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ECOLOGICAL AND ECONOMIC EFFICIENCY OF LOCALIZATION OF SOURCES OF POLLUTION OF SOILS OF TECHNOGENIC EFFLUENTS USING THE TECHNOLOGY OF THE DEVICE OF THE HORIZONTAL IMPERVIOUS SCREEN

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Scientific Research Institute of construction operations (Kiev, Ukraine) develops technology providing arrangement of horizontal impervious screen (HIS) under existing industrial facilities using technology of horizontally directed drilling. HIS acts as an artificial aquitard and is intended to protect soil and groundwater from contamination with toxic waste or radionuclide's, as well as for the localization of pollution. There was made environmental effect assessment of HIS adoption in water permeable soils combined with imperfect impervious diaphragm (ID), carried out by means of «diaphragm wall» in case of natural waterproof layer of soil absence, and also was determined ecological-economic effective application of HIS compared with perfect ID buried into a natural waterproof layer of soil.
Keywords: horizontal screen; impervious diaphragm; «wall in the ground»; ecological-economic impact; application area.

Formulation of the problem. Environmental safety of soils and groundwater's has become particularly relevant due to objective necessity related to the growth of harmful influence of human activity on the environment.

Need to ensure environmental protection of underground space is also associated with the Kyoto Protocol, signed by majority of large industrial countries, including Ukraine. Ukrainian legislation provides general requirements to environmental safety, including construction of underground facilities, where a special place is occupied by toxic and radioactive waste storages.

In case of violating hygienic requirements for disposal and destruction of toxic industrial wastes at temporary storage sites, soils might be polluted, which in chain may contribute to migration of toxic chemicals coming into contact with medium soil, into groundwater, underground and surface water basins.

Accident at the Chernobyl nuclear power plant resulted in contamination over 4.6 million. Ha of soil with radionuclide's including 3.1 million Ha of arable land.

Should be separately noted pollution of soil and groundwater as a result of infiltration of atmospheric precipitations through buried storages of radioactive waste (RW), which were spontaneously created on the territory of Chernobyl nuclear power plant when eliminating consequences of the accident. In these vaults there were buried remains of machinery, equipment, construction materials, animals and other things having come under ionizing radiation, at the same time proper waterproofing of these storage facilities generally has not been performed.

Analyzing possibility of soil contamination with various chemicals, elements should be divided into two groups: – The first group comprises substances and their compounds insoluble in water and therefore their penetration depth into soil is rather insignificant and does not exceed 2-3 m; – the second group – chemicals soluble in water and radionuclide's, which by means of infiltration may penetrate to considerable depths, contaminating soils and aquifers. Penetration depth and contaminated water filtration speed depends on the filtration properties of soils and barrier to spreading such contamination, in this case, may be natural impermeable soil layers, for example of clay.

Actuality of soil and aquifer protection from contamination with technogenic effluents of industrial enterprises and radionuclide's increases every day. Equally important is localization of already contaminated lithosphere and preventing toxic spread both in a horizontal sense and at the significant depth.

Analysis of recent research and publications. Preventing contamination proliferation at large territory and localization of contaminated soils and groundwater's is possible by constructing impervious diaphragm (ID) in the perimeter of contamination source, for example, «wall in the ground», to cut the ground aquifers, [1]. The effectiveness of such curtain is determined by the presence of waterproof layer of soil at a technically attainable depth.

If the waterproof layer of soil is missing or is technically inaccessible, or installing cutoff device to a considerable depth it is not economically feasible, there is a need in the artificial creation waterproof layer, for example, horizontal impervious screen (HIS) (Fig. 1) [2; 3].

The analysis of the works Smorodinov M.I., Filatova A.L, Zubkov V.M., Kruglikova N.N. Chernukhina A.M., studies in NIIOSP im. Gersevanov N.M. (Moscow), NIISP (Kiev), showed the need to improve methods of locating contaminated soil and groundwater in the absence of the reachable depth of the impermeable layer [4; 5; 6].

Unsolved aspects of the problem. Technology of impervious curtain construction (GWC) made by method of «wall in the ground» includes development of a vertical trench (cavity) protected by clay mud as a rule plunged in the waterproof layer at depth of 1-2 m, and filling of the trench with watertight material.

New construction technology of horizontal impervious screen (HIS) is based on the known method of horizontal directional drilling (HDD), and includes location of two parallel guiding horizontal wells protected by clay mud in the plane authentic to base of the facility, soil excavation between the holes is made by relevant body to form a cavity and further filling this cavity with impervious material (IM) [7; 8].

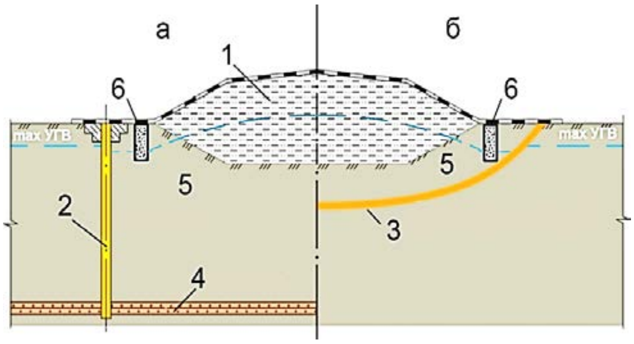

Fig. 1. Scheme of protection of soil and groundwater against contamination: a – at presence of waterproof layer; b – at absence of waterproof layer; 1 – storage; 2 – GWC; 3 – HIS – artificial waterproof layer; 4 natural waterproof layer; 5 – contaminated soil; 6 – drainage

Link: developed by the authors

Technologies of construction of ID and HIS have a number of common features: environmental protection, application of clay solutions to hold the trench walls from collapse, formation of cavities (vertical and horizontal) and their subsequent filling with impervious material.

However, scope of the technologies significantly varies due to the fact that the new HIS construction technique can be applied to a depth of 5 m from the surface, while the depth of ID construction by «wall in the ground» method may reach depths of over 100 m., depending on the equipment used.

Application of the above technologies could provide equal environmental effect localizing equal areas to prevent spread of soil and groundwater contamination, but volume of contaminated soil and, accordingly, comparative economic effect determined by lithosphere treatment (recovery) cost will be different.

Thus, for territories equal in area, level of soil contamination with water soluble toxic substances and/or radionuclide's, for HIS technology will be determined by the depth of the artificial waterproof layer (5 m), and for the ID, «wall in the ground», hypothetically, in case of water permeable soil, by natural impermeable soil layer depth.

Other words, ecological and economic effect of creating an artificial waterproof layer by constructing HIS is to reduce the amount of polluted soil subject to further recovery.

The purpose of the work. The definition of the ecological and economic impact and efficient use of the horizontal impervious screen in dependence on the depth of location of the impermeable soil layer.

The main content. To estimate the ecological and economic benefits from the construction of HIS, compared with the construction of ID as «diaphragm wall» it is necessary to determine initial data to calculate both options (Figure 2.3) Provided that:

– contamination source – buried storage of toxic and/or radioactive waste located in sandy (sandy loam) soils 1-2 class of excavation difficulty;

– storage dimensions: length – 50 m, width – 46 m, underground part of storage recessed by 3 m;

Variant I (Fig. 2a):

– HIS is performed in accordance with technological map [9] at a depth of 5 m from the ground (2 m from the base of the vault). Screen material – clay-cement-sand mortar. Waterproof layer of soil at attainable depths is absent;

– to create closed loop and to prevent filtration on both sides of the screen at a distance of 2 m from the storage imperfect ID «wall in the ground» is arranged 1 m below HIS. ID material is clay-cement-sand paste, possibly contaminated area (localization area) – 5000 m².

Variant II (Figure 2b):

– HIS is performed under Var. 1;

– to create closed loop, prevent filtration, reduce possible contamination area (territory of localization) imperfect ID «wall in the ground» is constructed at the perimeter of the storage at a distance of 2 meters from its boundaries 1m below HIS, possibly contaminated area (localization area) – 2,700 m².

Variant III (Figure 3):

– along the perimeter of storage at a distance of 2 meters from its borders is arranged perfect ID «wall in the ground» recessed in the waterproof layer of soil at 1 meter. Material of curtain – clay and sand-cement paste, waterproof layer soil –

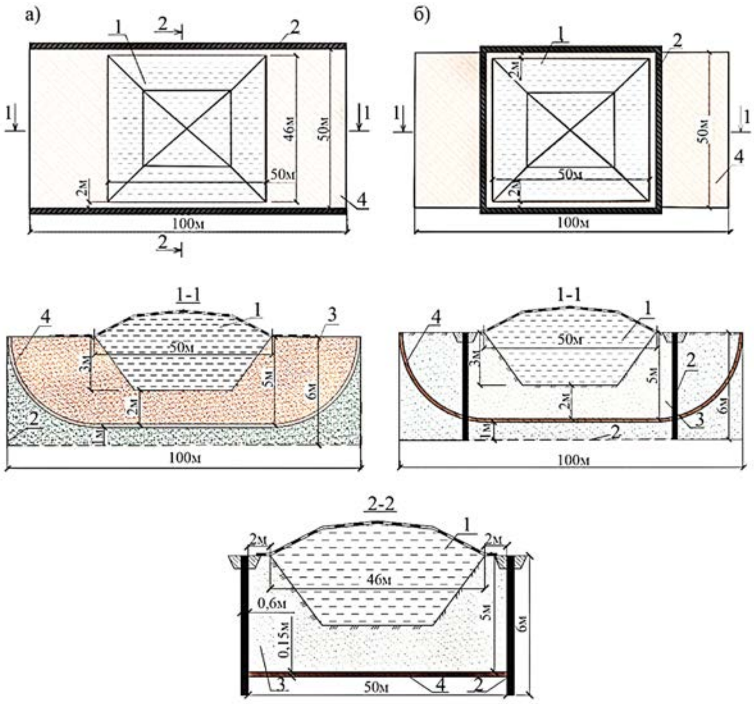

Fig. 2. Localization variant for storage without waterproof layer of soil
a) curtain at both sides of the screen; b) a curtain along the perimeter of storage 1 – storage; 2 – imperfect ID; 3 – contaminated soil; 4 – HIS – artificial waterproof layer of soil

Link: developed by the authors

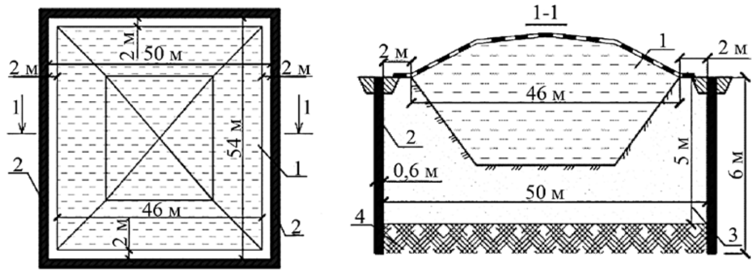

Fig. 3. Localization variant for storage with an waterproof layer of soil
1 – storage; 2 – perfect ID; 3 – polluted soil; 4 – natural waterproof layer of soil

Link: developed by the authors

Clay of 3 excavation difficulty class, possibly contaminated area (localization area) – 2700 m^2.

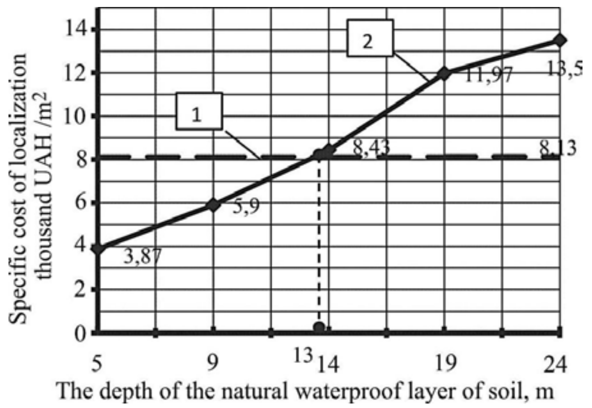

Fig. 4. Graph of the specific localization cost depending on the depth of the waterproof layer of soil
1 – HIS combined with ID without the natural waterproof layer; 2 – ID at presence of natural waterproof layer of soil

Link: developed by the authors

To estimate cost of implementing new construction technology HIS there were used regulatory estimates of labor and material resources, defined on the basis of technological map [9, 10].

Construction of IDs by «wall in the ground» method is widely displayed in regulatory framework of Ukraine and, therefore, to estimate cost there were used existing resource elemental estimate standards that display corresponding process.

Technical and economic indicators of the implementation of above options are shown in Table 1. Moreover in Table 1 for comparison are provided indicators of ID construction variants at depth 10, 15, 20 and 25 m with a natural waterproof layer of soil at depth of 9, 14, 19 and 24m and corresponding possible contamination area (localization area).

Figure 4 shows a plot of the specific cost of localization for equal areas (ratio of ID cost to localization area) depending on the depth of the natural waterproof layer of soil in comparison with localization cost of the contaminated soil without waterproof layer of soil using HIS technology combined with imperfect ID.

At equal localization areas, comparing construction cost of HIS combined with imperfect ID with depth of 6 meters and construction of a perfect ID discovers effectiveness of building artificial waterproof layer of soil under the condition of natural aquitard presence at depths exceeding 13 m.

As mentioned above area of contamination can not characterize environmental damage caused by contact of toxic radionuclide's with the ground, since such loss is estimated by cost of treatment (recovery) of the whole soil volume which is depending to a large extent on the depth of penetration of contaminants.

Defining the counter of possible soil contamination volumes and corresponding damage including localization cost, we can estimate ecological and economic effect of preventing spread of pollutants, using HIS combined with imperfect ID with depth of 6 m, compared with the construction of a perfect ID.

According to the «Methodology...» [11] amount of damage from land pollution is determined by the formula (1):

$$S = A*G*P*K1-K2-H, \quad (1)$$

where: S – size of damage caused by soil contamination (cost of soil treatment (recovery)), UAH;
A = 0.5 – specific costs to eliminate the impact of plot pollution;

Table 1

Technical and economic indicators of pollution localization variants

Localization variant	Kinds of works	Natural waterproof layer		Screen / diaphragm depth, m	Screen / diaphragm area, m^2	Screen / diaphragm volume, m^3	Localization cost, million UAH	Localization area, m^2	Specific cost of localization thousand UAH /m^2	Volume of localized soils subject to treatment, m^3
		Availability	Depth, m							
I	HIS	––	––	5	5000	750	21,65	5000	4,33	19250
	ID			6	1200	720				
II	HIS	––	––	5	5000	750	21,96	2700	8,13	13500
	ID			6	1248	749				
III	ID	+	5	6	1248	749	10,45	2700	3,87	13500
IV	ID	+	9	10	2080	1248	15,92	2700	5,90	24300
V	ID	+	14	15	3120	1870	22,76	2700	8,43	37800
VI	ID	+	19	20	4160	2496	29,61	2700	11,97	51300
VII	ID	+	24	25	5200	3120	36,45	2700	13,50	64800

Link: developed by the authors

G = 94.5 UAH/m^2 – normative monetary valuation of a polluted land plot. It is assumed at the level of 4.5 thousand US dollars per 1 hectare. [12];

P – area of a polluted land plot (localization area), m^2 (see tabl. 1);

K_1 – coefficient of a land plot pollution, characterizing amount of the pollutant in the volume of contaminated land, depending on infiltration depth;

K_2 = 4.0 – hazard ratio of the pollutant. Assumed according to [11], Appendix 1 «extremely dangerous»;

H = 0.2 – ecological and economic purpose of land scale indicator. Assumed according to [11, Appendix 2] «industrial land, transport, communications, energy, defense»;

K_1 – pollution coefficient of a land plot calculated according to the formula (2):

$$K_1 = O/T^*P^*1n, \qquad (2)$$

where: *O* – the amount of the pollutant, m^3. Accepted conditionally on the level of 1% of the volume of localized (polluted) soil;

T = 0.2 m – thickness of earth layer, which is dimensional unit to calculate remediation costs, depending on the infiltration depth [11].

1_n – correcting index to expenses for liquidation of pollution, depending on pollutant infiltration depth.

According to [11] 1п is calculated only to the depth of infiltration 2 m (tab. 2). In this case, specified that expenditures for the implementation of activities to reduce or eliminate land pollution increases depending on the depth of pollutant infiltration in the ratio of 10: 3. I.e. as depth increases of 10 times thicker than land at 0,2 m costs for the pollution elimination increase 3 times.

Table 2

Correction indexes to expenses (Iп)

Infiltration depth	*In*	Infiltration depth	*In*
0-0,2	0,100	0-1,2	0,049
0-0,4	0,082	0-1,4	0,044
0-0,6	0,070	0-1,6	0,040
0-0,8	0,060	0-1,8	0,037
0-1,0	0,054	0-2,0	0,033

Link: [11]

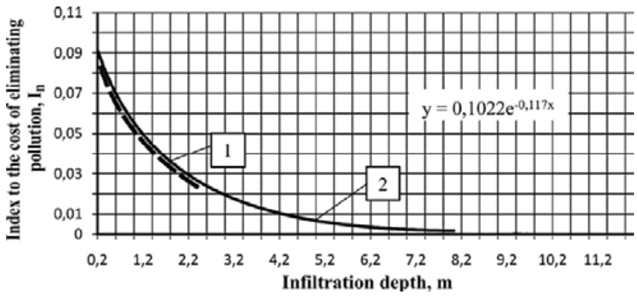

Fig. 5. Graph of dependence I_n of Infiltration depth contaminated water 1 – curve according to the table. 2; 2 – approximated curve

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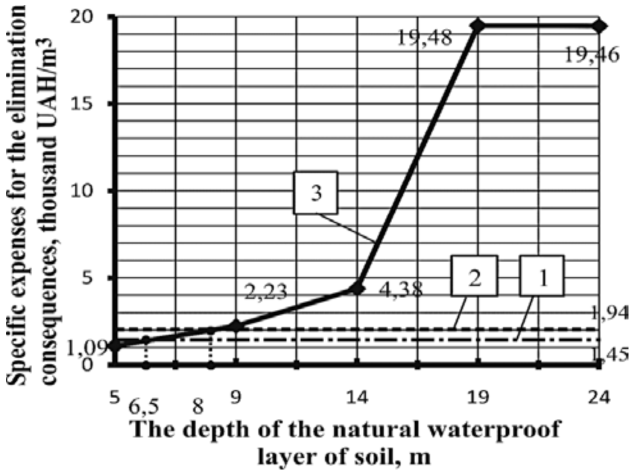

Fig. 6. Graph of the specific costs of pollution elimination against the depth of the waterproof layer of soil 1 – HIS combined with ID along the two sides of the screen, without the natural waterproof layer (Fig 2a.); 2 – HIS combined with ID at the perimeter of the storage without natural waterproof layer of (Figure 2b.); 3 – ID at presence of natural waterproof layer (Figure 3)

Link: developed by the authors

Analyzing the graph of the exponential approximation of the data in Table 2 (Fig. 5), it can be argued that at considerable depths infiltration Index

Table 3

Technical and economic indicators of soil pollution liquidation variants

Localization variant	Kinds of works	Screen / diaphragm depth, m	Natural waterproof layer of soil depth, m	Localization area, m^2	Volume of localized soils subject to treatment, m^3	Localization cost, million UAH	Pollutant volume, м^3	Treatment costs, million UAH	Liquidation of pollution consequences, million UAH	Specific expenses for the elimination thousand UAH/m^3
I	HIS	5	––	5000	19250	21,65	192,5	6,06	27,71	1,45
	ID	6								
II	HIS	5	––	2700	13500	21,96	135,0	4,25	26,21	1,94
	ID	6								
III	ID	6	5	2700	13500	10,45	135,0	4,25	14,70	1,09
IV	ID	10	9	2700	24300	15,92	243,0	38,27	54,19	2,23
V	ID	15	14	2700	37800	22,76	378,0	142,88	165,64	4,38
VI	ID	20	19	2700	51300	29,61	513,0	969,57	999,18	19,48
VII	ID	25	24	2700	64800	36,45	648,0	1224,72	1261,17	19,46

Link: developed by the authors

of corrections to cost 1P approximates to values close to zero.

According to the schedule, to calculate coefficient of pollution for a land plot Кз regarding infiltration depth: 0-5 m $1_п$ Index of corrections to costs is accepted 0,006 for depths of 0-10 m – 0.0012, for the depths of 0-15 – 0.0005, and for infiltration depth more than 15 m – 0.0001.

Calculations discovered possibility of significant reducing volume of soil pollution with radionuclide's or toxic waste and, accordingly, a significant reduction in its recovery cost in case of using HIS localization variants (Table 3).

The graph in Figure 6 shows efficiency of HIS construction combined with imperfect ID of 6 m depth, compared with the construction of a perfect ID as a part of complex activities on liquidation of consequences of soil pollution in case of natural waterproof layer of soil is present at depths of more than 6.5-8 m.

Conclusions. 1. Comparing localization costs of land sites of equal area polluted with toxic waste or with radionuclide's, shows efficiency of building a horizontal impervious screen (artificial aquitard) at a depth of 5 m combined with imperfect grout curtain of 6m depth, compared with the construction of perfect curtain, if the natural waterproof layer of soil is located at depths exceeding 13 m.

2. The construction of the horizontal impervious screen (artificial waterproof layer of soil) in combination with imperfect grout curtain would greatly reduce possible volumes of soil pollution and, therefore, significantly reduce soil treatment costs (recovery).

3. Application of horizontal impervious screen (artificial a waterproof layer of soil) as part of a complex of actions on liquidation of consequences pollution of soils at a depth of 5 m combined with imperfect grout curtain of 6 m depth of the shows screen efficiency in comparison with a perfect grout curtain under the condition of the natural waterproof layer of soil location at depths of more than 6.5-8 m.

4. Ecological and economic effect of the application together with a vertical screen, horizontal impervious screen, is to reduce 10 times the cost of restoring contaminated soil from 19.48 to 1.94 thousand UAH. for 1 m^3.

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ЕКОЛОГО-ЕКОНОМІЧНА ЕФЕКТИВНІСТЬ ЛОКАЛІЗАЦІЇ ДЖЕРЕЛ ЗАБРУДНЕННЯ ҐРУНТІВ ТЕХНОГЕННИМИ СТОКАМИ З ВИКОРИСТАННЯМ ТЕХНОЛОГІЇ ВЛАШТУВАННЯ ГОРИЗОНТАЛЬНОГО ПРОТИФІЛЬТРАЦІЙНОГО ЕКРАНУ

Анотація
У Науково-дослідному інституті будівельного виробництва (Київ, Україна) ведуться дослідження технології улаштування горизонтальних протифільтраційних екранів (ГПЕ) під існуючими спорудами з використанням методу горизонтально-направленого буріння свердловин. ГПЕ виконує роль штучного водоупору і призначений для захисту ґрунтів і ґрунтових вод від забруднення токсичними відходами або радіонуклідами, а також для локалізації забруднень. Проведена оцінка екологічного ефекту від застосування ГПЕ у водопроникних ґрунтах у поєднанні з недосконалою протифільтраційною діафрагмою (ПФД), що виконується способом «стіна в ґрунті» у разі відсутності природного водоупора, а також визначено область ефективного застосування ГПЕ порівняно з досконалою ПФД, заглибленою в природний водоупор.
Ключові слова: горизонтальний екран; протифільтраційна діафрагма; «стіна в ґрунті»; еколого-економічний ефект; область застосування.

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ЭКОЛОГО-ЭКОНОМИЧЕСКАЯ ЭФФЕКТИВНОСТЬ ЛОКАЛИЗАЦИИ ИСТОЧНИКОВ ЗАГРЯЗНЕНИЯ ГРУНТОВ ТЕХНОГЕННЫМИ СТОКАМИ С ИСПОЛЬЗОВАНИЕМ ТЕХНОЛОГИИ УСТРОЙСТВА ГОРИЗОНТАЛЬНОГО ПРОТИВОФИЛЬТРАЦИОННОГО ЭКРАНА

Аннотация
В Научно-исследовательском институте строительного производства (Киев, Украина) ведутся исследования технологии устройства горизонтальных противофильтрационных экранов (ГПЭ) под существующими сооружениями с использованием метода горизонтально-направленного бурения скважин. ГПЭ выполняет роль искусственного водоупора и предназначен для защиты грунтов и грунтовых вод от загрязнения токсичными отходами или радионуклидами, а также для локализации загрязнений. Проведена оценка экологического эффекта от применения ГПЭ в водопроницаемых грунтах в сочетании с несовершенной противофильтрационной диафрагмой (ПФД), выполняемой способом «стена в грунте» в случае отсутствия естественного водоупора, а также определена область эффективного применения ГПЭ по сравнению с совершенной ПФД, заглубленной в естественный водоупор.
Ключевые слова: горизонтальный экран; противофильтрационная диафрагма; «стена в грунте»; эколого-экономический эффект; область применения.