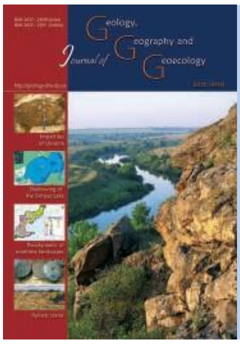

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Problems of technical exploitation and ecological safety of hydrotechnical facilities of irrigation systems

Leonid M. Rudakov[1], Hennadii V. Hapich[1], Olga V. Orlinska[1], Dmytro S. Pikarenia[2], Volodymyr V. Kovalenko[1], Iryna V. Chushkina[1], Viktoriia Y. Zaporozhchenko[1]

[1]Dnipro state agrarian and economic university, Dnipro, Ukraine, elner@ukr.net
[2]Dniprovsk State Technical University, Kamianske, Ukraine, nippel@rambler.ru

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Abstract. In this work, we analyzed and studied the Ukrainian typical hydrotechnical structures of the ameliorative complex on soil materials. On the examples of such objects in Dnipropetrovsk oblast, we carried out research and determined the technical condition of the transporting (main irrigation canals) and regulating (retention ponds) hydrotechnical structures (HTS). The main factors and the reasons for the negative engineering-geological processes occurring in those structures and affecting the ecological balance of adjacent territories were determined. The study revealed that the long period of exploitation and absence of corresponding technical care have led to significant losses of irrigation water from the canals and retention ponds. Due to the systemic absence and low use of monitoring researchers, we have proposed the use of prompt and low-cost methods and means of technical diagnostics. The article presents the possibility of using a complex of geophysical methods of natural impulse magnetic field of the Earth and vertical electrical sounding for the purposes of technical diagnostics. The possibility of recording plots and parameters of zones of seepage deformations in the body and at the base of the structures was visually determined and instrumentally proven. This allows identifying the amounts of technical and material resources, stages and order of implementation of repair-restoration works. It was determined that share of the damaged zones accounts for 20 to 35% of the total length of the hydrotechnical structures depending on their type and parameters of the constructions. In such conditions, the estimated losses of water equal 17-22% of the total amount of the delivery. The surveys showed that further operation of HC poses an ecological threat because of significant worsening of quality of water resources. The article presents disturbing dynamics of change in the irrigated areas involving the danger of secondary salinization, sodification, alkalinization, and toxification as a result of watering. We indicated threatening changes in the structures of the areas irrigated with low-quality water, which, according to various indicators of danger, increased by 1.4 times regarding threat of secondary salinization and by 2 times regarding threat of sodification. We proposed and substantiated approaches to improving the general technical and technological level of functioning of ameliorative structures in the context of maintaining ecological balance and economic practicability of their further use, based on the principles of systemic optimization of complex technical-natural ecosystems.

Key words: hydrotechnical facility, irrigation canal, retention pond, technical condition, seeping losses, geophysical methods of survey

Проблеми технічної експлуатації та екологічної безпеки гідротехнічних споруд зрошувальних систем

Л. М. Рудаков[1], Г. В. Гапіч[1], О. В. Орлінська[1], Д. С.Пікареня[2], В. В. Коваленко[1], І. В.Чушкіна[1], В. Ю. Запорожченко[1]

[1]Дніпровський державний аграрно-економічний університет, Дніпро, Україна, elner@ukr.net
[2]Дніпровський державний технічний університет, Кам'янське, Україна, nippel@rambler.ru

Анотація. В роботі розглянуті та досліджені типові для всього меліоративного комплексу України гідротехнічні споруди з ґрунтових матеріалів. На прикладі таких об'єктів у Дніпропетровській області, проведені дослідження та встановлено технічний стан транспортуючих (магістральні зрошувальні канали) і регулюючих (регулюючі басейни) гідротехнічних споруд (ГТС). Визначено основні фактори та причини негативних інженерно-геологічних процесів, які відбуваються в цих спорудах і чинять вплив на екологічну рівновагу прилеглих територій. Виявлено, що тривалий період експлуатації та відсутність належних технічних доглядів призводять до значних втрат поливної води з каналів і регулюючих басейнів. У зв'язку з системною відсутністю та низьким застосуванням моніторингових досліджень, запропоновано використання оперативних, достовірних та недорогих методів і засобів технічної діагностики. Представлена можливість застосування комплексу геофізичних методів природного імпульсного електромагнітного поля Землі та вертикального електричного зондування для цілей технічної діагностики. Візуально встановлено та інструментально підтверджено можливість фіксації ділянок та параметрів зон фільтраційних деформацій в тілі й основі споруд. Це дозволяє визначити об'єми технічних та матеріальних ресурсів, етапність та черговість реалізації ремонтно-відновлювальних робіт. Встановлено, що частка порушених зон складає від 20 до 35% загальної протяжності гідротехнічних споруд залежно від їх типу і параметрів конструкції. За таких умов розрахункові втрати води сягають 17-22% від сумарного об'єму подачі. Показано, що подальша експлуатація ГТС є екологічно небезпечною внаслідок значного погіршення якості водних ресурсів. Наведено загрозливу динаміку зміни зрошуваних площ за небезпекою вторинного засолення, осолонцювання, підлуження та інтоксикації внаслідок поливу. Відзначено загрозливі зміни в структурі площ политих водою низької якості, які за різними ознаками небезпеки збільшились від 1,4 рази за небезпекою вторинного засолення до 2-х разів за небезпекою осолонцювання. Запропоновано та обґрунтовано підходи з підвищення загального технічного і технологічного рівня функціонуючих меліоративних споруд за умови збереження екологічної рівноваги і економічної доцільності їх подальшої експлуатації, які базуються на принципах системної оптимізації складних техно-природних екосистем.

Ключові слова: гідротехнічна споруда, зрошувальний канал, регулюючий басейн, технічний стан, фільтраційні втрати, геофізичні методи досліджень

Introduction. Implementation of a strategic direction of the development of the agricultural sphere regarding the use of water, energy and material resources is oriented towards increase in the agricultural production volumes. An integral constituent of the provision is the technical condition and ecological reliability of hydrotechnical structures (HTS) of the ameliorative complex.

One of the most developed regions of the country is Dnipropetrovsk Oblast located in the north-east part of Ukraine, in the basin of the middle and lower reaches of the Dnipro. The total area of the territory of the oblast is 3,129 thou ha, including 2,569 thou ha (82%) of agricultural fields.

According to the amount of atmospheric precipitations, Dnipropetrovsk Oblast belongs to the zone of unstable moisture. The average annual amount of precipitations is 465-553 mm. Variation of the distribution ranges from 227 mm in low moisture years to 900 mm in high moisture years.

In summer precipitations usually come as cloudbursts, thus, their beneficial use for vegetation of plants is low, and insufficient moistening of the upper (arable) layer of the soil creates unfavourable conditions for the agricultural production. Therefore, high and stable yields of agricultural crops require additional moistening, i.e. organizational and technological provision of irrigation of land.

In view of food security of the state, we should consider that relevant research which would help to obtain stable and high yields of agricultural crops should include that oriented towards further improvement and ensuring of the norms of the current level of exploitation of any complex technological-natural ecosystems, including land-ameliorative structures. For this purpose one must consider their ecological reliability and safety.

Analysis of literature data and description of the problem. In the historical aspect, the hydromeliorative measures, particularly irrigation, in Katerynoslav Governorate (now Dnipropetrovsk Oblast), began to be implemented in the early XX century, only after catastrophic crop failure in the southern part of what was then Russia.

Since 1880 the tsar's government organized a number of expeditions with the purpose of creating a corresponding scientific base for fighting droughts and crop failures. The results of these expeditions gave a specific impulse to the development of irrigated arable farming in Dnipropetrovsk Oblast (Shevelev et al., 2005). Already in 1917 the area of irrigated fields in the Oblast accounted for 110 ha.

In 1930-1933 the Seliansky irrigated site 1,200 ha in area, Kamensky irrigated site 1,300 ha in area, and the 600 ha irrigated plot on Khortytsia island were projected and constructed. In 1939, in Kamianka Kolkhoz in Sofiivka district, an irrigated site of 500 ha was constructed, where for the first time in Ukraine fixed position sprinkler machines were employed, - these machines inspired development of sprinkler machines Volzhanka and Dnipro (Regional office of water resources in Dnipropetrovsk region).

In 1941 the area of irrigated fields in Dnipropetrovsk Oblast equaled 10,222 ha. Tempi of constructions of irrigated areas increased, accounting for 19 thou ha in 1960, 64.2 thou ha in 1965, and 124 thou ha in 1970.

In the late 1980s and early 1990s, in the irrigated fields, far-reaching sprinkler machines were being used and the area of irrigated land in Dnipropetrovsk Oblast in 1990 reached 219.6 thou ha. In the future, the governing bodies of the state expected to increase the area of irrigated lands in the Oblast to 540 thou ha by the year 2000 as a result of construction of large irrigation systems withdrawing water from the Dnipro, Dnipro-Donbass, the Dnipro-Kryvy Rih, Dnipro-Inhulets canals and by using drainage water from settlements (Shevelev et all., 2005; Regional office of water resources in Dnipropetrovsk region).

Over the recent years, due to the difficult economic condition, construction of new irrigation systems has been stopped. Old objects are gradually going out of order. Only in separate farms is complete watering of agricultural crops carried out. In some cases, in absence of sprinkler equipment surface irrigation (mainly vegetable crops) is applied. At the same time the area under irrigation changes all the time (Fig. 1).

tion of technical conditions and non-correspondence to the modern requirements of exploitation (Weyer et all., 2008; Huang et all., 2010; Shchedrin et all., 2011; Bedjaoui et all., 2011).

Projects of construction at some facilities include setting up designed control-measuring equipment, piezometers and monitoring drainage wells for the

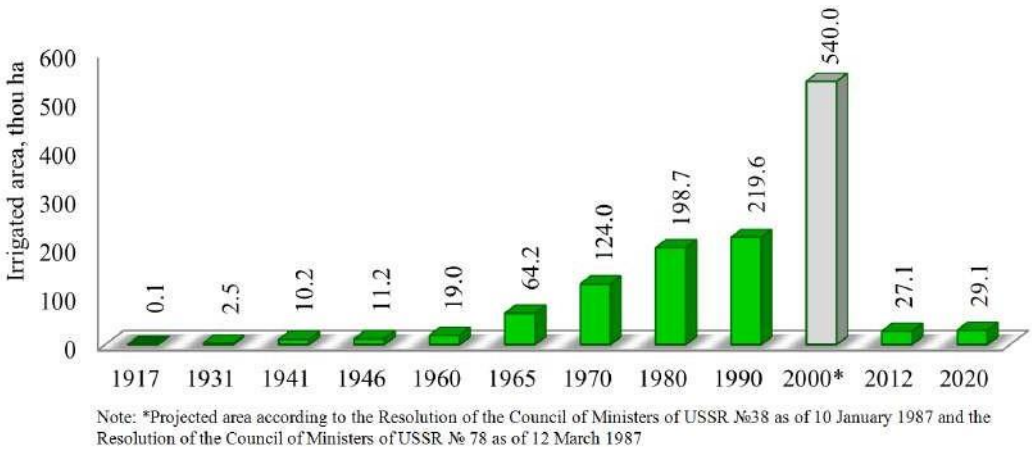

Fig. 1. Dynamics of changes in the irrigated areas in Dnipropetrovsk Oblast

The planned parameters of 540 thou ha under irrigation by the year 2000 were not achieved, instead more and more small systems of drip irrigation were built using water intake constructions and equipment of existing capacities. Gardens and vegetable crops are watered. At the same time, apart from irrigation, novel technologies of cultivation are used and such fertilizers and varieties are used which may significantly increase the efficiency of agricultural production and decrease the period until return on investments.

In terms of districts of the Oblas, the irrigated lands are arranged unevenly, primarily due to the presence of irrigation sources (Rudakov et all., 2019). Figure 2 depicts a schematic map of the oblast with the information on built and potential irrigation systems and their areas.

Currently, actually, the problematic issues of agricultural hydrotechnical land ameliorations in Ukraine have two main onward scientific vectors - the theoretical and the practical . The first is related to renovation of irrigation land-development, maintenance, recreation and rational use of fields and aquatic resources in the territory of our country (Ushkarenko et al., 2005; Vozhegova et al., 2013; Romashchenko et al., 2015, 2017). The second orientation is associated with the technical and technological component of the work of hydrotechnical facilities and land-development complexes. It is related to the assessment of technical condition, level of reliability and safety of exploitation of the objects. Global and domestic experiences indicate significant periods of work, deteriora-

control of losses of water and level of groundwater in the zone of influence of HTF. In most cases these components of technical equipment are non-functioning or ruined. It should be noted that currently the instrumental methods of investigating such facilities in Ukraine are practically unused. Sometimes, episodically, surveys using electrometric methods of geophysics are performed (Litvinenko et all, 2009). The investigations are conducted on a small number of objects due to the high cost and labour-intensity entailed. At the same time, except for visually noticeable damaged areas, a significant amount of zones of deformation, suffosion, water saturation, formation of fractures are impossible to determine visually at the initial stages of their development. Hence, this situation indicates the practicability of performing diagnostics of technical condition applying contemporary methods and means of distant control.

Objectives and purposes of the study. The conducted surveys were oriented towards identifying the level of current technical exploitation of hydrotechnical facilities of irrigation systems and their influence on ecological-ameliorative condition of their location within Dnipropetrovsk Oblast. The main water-transporting and water-regulating facilities in the irrigation systems are open canals and regulatory basins which provide uninterrupted supply and accumulation of irrigation water for watering agricultural crops.

To achieve our goals we solved the following tasks:

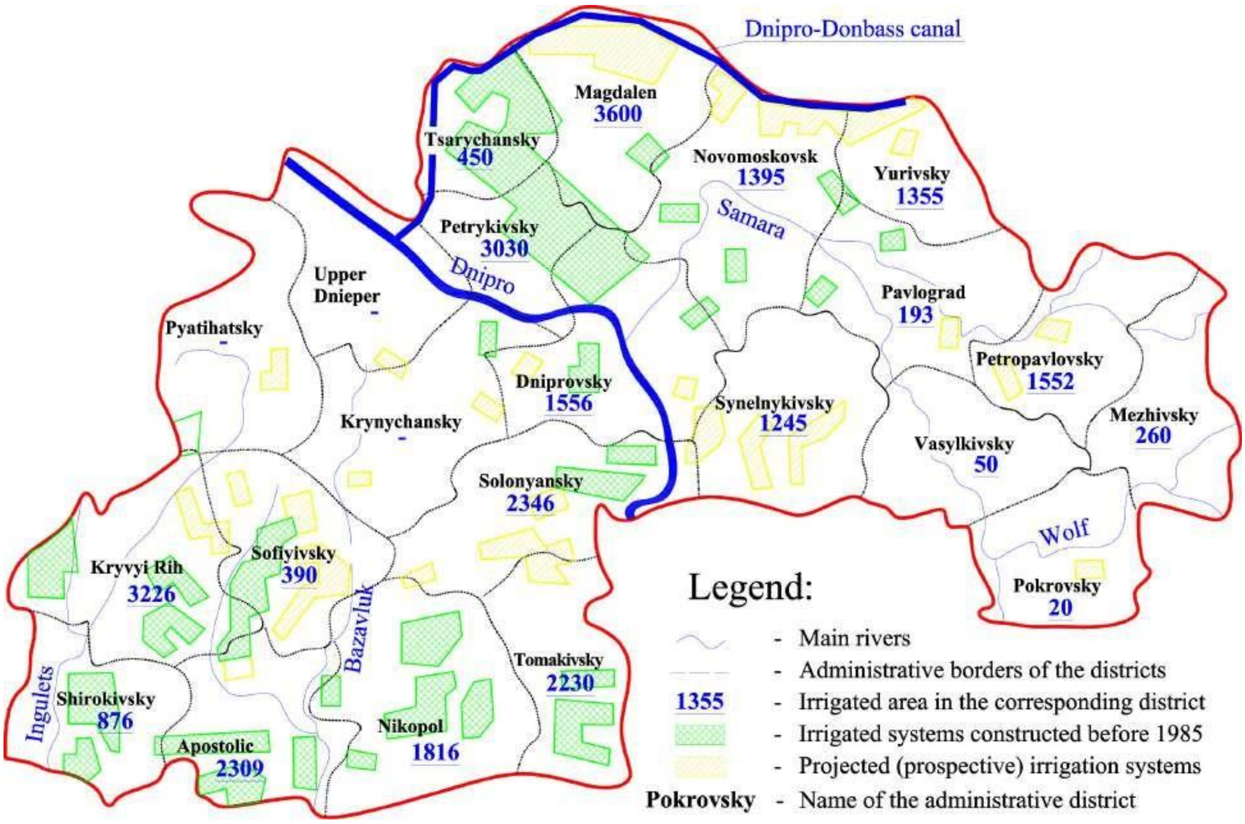

Fig. 2. Schematic location of irrigated areas in Dnipropetrovsk Oblast (developed by the authors using the materials (Duplyak et all, 1985)).

analyze the historical experience of creation and functioning of hydrotechnical facilities of ameliorative complexes in the territory of Dnipropetrovsk Oblast in different conditions of their operation;

determine the contemporary technical condition of hydrotechnical facilities by visual diagnostic monitoring using instrumental geophysical methods of surveys;

assess the geoecological influence on the adjacent territory, ecological reliability and safety of future exploitation of irrigation systems;

propose ways and approaches to ecologically-and-economically based improvement of technological level of functioning of the objects.

Materials and methods of surveys. The studies were conducted using the following methods: 1) visual diagnostic monitoring of bodies and the bases of the facilities; 2) field studies using complex of geophysical methods of Earth's natural pulse electromagnetic field (or ENPEMF) and vertical electric sounding (VES); 3) processing, analysis and generalization of the obtained results using mathematical methods and modern program complexes Microsoft Excel, AutoCad, Golden Software Surfer, IP2Win, Google Earth Pro.

The Earth's natural pulse electromagnetic field is one of the geoelectric fields. Methods and methodology of studying it began to be developed in the mid 1970s in the Tomsk Polytechnic State University under the leadership of O. A. Vorobiev. Since then the method has been introduced into geophysics under the name ENPEMF method. With time it has been improved, new methods and apparatus base have been developed, and the range of tasks it is capable of solving has been broadening. Contemporary devices allow us to perform various engineer-geological and hydrogeological surveys, determine zones of fractures and rupture damage, study and predict the development of shifts, etc (Pikarenya et al., 2009).

ENPEMF is characterized by non-stationary condition in any moment of time. Due to its wave nature, ENPEMF spreads in the Earth`s crust, but in the areas where fractures have formed, cavities appeared and became filled with fluid (water), the intensity of electromagnetic radiation (EMR) sharply decreases. Energy of EMR dissipates in gas or is absorbed by fluid. Because hydrotechnical facilities are made of soil materials, they are "transparent" for ENPEMF, but when fractures occur or soils become humid inside, the intensity of the field decreases. This reflects in decrease of density of the current of impulses of ENPEMF magnetic component, i.e. in the amount of impulses recorded during measurements (usually 0.5 – 1.0 sec). At the same time impulse is considered any excess of frequency-wave amplitude or energy of

ENPEMF over a certain determined level of discrimination (background value). Particularly the value of density of the flow of impulses is the basis for interpretation of studies adopting ENPEMF. Therefore, use of this method allows one to determine areas of seeping deformations and damaged zones on the bodies and bases of facilities.

Apparatus and equipment. Monitoring using ENPEMF was performed using a MIEMP-14/4 device (SIMEIIZ series) with simultaneous use of three antennae oriented length-wise, across and vertically downwards at the distance of 15-20 cm from the surface of the facility. Survey was performed using the following parameters of the device, similar for all antennae: frequency of discretization – 50 kHz, duration of measurement – 0.2 sec, coefficient of increase of signal – 10 V/mV, level of discrimination – 2 mV, measurement regime – simultaneous.

Substantiation of possibility and expedience of applying the ENPEMF method for the survey`s goals is described in-detail in the following studies (Orlinskaya et al., 2012; Hao et al., 2012; Wang et al., 2017; Kuzmenko et al., 2018; Chushkina et al., 2019). This method of geophysical studies is included in a number of state standards of Ukraine (Zbirnyk koshtorysnykh norm na heolohorozviduvalni roboty (ZUKN), 1999; Inzhenerni vyshukuvannia dlia budivnytstva, 2014).

The method of vertical electric sounding (VES) is one of the oldest methods of electric sounding, and therefore quite well=known and broadly used in geophysical practice. Its main advantage is simplicity of application and ostensible results, substantiating its active employment around the world. To carry out the studies using the VES method, we used standard electric-survey mine apparatus SERS 5 M (*Ukrainian* -ШЕРС 5 М). It has current A and B and measuring (reception) M and N electrodes (Fig. 3). As electrodes we used metal pins inserted into the ground. For installation of current and reception lines, we used steel-copper wires and cables. Electrodes were aligned in one line in relation to the center of the device.

The results of the studies using the VES method were analyzed using a special program IPI2Win developed by Bobechov O. A., which was created for automated and semi-automated interpretation of the data. This allowed us to obtain the depth of embedding of ground water and position of the water-resistant layer in the territories adjacent to the canals and basins. Further these data were used to determine quantitative parameters of losses of water from the irrigation systems and determine the level of waterlogging in the adjacent territory.

To calculate the seepage loss of water from the canals and regulating basins, we used classic generally-accepted methods (Vedernikov, 1939). Specific loss of water per 1 m of length of the seepage zone is determined using the formula:

$$q = k_f \cdot (B + A \cdot h_0) \cdot (1 + \frac{h_0 + h_k}{Y}), \quad (1)$$

where k_f – coefficient of seeping of soil of slope, m/24 h; B – length from the start of the slope to the point with stable level of groundwater, m; A – coefficient which takes into account side spilling of the seeping flow; h_0 – depth of water in the structure, m; h_k – height of capillary elevation, m); Y – depth to the water-resistant layer, m.

Ecological risks of waterlogging of the territory near the irrigation hydrotechnical facilities were predicted based on the standard methods (Ministry of Housing and Communal Services of Ukraine, 2010). Risk coefficient of waterlogging in this territory R was determined using the formula:

$$R = \lambda \cdot \nu, \quad (2)$$

where λ – coefficient of threat of waterlogging;

ν – coefficient of vulnerability to waterlogging.

Objects, conditions and methods of studies. Objects of the study were water-conveying (main canals) and water-regulating (retention ponds) hydrotechnical facilities made from soil materials which are the constituents of land-ameliorative complex. All surveys were performed within a day in favourable weather and climatic conditions. Field surveys were conducted on 3 main canals of Vyshchetarasivska, Soloniano-Tomakivska and Kilchenska irrigation systems (Tomakivsky, Soloniansky, Dniprovsky, Petrykivsky, Mahdalynivsky and Tsarychansky districts) and 10 retention ponds of the Petrovska (2), Soloniansko-Tomakivska (2), Vasylivska, Tsarychanska (3), Troiitska and Kalynivska irrigation systems. The first 5 basins are located in Soloniansky

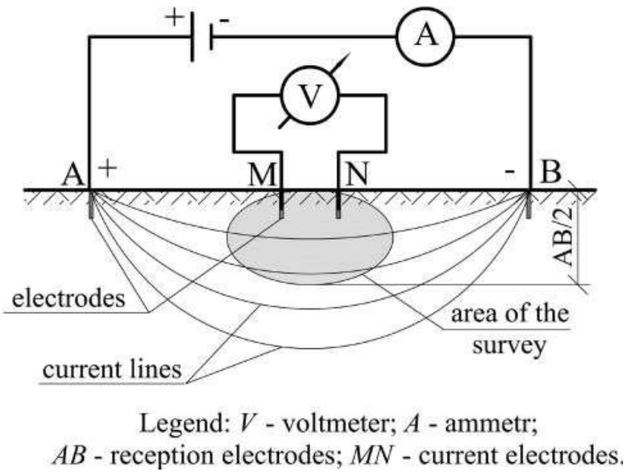

Fig. 3. Scheme of survey using VES

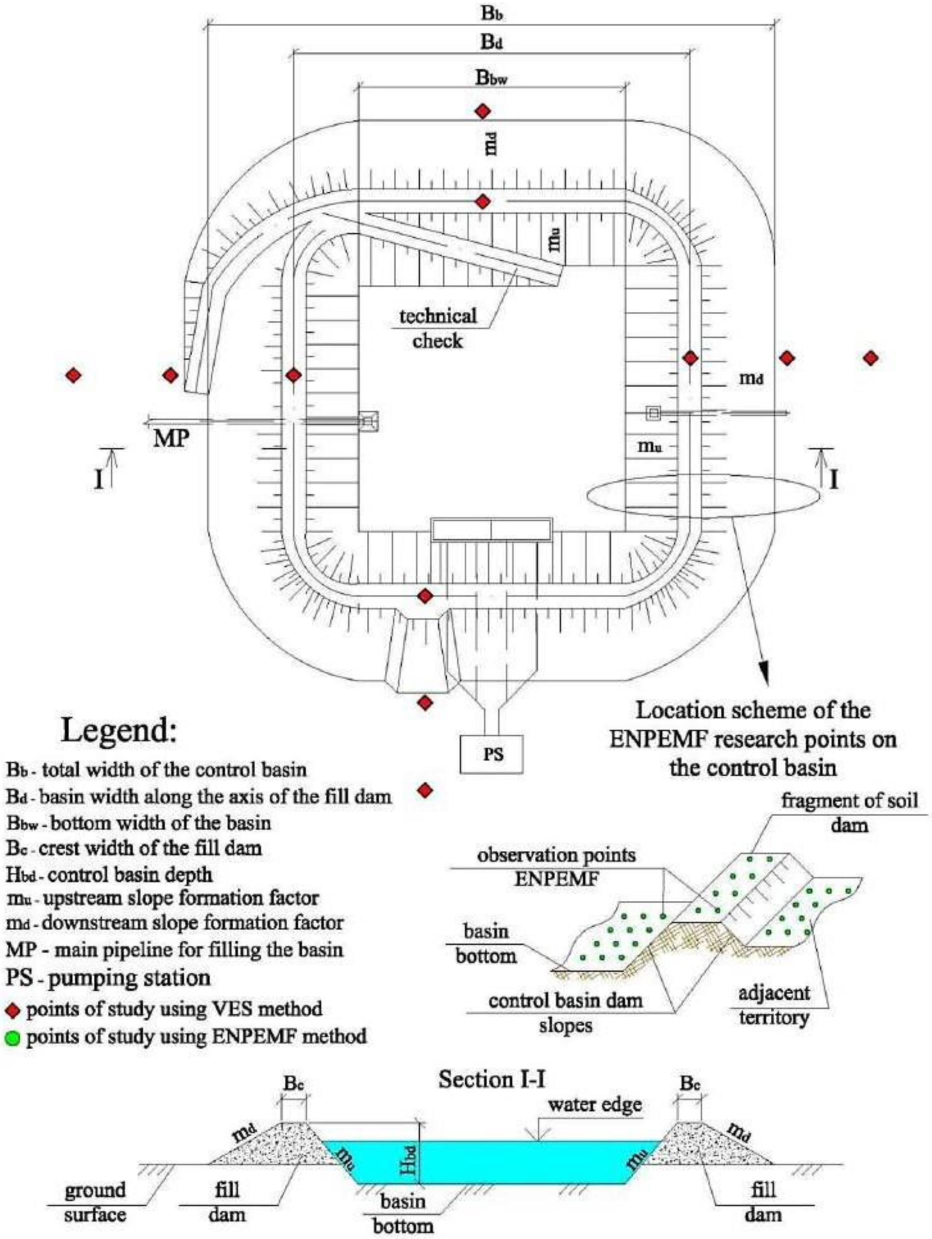

Fig. 4. Constructive scheme of retention pond and methods of performing surveys using geophysical methods of ENPEMF and VES.

district, 3 basins in Tsarychansky and 1 in each Mezhivsky and Synelnykivsky districts.

Retention ponds (Fig. 4) are quadratic facilities with the length of sides measuring 50 to 100 m and average depth of 4 to 6 m. They are located in a half-furrow-half-mound, at the same time the projects include anti-seeping cover of polyethylene film and reinforced-concrete slabs. Their main purpose is to act as reservoirs with pump stations of support located near the irrigation complexes for accumulation and retention of projected volumes of water for irrigation.

The peculiarity of the method of conducting field surveys using the ENPEMF method in retention ponds is survey in profile-area variant. The profiles are located on the dams` ridges, covering the bed and territory adjacent to the pond. In spite of insignificant sizes of the objects, compared with the canals, the total area we examined accounted for almost $15 \cdot 10^3$ m^2. Distance between profiles and points of observation on profiles equaled 3 to 5 m. The research was performed in two stages: when filled with water and empty. This allowed us to substantiate, reliably study and determine the regions of increased seeping, zones of formation of fractures and suffusion processes at early stages of development.

Open canals in most cases have trapezium-like shape and run through the furrows or half-furrow-half-mound (Fig. 5).

Technical service includes arrangement of technological berms. Canals, similarly to the ponds, should

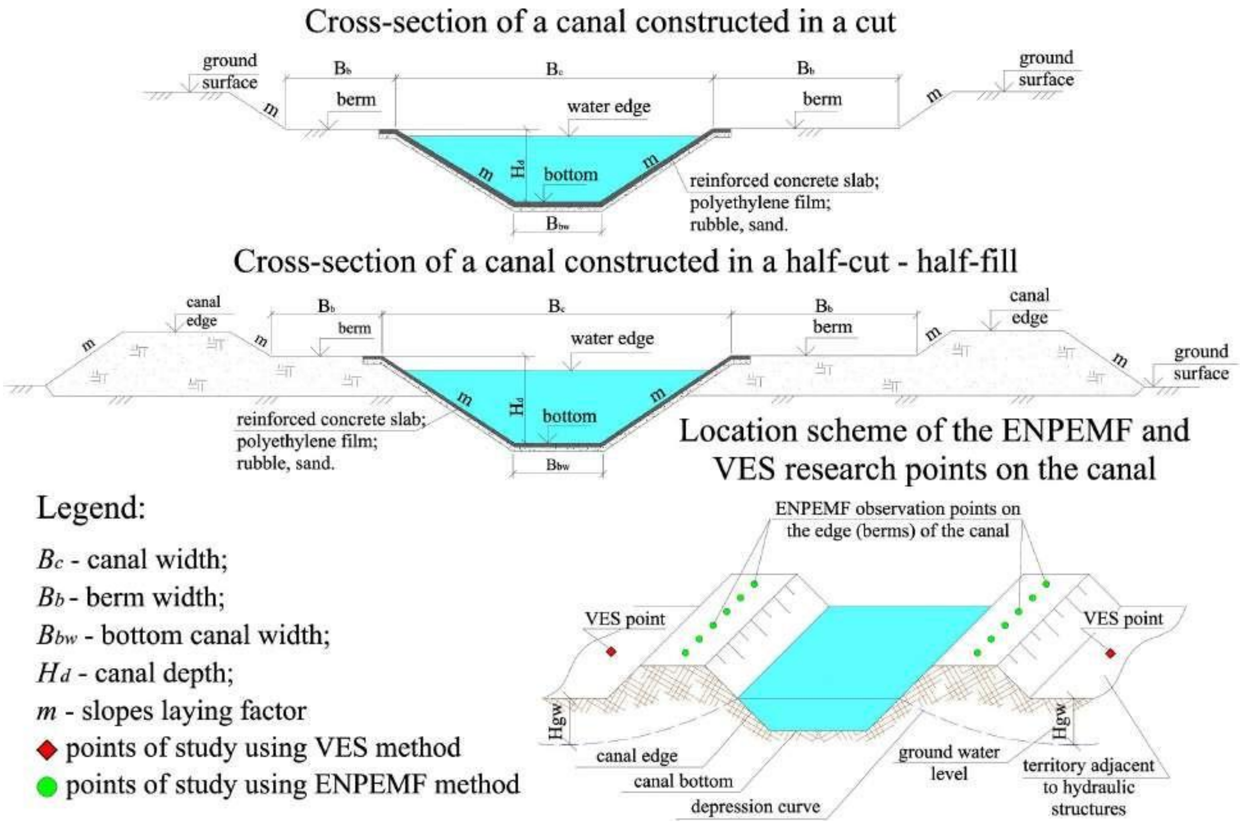

Fig. 5. Constructive scheme of irrigation canal and methods of surveys using geophysical methods of ENPEMF and VES.

have anti-seepage facing in the form of polyethylene film and reinforced-concrete slabs, The main purpose of the canals is transportation and provision of water to remote locations.

Peculiarities of methods of field surveys on main canals depend on the constructive characteristics of the objects. Because the canals are long and have insignificant width, the works were carried out in the profile variant, one profile in each of left and right dams at the distance of 2-3 m from the internal bank. The distance between the monitoring points in the profiles equaled 3 to 5 m. In both cases of surveys, the topographic division of the network was not needed, GPS navigator references were enough.

According to the data of study using ENPEMF method, the objects had damaged areas and zones of increased seepage of water. We should note that this method can not only prove visually recorded zones, but also determine externally unnoticeable areas of seeping deformations on the constructions and early stages of concentration of water seeping from the structures. To determine the level of groundwater and calculate quantitative parameters of water discharge, in the detected zones we made measurements using VES. Generalized results of visual monitoring and surveys using geophysical methods allowed us to sufficiently accurately and quickly obtain data on the technical condition of the facilities and discharges of water from them on large areas of irrigation networks.

Using this method the authors performed a considerable amount of monitoring in different districts of Dnipropetrovsk Oblast (Orlinskaya et al., 2012; Pikarenya et al., 2013)

Results and discussion. The long period of exploitation and absence of required technical monitoring and repair works have led to worsening of the conditions of safe and reliable operation of the facilities. According to the results of visual diagnostic monitoring of the main canals and retention ponds of the irrigation systems, we determined the following types of damage in the constructions (Fig. 6) which are typical for all objects of the ameliorative complex of the country: reinforced-concrete cover slabs were partly ruined, and completely absent at some of the sites; polyethylene anti-seeping film was damaged and required substitution; on the slopes active development of shrub vegetation was seen, which ruins the integrity of the body of the hydrotechnical structure. Such situation was observed in most HTFs. Unsatisfactory technical conditions of the facilities causes significant losses of water from the irrigation systems, decreasing their efficiency coefficients.

Thus, water-transporting and water-regulating elements of the irrigation systems have become potentially ecologically dangerous objects which negatively affect the ecological-ameliorative condition

a b

Fig. 6. Ruined areas of anti-seeping coverage at the current stage of technical exploitation of the structures: a – retention pond; b – main canal

of the neighbouring territories. Just according to the results of visual monitoring alone, the condition of the vast majority of the facilities requires significant impovement in the level of technical and ecological reliability and further safe operation.

The volume and substantiality of the results of our studies are proved by a large number of conducted experimental and practical surveys (Table 1).

cess of actual discharges as over 2.6 times compared with the projected ones (Reclamation systems and structures, 2000).

Therefore, the surveys revealed the total length of damaged areas which according to the total length of the facilities vary from 20% in the retention ponds up to 34% in the canals, indicating the unsatisfactory technical condition of the objects. We determined that

Table 1. Quantitative parameters of executed experimental and practical works

Hydrotechnical facilities*	Number of surveyed objects	Total length of soil dams, m	Number of profiles using ENPEMF	Total length of surveyed profiles, m	Number of points of observations using ENPEMF	Number of points of observations using VES	Length of damaged areas of the constructions, m	Structure of damaged zones to the total length of objects, %
RP	10	3,450	353	61,578	12,908	65	685	19.9
MC	3	56,500	10	74,165	26,474	41	19,316	34.2
Total	13	59,950	363	135,743	39,382	106	20,001	-

Note: RP – retention ponds; MC – main canals

Based on the performed research using the methods of Earth's natural pulse electromagnetic field (ENPEMF) and vertical electric sounding (VES), there are presented the generalized calculations of seepage discharges depending on the length of structures and determined evaporation losses depending on the area of the water table.

Seepage discharges of water from elements of irrigation systems were calculated in the conditions of homogenous soil in the context of seeping flow without pressure. General parameters for 3 main canals and 10 retention ponds of Dnipropetrovsk Oblast were calculated at minimum and maximum levels of water in the structures (Table 2). We should note that on the example of retention ponds, we determined excess non-productive losses of water for irrigation may vary from 3.95 M m^3 at minimum levels of water in the structures to over 5 M m^3 at maximum levels. Currently, for the needs of irrigation, around 23 M m^3 of water is withdrawn from various sources. Thus, the volume of irreversible losses from the elements of irrigation systems can reach 17 to 22% of the total. In the current conditions of operation, at average cost of irrigation water equaling about 4 hryvnias per 1 m^3 , oriented loss in the money equivalent can account for ~16 -20 M hrn per season.

The large amounts of seepage losses also affect the level of groundwater in the adjacent territories, leading to waterlogging of the lands, change in the qualitative and quantitative parameters of ecological-

Table 2. Calculation of water losses from the elements of ameliorative systems (generalized indicators)

Hydrotechnical facilities*		Calculated seeping water losses (taking into account parameters of detected areas of breakdowns and damages in the structures)		
Per 24 h, q, m^3/24 h		Per month, q, m^3/month	Per watering season (5 months), q, m^3/season	
RP	min	1,723	51,675	258,375
	max	1,915	57,460	287,300
MC	min	24,616	738,468	3,692,340
	max	31,598	947,936	4,739,680
Total	min	26,338	790,143	3,950,715
	max	33,513	1,005,396	5,026,980

Note: RP – retention pond; MC – main canal; min – calculations at minimum water level; max – calculations at maximum water level in the structure.

ameliorative condition of irrigation sites and chemical composition of groundwater. An additional factor of ecological threat is low quality of irrigation water (Rudakov et all., 2019). We should note the threat of deterioration of the quality of water resources for the needs of irrigation (Fig. 7).

salinization, sodification, alkalinization, toxification of lands, etc.

Fig. 8 presents the dynamics of change in the irrigation areas of Dnipropetrovsk Oblast according to the threat of impact on soils as a result of watering with low-quality water.

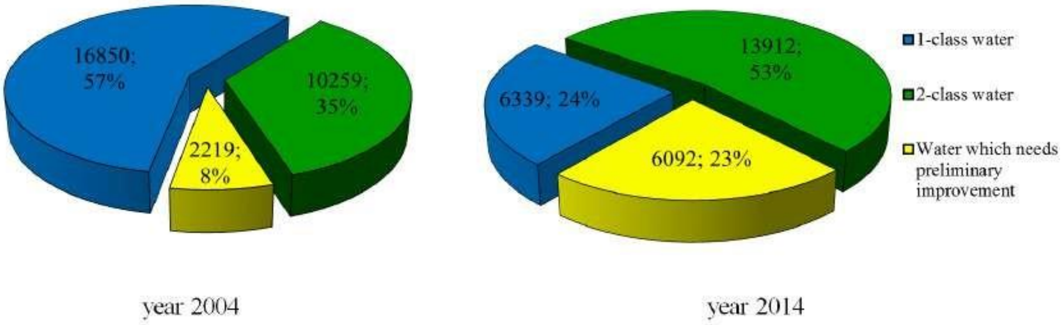

Fig. 7. Deterioration of quality of water for irrigation in relation to irrigated areas (ha; %) in Dnipropetrovsk Oblast in 2004-2014.

The territory of the sites irrigated with water which needs preliminary improvement increased from 2,219 ha in 2004 to 6,092 ha in 2014, i.e. by 2.75 times over 10 years.

The quality of irrigation water directly affects the evolution of soils. Watering with low-quality water leads to dangerous processes, particularly secondary

Analysis of the data given in Fig. 8 suggests significant changes in the irrigated areas according to several types of threat, rapidly deteriorating ecological situation in the irrigated sites and neighbouring territories. Therefore, the dynamics of irrigated areas over ten years (from 2004 to 2014) indicates a 1.4-fold increase in danger of secondary salinization, 2-fold

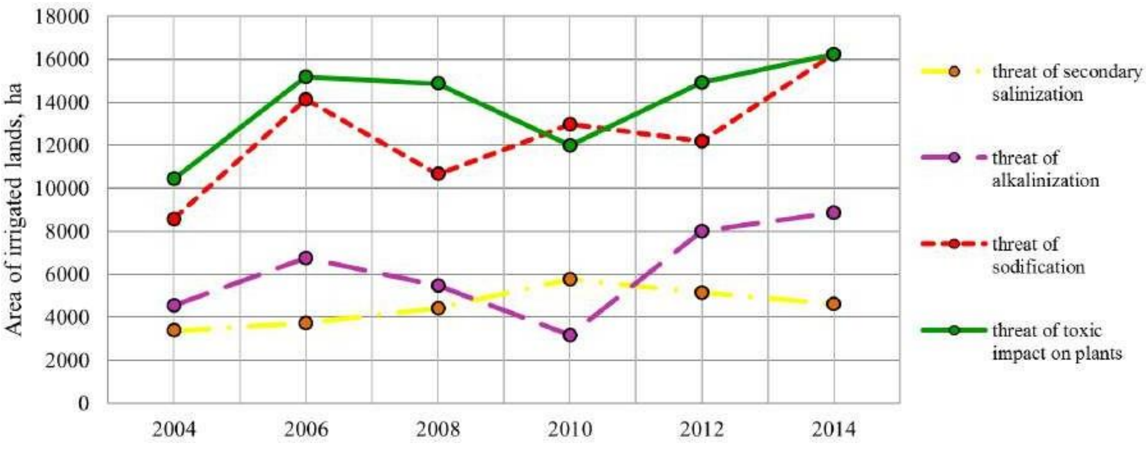

Fig. 8. Dynamics of change in the area of irrigated lands of Dnipropetrovsk Oblast in 2004-2014 according to the threat of impact of soils as a result of low quality of aquatic resources.

increase in the threat of sodification, 1.9-fold increase in danger of alkalinization, and 1.5-fold increase in threat of toxic effect on plants.

An indicatory element of deterioration of the ecological component of managing irrigational land development is the structure of changes in the irrigated areas (Fig. 9). Among the abovementioned elements of hazardous impact, we can clearly see a rapid decrease in the area of fields irrigated with water of normative quality. Such territories decreased by 2.65 times.

Discussion of the results. The presented quantitative parameters of experimentally determined damaged areas of the hydrotechnical facilities indicate significant deterioration in the technical condition of the vast majority of hydrotechnical facilities in Dnipropetrovsk Oblast, which is typical for the ameliorative complex of the country. Long absence of repairs and required technical monitoring, violation of requirements concerning expected loads and effects over the substantiated period of operation of the facilities have led to a collection of a number

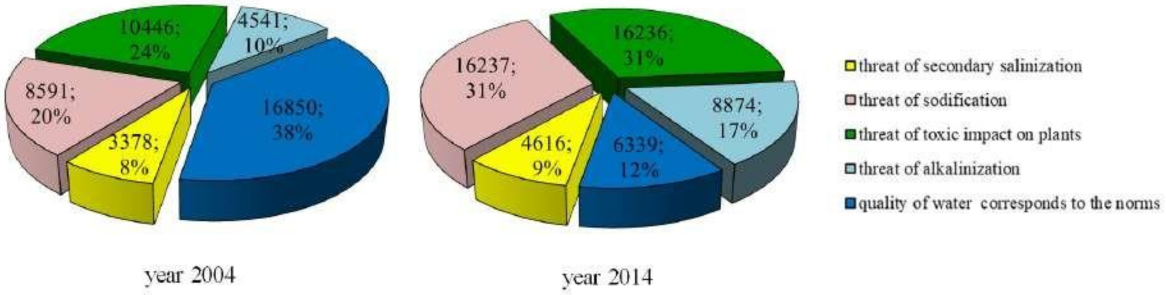

Fig. 9. Structure of change in the area of irrigated lands (ha; %) in Dnipropetrovsk Oblast according to threat of impact on soils as a result of low quality of aquatic resources for the period of 2004-2014.

Water lost from the hydrotechnical facilities is not lost unnoticeably – it elevates the level of groundwater and leads to formation of excessively moistened areas along the canals with plots of marsh-reed vegetation, significantly affecting the ecological balance in the agrolandscapes.

The obtained results of the surveys indicate ecological threat of further exploitation of the retention ponds and main canals not only due to unsatisfactory technical condition, but also due to significant deterioration in the quality of water resources. This underlines the necessity of improving the technical condition of hydrotechnical facilities and setting greater requirements regarding the quality of irrigation water.

In view of the facts mentioned above, a relevant issue is the assessment of risks of waterlogging in the territories adjacent to the canals and ponds. Risk coefficient R determined based on the extent of threat and level of vulnerability to waterlogging is evaluated according to the principle of crossing of these events. On the example of the studied objects it was determined in correspondence to the normative document (Ministry of Housing and Communal Services of Ukraine, 2010) ranging 0.05 to 0.2.

Generalization of the obtained parameters allows us to state the extent of risk, classifying it as low and moderate. At the same time, we should emphasize that decrease in the level of ecological threat as a result of large losses and low quality of water resources has a remote-in-time accumulating effect.

of technical problems, thus categorizing the objects as ecologically dangerous. In order to solve this problem of restoration and further development of ameliorative systems, it is relevant to determine the amounts of work and resources needed to perform repair-restoration works, and also the order of their implementation. First of all it is necessary to determine the most potentially threatening areas using monitoring surveys.

The main directions of implementation of and methodological approaches to improvement of technical and ecological condition of the facilities must be based on the methods of systemic optimization of complex technical-natural systems (Turchenyuk et al., 2017).

The presented list of measures is expedient from the practical perspective, therefore allows providing efficient functioning of HTFs in irrigation systems due to the ecologically-economically based optimization of constructive, technical and technological parameters and indicators of operation of the facilities. An approach to complex mechanism of regulation of the mentioned elements of functioning of HTF of the ameliorative complex is proposed (Fig. 10).

Conclusions

1. The performed historical analysis of existing sources presents the main stages of development of the ameliorative complex in the territory of Dnipropetrovsk Oblast. We determined the significant periods of work of most objects, and also their non-

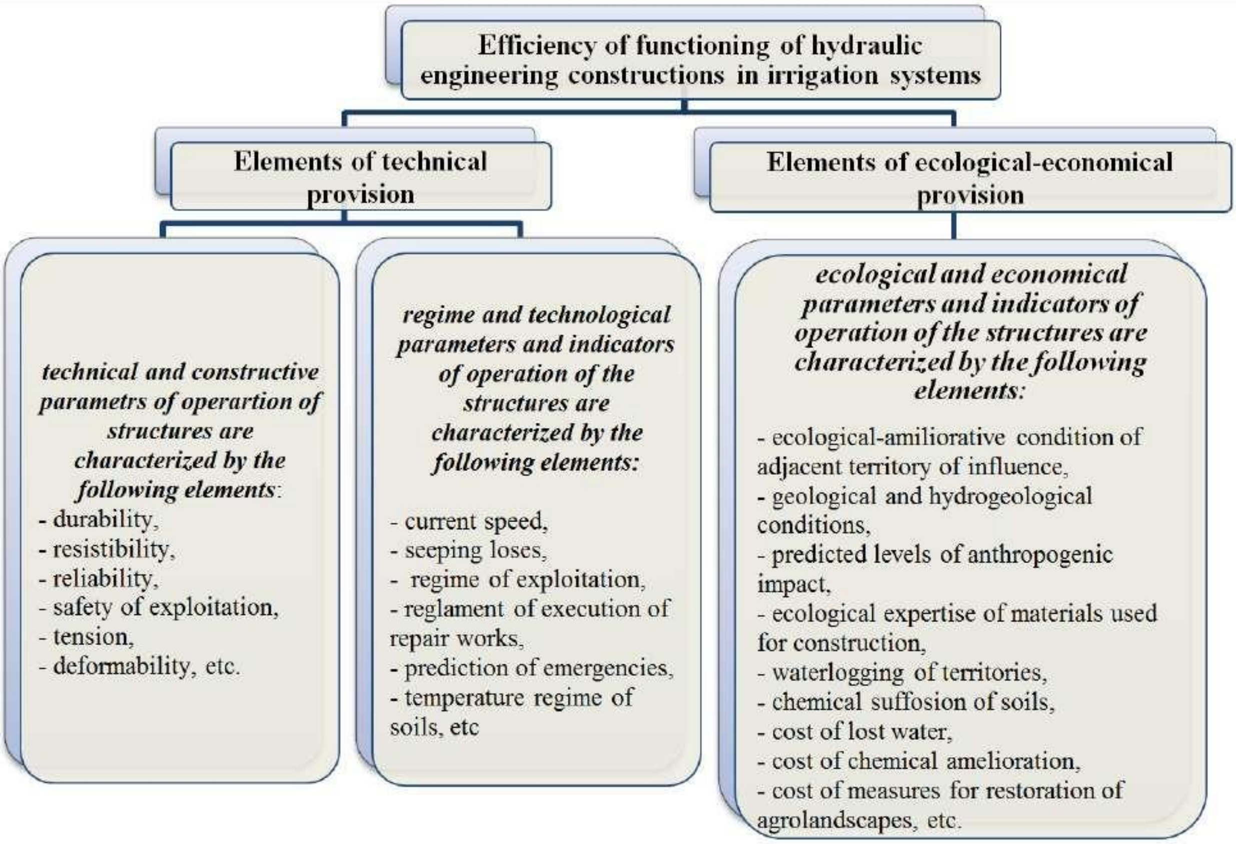

Fig.10. Elements of technical and ecological and economic support of efficiency of functioning of hydraulic engineering constructions on irrigation systems

correspondence to the contemporary requirements of technical and ecological reliability of exploitation.

2. We performed field surveys to determine the current level of technical exploitation of the hydrotechnical facilities. We conducted visual diagnostic monitoring, and also instrumental surveys using a complex of geophysical methods of Earth's natural pulse electromagnetic field (or ENPEMF) and vertical electric sounding (VES). The reliability of the obtained results is proved particularly by the significant amount of survey-methodological work carried out and their practical implementation.

3. We determined that the share of the damaged areas where zones of water seepage and suffusion were found is 20 to 35% depending on the type of construction of the facilities. The main disadvantages of technical condition are ruination of anti-seeping cover of reinforced-concrete slabs and polyethylene film, development of shrub vegetation on slopes and berms of the facilities, formation of areas of seepage deformations.

4. We determined the amounts of seepage losses from the transporting and regulating hydrotechnical facilities. Depending on the level of water they accounted for 3.9 to 5 M m^3, which in the contemporary economic conditions of water provision are equivalent to money losses equaling 16-20 M hryvnias per season.

5. The article shows that further exploitation of the facilities threatens the ecology because of significant worsening of quality of surface water resources. We showed the threat of changes in irrigated areas according to the danger of secondary salinization, sodification, alkalinization and toxicification. The areas of land where irrigation water requires preliminary improvement of qualitative parameters account for around 20 thou ha, which is 76% of the total area of watered land.

6. We calculated the coefficient of ecological risk of waterlogging of territory in the zone of influence of the hydrotechnical facilities, which is mostly classified as low or moderate.

7. We proposed and substantiated the approaches to improvement of the general level of technical exploitation of hydrotechnical facilities. The practical task is implementation of the constituents of technical and ecological-economic provision of efficiency of functioning of the objects, based on the methods of systematic optimization of components of technical-natural complexes.

8. We substantiated the expedience of using contemporary, relevant and low-cost methods and

means of technical diagnostics of the facilities, which would allow not only identification of externally unnoticeable areas of deteriorated condition, but also for them to be identified at the stage of initial development and then repaired. Timely diagnostics and technical evaluation would contribute to the prediction of composition, amounts and order of performance of repair-restoration works at different stages of operation.

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