NPEMFE and VES takes less time (daylight hours are sufficient to inspect 2 retention basins), involves 3-4 workers, and is cheaper to compare with other geophysical methods.

Starting from 2013, NPEMFE and VES methods were applied to examine ten retention basins in Dnipropetrovsk Region; two of them have been inspected three times [1]. First, the abovementioned helped understand possibility, expediency, and economic feasibility of the methods; second, it helped compare results of research carried out during several years; and third, it makes it possible to detect development dynamics of the seepage areas in terms of surface and depth.

Monitoring of retention basin *Kalyna* has shown the following:

1. Decrease in magnetic component flow density within the northwest and east shares of the basin slopes. The first anomaly, identified in 2013, 2017, and 2018, corresponds to a seepage area within the basin dam. The second anomaly was registered in 2018 though its first features were mapped in 2017.
2. During three years, underground water level is 12.5-13 m remaining almost invariable.
3. All the anomalies of both higher and lower levels alternate; moreover, they are oriented northwest with 345-350° strike azimuth. The direction coincides with fracture zone orientation of Dnipropetrovsk-Pryazovia deep northwest fault [20]. The fact may support good drainage capacity of the territory in terms of fracture systems of Ukrainian Shield basement in *Sukha Kalyna* ravine at 1.5 km distance.

Monitoring of retention basin *РБ-6* has helped conclude the following:

1. Survey area registers four anomalies of higher values; almost all the territory demonstrates decrease in NPEMFE pulse flow supporting significant water intrusion of the studied area.
2. According to the data of survey 2018, zones of seepage and water intrusion, singled out in 2016, increased.
3. According to VES data, underground water level in 2016 was 4 m in the eastern share of the basin up to 5-6 m in its western share; in 2018, it increased up to 3 m in the eastern share.
4. Terrain lowering, being down to 1 m, is observed within the 50 m area in the eastern share of the basin which may depend upon loess watering as well as gap phenomenon development.
5. All the anomalies of higher and lower values of flow density of magnetic NPEMFE component alternate; moreover, they are directed linearly northwesterly with 300-310° strike azimuth.

Analysis of maps with geophysical survey results has helped understand that patterns of NPEMFE field around certain retention basins differ. One of them demonstrates linear elongated compressed anomaly isolines; another one shows more isometric isolines with significant distance between them. In addition, despite almost similar amount of seepage losses from retention basins (i.e. 5269 and 5250 m^3 per month), VES survey results have explained that for 5 years, ground water level around *Kalyna* basin experienced its 0.5 m rise; 2-year period demonstrated 1-1.5 m rise in water level around *РБ-6* basin. Only difference in drainage levels of different areas cannot explain the fact. Moreover, that suggests the idea that the data depend upon specific geological structures of the territories within which the basins are located.

Actually, watering zones around *Kalyna* basin are 340-350° oriented coinciding with a strike of Dnipropetrovsk-Pryazovia deep fault within the Ukrainian Shield basement and the associated fracture zones being natural drain lines. Sedimentary cover is thin; hence, seepage water overfloods the basement fractures.

Around *РБ-6* basin, water zones direction is 305-310° which also coincides with strike of Perzhansk-Dniprodzerzhynsk deep fault. However, fissured basement rocks within the area occur deep; sedimentary formation is thick; and seepage water saturates it. Several aquifers of temporary water and ground water, having hydraulic connection, are observed; hence, their more significant rise takes place.

To inspect the abovementioned assumption, specific analysis of technical condition of the retention basins, located within the areas differing heavily in their geological structure, has been carried out.

CHARACTERISTIC OF THE OBJECTS AND THE RESEARCH METHODS

Such retention basins as *Zvonetsky*, located in Solone District of Dnipropetrovsk Region (Ukrainian Shield) and *Kulishi*, located in Tsarychanka Region of Dnipropetrovsk Region (Novomoskovsk-Pavlivka monocline – slope of Ukrainian Shield) are selected as the research objects.

Zvonetsky basin (Fig. 1) is within Seredniooprydniprovsky block of Ukrainian Shield. The territory is characterized by significant rock fragmentation of crystalline basement, resulting from deep faults and fracture zones, superposed with thin up to 20 m sedimentary cover. Aquifers and systems, belonging to sedimentary Kainozoic Era as well as to the fissured rocks of the crystalline basement, have been developed there [21]. Underground water of the sedimentary cover is non-pressure one; fissure water is pressure one; the levels are

FIGURE 1. Ground location of the studied objects. Retention basin *Kulishi* (Ku) is on the left; retention basin *Zvonetsky* (Zv) is on the right

characterized by average water content. Neither geological structure nor geomorphologic features favour accumulation of large amount of underground water.

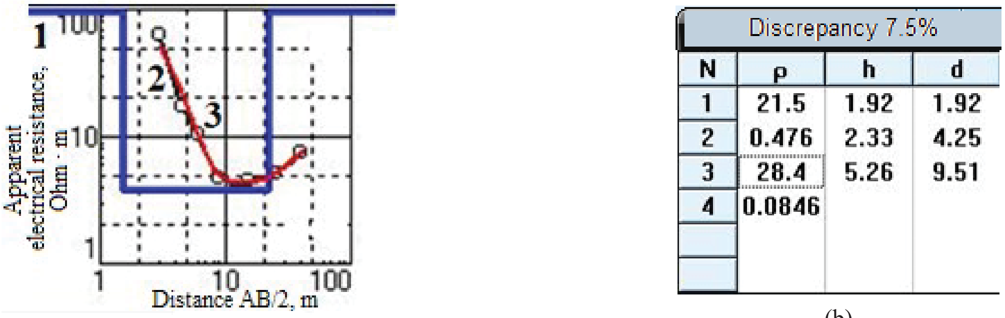
Kulishi basin (Fig. 1) occupies the territory of Novomoskovsk-Pavlivka monocline of the Dnieper-Donets Depression [21]. It is characterized by thick sedimentary cover (hundreds to several thousand meters); the cover is more than one hundred meters right within the retention basin location. Aquifers and systems are available within Quarternary, Neogene, and Palaeogenic deposits [21]. Tectonic structure is less complicated; there are no deep faults and extended powerful fractured zones.

Field geophysical studies of the basins were performed in autumn 2020 and in spring 2021 as follows.

NPEMFE surveys were carried out in a profile option with 2 m distance between the profiles. Two stages were involved. Stage one measured NPEMFE parameters when the retention basins were full of water. Each basin wall was analyzed separately. Observation profiles were routed in parallel with a wall axis. In general, there were five profiles. Depending upon survey conditions, their number either decreased down to 3 or 4 or increased up to 6. The profile were located in such a way: the first one was within a foot of an external slope; the second one – within the central share of the slope; the third one – within the external edge of the dam; the fourth one – within the central share of the dam; and the fifth one – within the internal edge of the basin dam. Stage two was performed when the basins were empty during no less than three weeks. The NPEMFE surveys were carried out on one profile at each wall. The profiles were located within the central share of an upper surface of the dam.

The measurements were made during daylight hours, in fine weather, and under a weak wind. *МИЕМП-14/4 (MIEMP-14/4)* device (*СІМЕЇЗ* (*SIMEIZ*) series) was applied for the NPEMFE surveys with similar use of three antennas adjusted on the north-south, west-east, and vertically downwards at 15-20 cm distance from the earth's surface. Adhesive tape was used to attach the antennas to a wooden bolt; and specific attention was paid to insulate them. The survey was performed when the device parameters coincided for all the antennas, i.e. 50 Hz discretization frequency; 0.2 s survey period; 10 V/mV signal multiplication coefficient; 5 mV discrimination level; and simultaneous measurement mode. While processing materials of the field survey of such planar objects as retention basins, NPEMFE survey results were visualized by means of schematic mapping of pulse flow density using Golden Software Surfer 8. The schematic map interpretation is based upon the standard method of geophysical data processing, and upon the assumption that the inundated areas of basin slopes and bottom within the NPEMFE field should correspond to the zones of low-differentiated 'washed-out' field with low density of pulse flow. Conversely, areas with high values of pulse flow density means relatively normal health of HS body soil [22].

Four-electrode symmetric device of Schlumberger type has been used for the VES method. The device involves energizing A and B electrodes and measuring or receiving M and N electrodes [23]. Metal spikes, driven in soil, were applied as electrodes. The energizing and receiving lines were installed with the help of steel and copper wires and cables. The electrodes were arranged on a straight line relative to the device centre. The measurements were made by means of electric exploration mine facilities *ШЕРС-5М* (ShERS-5M) with following parameters: 1) 3-, 4-, 5-, 6-, 9-, 15-, and 25-m energizing AB interelectrode distance; and 2) and 1- and 3-m receiving MN distance during the surveys. Sounding curves or VES curves have been plotted resulting from the measurements performed with the help of IPI2Win software [24]. Approach to interpretation, implemented in IPI2Win, is based upon selection of a concept of geological structure of a profile; it allows using in the most appropriate way priory information in the complicated geological situations. Fig. 2 demonstrates the results of VES method application.



Discrepancy 7.5%

N	ρ	h	d
1	21.5	1.92	1.92
2	0.476	2.33	4.25
3	28.4	5.26	9.51
4	0.0846		

(a) (b)

FIGURE 2. Findings using VES in terms of IPI2Win software: a – box of the models: 1 – Pseudo-Logging curve (blue); 2 – Experimental curve (black); 3 – Theoretical curve (red); and b– box of the model parameters in terms of IPI2Win software: ρк, ρ – apparent electrical resistance, Ohm · m; N – the number of the layer from the surface; h – the thickness of the layer, m; d – the depth of the bottom of the layer, m

Points for VES were scheduled relying upon the NPEMFE data. The abovementioned has helped reduce amount of activities as well as their labour intensity.

The formula [25] is used for calculation of seepage losses from retention basins in homogeneous soil at a pressureless constant seepage stream.

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

where: q - specific seepage losses per 1 m of the length of the sepage zone;
C_p - permeability coefficient in the slope, m/day (for loess loam $C_p = 0.1$ m/day,
for loamy clay $C_p = 0.03$ m/day);
B - length from the beginning of the slope to a point with a constant groundwater level, m;
A - coefficient of the lateral spreading of the seepage stream ($A = 1.7$ m);
h_0 - depth of water in the retention basin, m ($h_0 = 3.0$ m);
h_k - height of capillary rise of ground water, m ($h_k = 3.0$ m);
Y - depth to the impervious stratum, m.

THE RESEARCH OUTCOMES

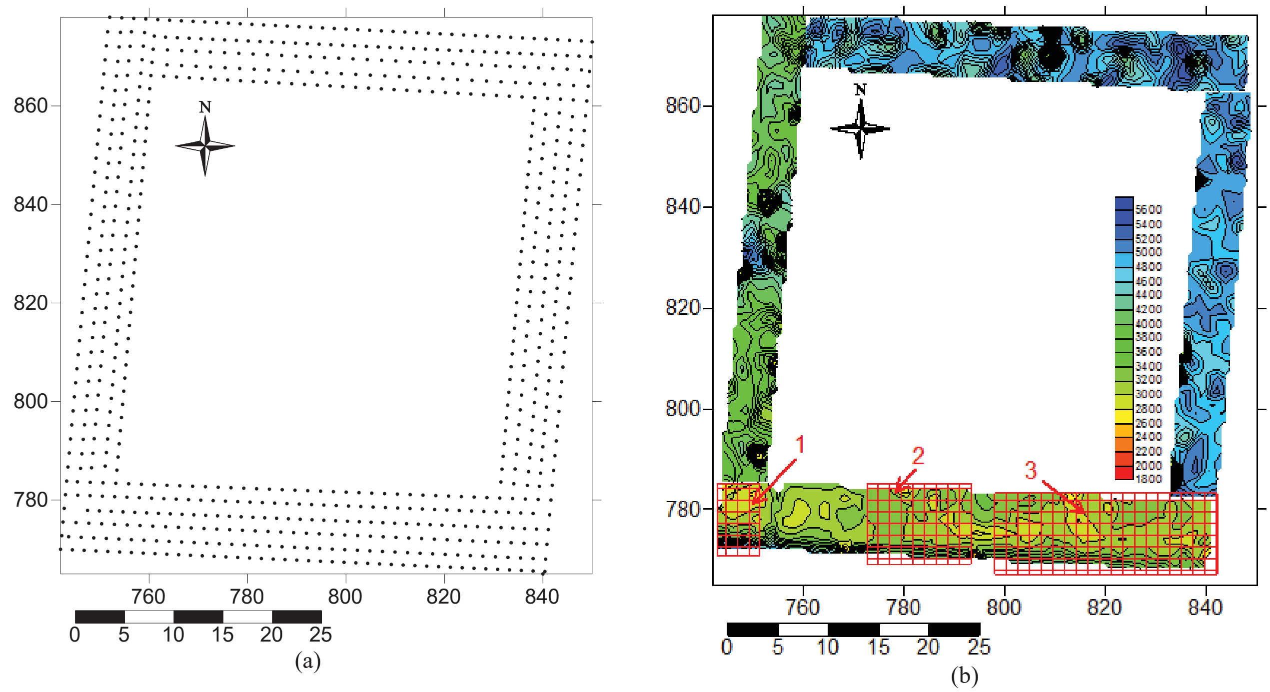
Retention basin *Zvonetsky*

The NPEMFE survey has been carried out in terms of a network shown in Fig. 3(a). A schematic map and complex interpretation result from it (Fig. 3(b)).

The map demonstrates clearly three zones of NPEMFE signal absorption within the southern slope shown in hatching. Length of zone 1 is 8 meters; length of zone 2 is 12 meters; and length of zone 3 is 41.5 meters. The total length of the seepage zones is 61.5 m.

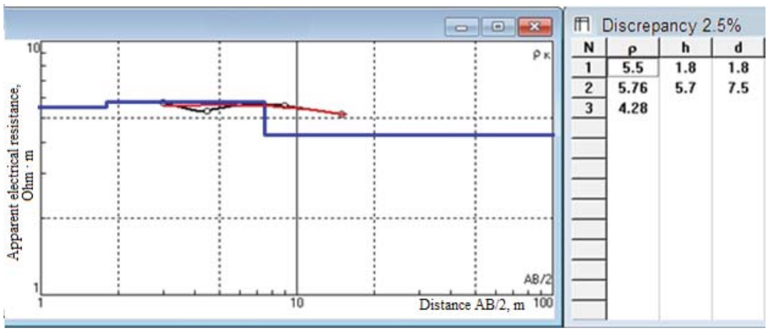
Calculation of seepage amounts through the zones explains that daily water losses from the basin are 130.3 m^3 or 3911 m^3 per month.

Ground water level has been determined according to interpretation of imaginary rock electrical resistance (Fig. 4). As the right-hand part of the Figure shows, geoelectric section detaches three layers of imaginary rock electrical resistance. Thickness of a layer one (upper layer) is 1.8 m; it is represented by black soil. Layer two is at 1.8 to 7.5 m depths; its thickness is 5.7 meters. It is represented by loess loam being a waterproof rock. Layer three from 7.5 m depth corresponds to the ground water zone; it turned out to be impossible to identify its depth occurrence. Hence, it is possible to state that underground water starts from 7.5 m depth. The principal geotechnical cross-section through the retention basin in the latitudinal direction is shown in Fig. 5.



(a) (b)

FIGURE 3. Arrangement map of survey points using the NPEMFE technique (a) and Schematic map of density of the NPEMFE pulse flow (b) within retention basin *Zvonetsky*. Red hatch shows projections of zones of soil watering on the day surface and their numbers. Colourful scale demonstrates pulse flow density, pul/sec. Metric, conditional scale



Discrepancy 2.5%

N	ρ	h	d
1	5.5	1.8	1.8
2	5.76	5.7	7.5
3	4.28		

FIGURE 4. Curves of apparent electric resistance, Ohm·m (a.e.r.) of rocks in the area of retention basin *Zvonetsky:* blue – Pseudo-Logging curve; black – Experimental curve; red – Theoretical curve; ρ_K, ρ – apparent electrical resistance, Ohm · m; N – the number of the layer from the surface; h – the thickness of the layer, m; d – the depth of the bottom of the layer, m

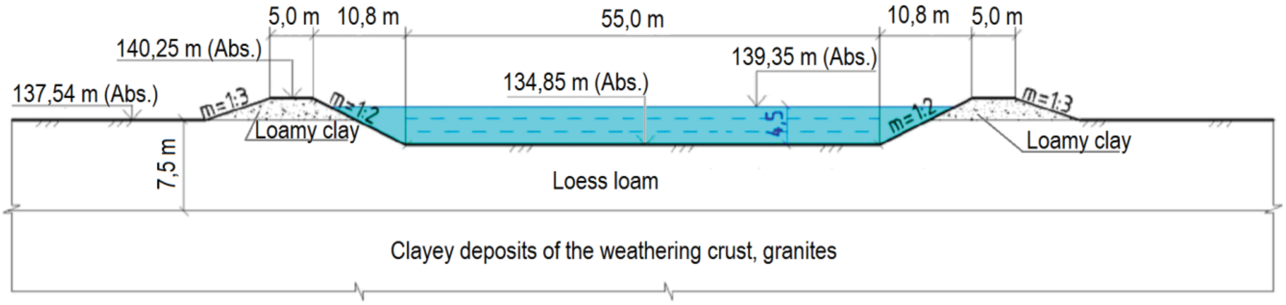
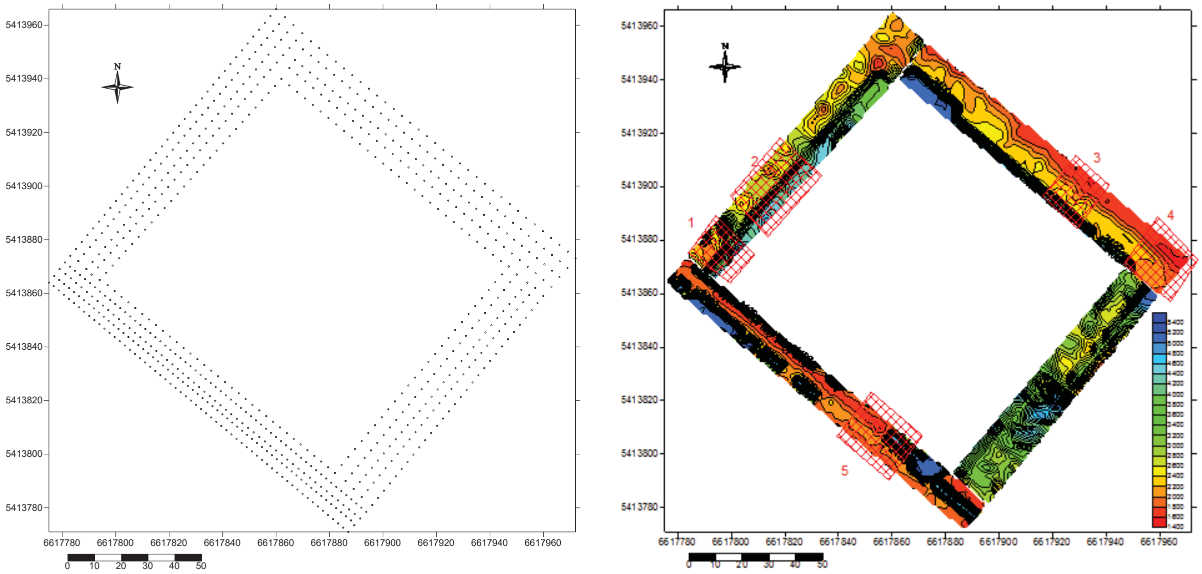


FIGURE 5. The principal geotechnical cross-section through the retention basin *Zvonetsky* in the latitudinal direction

Retention basin *Kulishi*

The NPEMFE survey has been carried out in terms of a network shown in Fig. 6(a). A schematic map and



(a) (b)

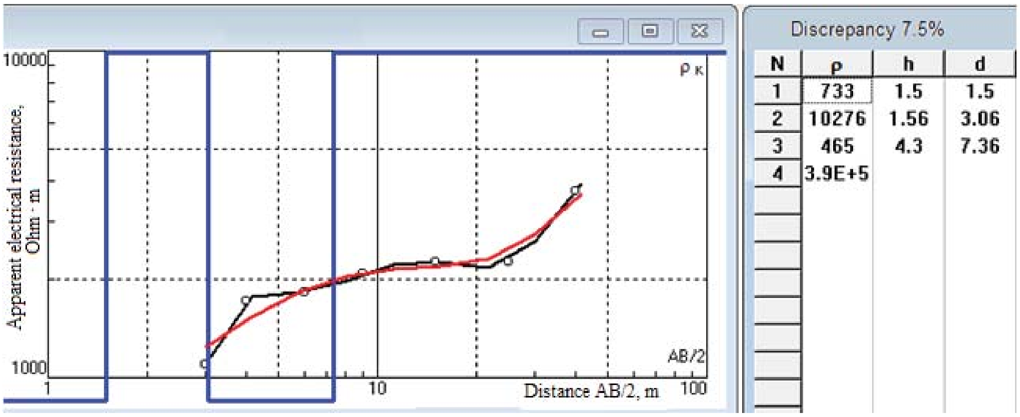
FIGURE 6. Arrangement map of survey points using the NPEMFE technique (a) and Schematic map of density of the NPEMFE pulse flow (b) within retention basin *Kulishi*. Red hatch shows projections of zones of soil watering on the day surface and their numbers. Colourful scale demonstrates pulse flow density, pul/sec. Metric, conditional scale

complex interpretation result from it (Fig. 6(b)).

Within the map, five sites of the decreased density of pulse flow of magnetic NPEMFE component, corresponding to water seepage zones, are singled out. Width of zone one is 11 m; width of zone two is 27.5 m; width of zone three is 13.2 m; width of zone four is 16.5 m; and width of zone five is 16.5 m. The total length of water seepage zones through the walls is 90.2 meters.

Calculation of seepage amounts through the zones explains that daily water losses from the basin are 303.3 m^3 or 9090 m^3 per month.

Ground water level has been determined according to the interpretation of electrical resistance of the imaginary rock (Fig. 7). As the right-hand part of the Figure shows, geoelectric section detaches four layers of electrical resistance of the imaginary rock. Thickness of layer one (upper layer) is 1.5 m; it is represented by the watered black soil. Layer two is at 1.5 down to 3.06 m. Its thickness is 1.56 m. It consists of loess loam and serves as a local aquiclude. Layer three from 3.06 down to 7.37 m depth corresponds to ground water layer; its thickness is 4.3 m. Layer four from 7.36 m depth has very high electric resistance, and it indicates location of the local aquiclude being clay and loam. Hence, within the area, ground water is closer to the surface. The principal geotechnical cross-section through the northeastern side of the retention basin and the position of the groundwater level is shown in Fig. 8.



Discrepancy 7.5%

N	ρ	h	d
1	733	1.5	1.5
2	10276	1.56	3.06
3	465	4.3	7.36
4	3.9E+5		

FIGURE 7. Curves of apparent electric resistance, Ohm·m (a.e.r.) of rocks in the area of retention basin *Kulishi*: blue – Pseudo-Logging curve; black – Experimental curve; red – Theoretical curve; ρκ, ρ – apparent electrical resistance, Ohm · m; N – the number of the layer from the surface; h – the thickness of the layer, m; d – the depth of the bottom of the layer, m

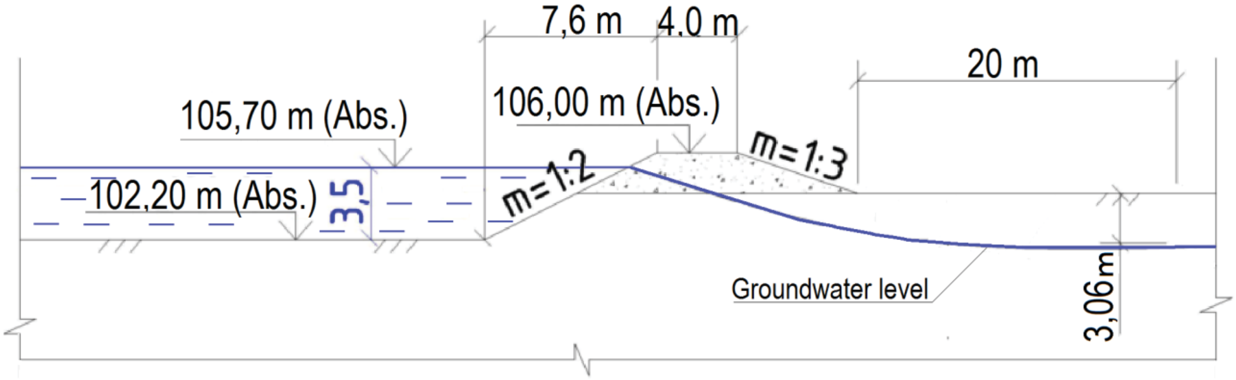


FIGURE 8. The principal geotechnical cross-section through the northeastern side of the retention basin *Kulishi*

DISCUSSING THE RESULTS

The research has shown unsatisfactory technical condition of the two basins; moreover, they have the sites with broken moisture proofing. Monthly, 3000 up to 9000 m^3 water losses are too large urging forward damage control. However, water migration from the basin is also a great problem. Actually, 20-50 thousand cubic meters of water are consumed by surrounding soil during each irrigation season to be abnormal thing for the regions. It is quite understood that the water replenishes ground water or is drained partially. As it has been mentioned before, the research tested the assumption that surcharge water drainage depends upon the features of geological structure of an area, within which retention basins are located. The research makes it possible to support the assumption and confirms reasonably the connection availability.

Thus, *Zvonetsky* basin is within Ukrainian Shield characterized by thin sedimentary cover as well as heavy fragmentation of its basement rocks. Hence, the water, resulting from the basin filtration, gets to the fractured zones, migrates in them, and discharges into the neighbouring ravines. The idea is supported by rather deep occurrence of underground water.

On the contrary, thick sedimentary formation is available within *Kulishi* basin area. Two aquifers are separated there. One of them corresponds to aeration zone, and exists from time to time. Another, constant one occurs deeper than 3 meters. Right the aquifer accumulates water leaking out of the basin through the broken moisture proofing. Consequently, ground water rises factoring into waterlogging of the territories and excessive moistening of the soil. That effects negatively cultivation of crops in turn requiring heavier fertilizer dressing; over the course of time, the fertilizers get to ground water downgrading it. In addition, other environment-damaging processes and phenomena make progress within the neighbouring territories, namely: waterlogging during heavy rains; suffusion subsidence events resulting from loess watering; resalinization as indicated by formation of salt films; evolution of moor vegetation etc.

The results make it possible to recommend insistently the forced drainage around retention basins located beyond Ukrainian Shield or in the areas with the developed thick sedimentary cover. Within the crystalline basement, natural drainage through fissures takes place; hence, the problem of artificial deaquation should be solved individually for each retention basin.

CONCLUSIONS

1. The research has demonstrated unsatisfactory technical condition of each retention basin. First of all, it depends upon their broken moisture proofing resulting in the losses of fresh water being valuable natural resource. Amounts of the losses are huge – dozen thousand cubic meters from one basin during an irrigation season. The basins need urgent repair or recovery.

2. Migration of water, passing through the walls and bottoms of retention basins in the underground space, depends on geological structure of the basin location. If crystalline rocks or thin sedimentary cover are available then water drains through basement fissures to the neighbouring ravines; underground water inflow is not significant; and its level rises very slowly. If a basin is within the area where thick sedimentary cover is developing then water, resulting from filtration, replenishes intensively underground water provoking its significant rise. It is dangerous from the viewpoint of origination and development of environment-damaging processes and phenomena

make progress; namely, waterlogging of territories is meant.

3. Basins, located within the areas where thick sedimentary cover is in progress, need the forced drainage around them; instead, artificial drainage problem for basins within the areas of crystalline rock development should be solved individually.

ACKNOWLEDGMENT

The research was carried out in terms of International project AgriSciencesPlatform financed by the Ministry of Foreign Affairs of Czech Republic (a grant for interdisciplinary research).

REFERENCES

1. Rudakov, H. Hapich, O. Orlinska, D. Pikarenia, V. Kovalenko., I. Chushkina and V. Zaporozhchenko. Problems of technical exploitation and ecological safety of hydrotechnical facilities of irrigation systems. *Journ. Geol. Geograph. Geoecology*. №29 (4). (2020). pp.776–788.
2. Irrigation and drainage strategy in Ukraine until 2030. Approved by order of the Cabinet of Ministers of Ukraine (2019) 688p.
3. Vainberg A.I. Reliability and safety of hydraulic structures. Selected problems. Kharkov, (2008), pp. 123-125.
4. Veksler A.B., Ivashintsov D.A. and Stefanishin D.V. Reliability, Social and Environmental Safety of Hydraulic Facilities: Risk Assessment and Decision Making, (2002), pp. 532-540.
5. Fedorov M.P., Shilin M.B. and Ivashintsov D.A. Environmental Engineering in Hydraulic Engineering. (1995), pp.68-84.
6. Liang C. and MacKay D.S. A general model of watershed extraction and representation using globally optimal flow paths and up-slope contributing areas. *International Journal of Geographical Information Science*. (2000), pp. 337-358.
7. Economic commission for Europe. Geneva. Dam safety in central Asia: capacity-building and regional cooperation. United Nations New York and Geneva (2007), pp. 70-74.
8. Connie Svoboda, P.E., Jeffrey Riley, P.E., Nathaniel Gee, P.E. Scoping Report: Public Safety of Low-Head Hydraulic Structures Research and Development. Office Science and Technology Program Final Report ST-2017-1799-01. (2017), pp. 9-13.
9. Musa Abubakar Tadda, Amimul Ahsan, Monzur Imteaz, Abubakar Shitu, Umar Abdulbaki Danhassan and Aliyu Idris Muhammad. Operation and Maintenance of Hydraulic Structures (2020).
10. 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.
11. Bestuzheva A.S. and Anakhaev K.K. Permeation through a homogeneous shut-off earthen dam on a permeable foundation. Energy and mechanical engineering. (2020) pp.147-153.
12. Stanley C. Nwokebuihe, Abdulrahman M. Alotaibi, Adel Elkrry, Evgeniy V. Torgashov and Neil L. Anderson. Dam Seepage Investigation of an Earthfill Dam in Warren County, Missouri Using Geophysical Methods. *AIMS Geosciences* (2017), pp. 1-13.
13. Aal G. Z. A., Ismail A. M., Anderson N. L. and Atekwana E. A. Geophysical Investigation of Seepage from an Earth Fill Dam, Washington County, MO. *Journal of Applied Geophysics* (2004), pp. 167-180.
14. Yin-Chun Hung,Tung-Tsan Chen,Tsai-Fu Tsai andHao-Xi Chen. A Comprehensive Investigation on Abnormal Impoundment of Reservoirs — Case Study of Qionglin Reservoir in Kinmen Island. *Water* (2021), pp.1458-1463.
15. Stanley C. Nwokebuihe, Evgeniy V. Torgashov and Neil L. Anderson. Investigation of a leaking earthfill dam in southwest Missouri. *Fast TIMES.* (2016), Pp. 49-56.
16. State building norms of Ukraine DBN B.2.4-3: 2010 Hydraulic, energy and reclamation systems and constructions, underground mining. Waterworks. Substantive provisions. (15 august 2021), 39 p.
17. State building norms of Ukraine DBN A.2.1-1: 2014 Engineering surveys for construction. (15 august 2021), 45p.
18. Methods of field surveys of earth dams and protective dams for water management. Manual for VBN B.2.4-33-2.3-03-2000. (2003), 36 p.

19. Chushkina I.V., Pikarenia D.S., Orlinska O.V. and Maksymova N.M. Experimental substantiation of the NPEMFE geophysical method to solve engineering and geological problems. (2019), pp. 109-123.
20. Tyapkin K.F. and Gontarenko V.N. Fault systems of the Ukrainian Shield. (1990), 183 p.
21. Ruban S.A. and Shinkarevsky M.A. Hydrogeological assessments and forecasts of the groundwater regime of Ukraine: monograph (2005), 572 p.
22. Salomatin V.N. Rapid assessment of the current state of the slopes of reservoirs and bodies of dams using the geophysical express method PEMFE. (20-22 September 2012), pp. 108-110.
23. Tyapkin K.F., Tyapkin O.K., Yakimchuk N.A. Fundamentals of Geophysics (2000), 248 p.
24. IPI2Win (c IPI_Res2, IPI_Res3): User guide IPI2Win. (2005). 26 p.
25. Zheleznyakov G.V., Ibad-Zade Yu.A and Ivanov P.L. Hydraulic structures (1983), pp.532-543.