https://doi.org/10.31713/m1317

MANAGING THE LOCALIZATION PROCESS POLLUTION WITHIN THE INFLUENCE OF LANDFILLS MINING PRODUCTION LOCALIZATION OF POLLUTION WITHIN THE LIMITS OF INFLUENCE OF MINING DUMPS

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Abstract

As a result of the intensive development of science and technology, a large number of various industries, which use the most modern technologies, have emerged. The complexity of technological processes increases the risk of situations that can cause irreparable damage to the environment. Therefore, the primary task of modern times has become the prevention of environmental problems and the reduction of the consequences to which their appearance may lead, or has already led. In particular, one of the important issues that need to be solved as soon as possible is the protection of underground sources from pollution that gets there as a result of active industrial activity of mankind, which significantly affects people's health.

Thus, managing the process of localization of soil and groundwater contamination is an important and urgent task. Its solution will increase the reliability of engineering systems for the environmentally safe operation of waste storage facilities, which will significantly reduce the morbidity of people within the limits of their influence.

Introduction

Ensuring the ecologically safe existence of all natural objects is one of the main problems of modern times. No one doubts this provision, especially since an adequate solution to this issue and its subsequent implementation will ensure not only comfortable living conditions for people and optimal sanitary and hygienic conditions for their production activities, but also the very possibility of the existence of the biosphere. That is why environmental safety is currently considered an integral element of national security, which is very relevant for almost all countries of the world. Various aspects of the problem of environmental safety are the object of attention of many researchers.

Unfortunately, anthropogenic changes have so far affected almost the entire ecosystem of the planet. Trying to actively adapt the environment to their needs, a person with his activity initiates a huge number of not only primary, but also secondary, as well as combined effects, many of which become dangerous for the normal functioning of various components of nature and society. The very emergence and active development of such situations is caused, first of all, by the rapidly growing pace of scientific and technical progress without sufficient consideration of the objective laws of development and renewal of natural resource complexes, which brings increasing pollution of the environment and destruction of natural landscapes. In many areas of the world, the threshold of invariance of natural objects has already been crossed, as a result of which the dynamic balance of the environment has been disturbed, as human activity has come into conflict with nature itself.

1. Ecological condition of soils and groundwater in the areas where man-made dumps are located

The problem of coordination of relations between production, on the one hand, and nature, on the other, becomes central to ensuring the environmentally safe existence of all its components. At the same time, it should be noted that compliance with these provisions is useful not only for the biosphere: the use of the principles of sustainable development of the environment in the formation of the strategy of any enterprise helps to achieve an optimal combination of economic and non-economic goals, which is a necessary condition for its long-term and successful functioning.

Ukraine, unfortunately, is not an exception in this regard, and the problems of environmental security affecting all its regions are no less, and sometimes more acute, than in other countries of the world, since the current state of the environment in our country is beginning to acquire negative properties, becoming a direct source of threat to the biosphere itself, as well as to the health and even life of its citizens. The main reason for this situation is still the same: excessive man-made load on natural objects without the appropriate level of environmental responsibility of those who manage the development of production - both agricultural and industrial to the same extent, which is increased by the current economic state of the state. Due to this, the rate of environmental degradation, and not only in the radius of direct influence of specific enterprises, begins to exceed (and in some areas has already exceeded) the adaptive capabilities of its components.

Pollution of surface and ground water can most often be observed within highly developed regions of both agriculture and industrial complexes. Very often, the presence of harmful substances in groundwater becomes known only after a long time since they entered the soil. One of the reasons why this happens is the slow rate of groundwater movement through aquifers. In soil flows, substances do not mix and spread as quickly as in surface flows. Therefore, pollution can remain for a long time in the form of concentrated localized spots that persist for many years. There are known cases when harmful substances that got under the surface of the soil more than 10 years ago became known only very recently. That is, today's practice can have a significant impact on water quality in the distant future.

In relation to groundwater, until recently, the prevailing opinion among researchers was that the soil creates a protective filter or barrier that does not allow pollution to penetrate deep into the earth's surface and thus protects underground sources from their negative effects. However, when pesticides and other chemical substances were found in groundwater, it became clear that natural filters do not provide reliable protection of underground sources from pollution that enters there as a result of active industrial activity of mankind.

During the development of mineral deposits, their extraction and processing, highly toxic waste is formed, which pollutes the environment, soils and groundwater.

These problems became especially acute during the implementation of the Program for the closure of unpromising coal mines and cuttings. In fact, immediately there were problems related to the flooding and waterlogging of the territories, the expansion of the leakage zones of highly mineralized mine waters, and the deterioration of the properties of rocks and soils.

Due to the fact that mine waters are highly mineralized (average mineralization is 2.0-4.0 g/dm^3) and contain a significant amount of toxic substances, there is a real threat of contamination of aquifers and the fertile soil layer.

The greatest threat to the quality of groundwater is represented by those organic compounds that are relatively soluble, do not evaporate and do not decompose chemically or biologically. In water, organic substances are eliminated under the action of bacteria. Their decomposition leads to a decrease in the concentration of dissolved oxygen in the water, thereby exposing the ecological balance of the water body to danger.

During the construction of large industrial enterprises, especially chemical ones, there is a need for safe and economical disposal of harmful industrial effluents, often of very high toxicity. This is a very serious problem that must be solved when designing an enterprise.

During the operation of the enterprise, damage to protective hydrotechnical structures may occur, which include: leaching of the cement curtain, formation of karsts at the base of the dam due to chemical suffusion , etc.

As a result of such damage and violations of environmental legislation, soil and groundwater may be contaminated with untreated water, which will inevitably lead to the deterioration of the ecological state of the environment.

Regarding the Rivne region, according to the materials of the geological exploration expedition, there are almost 1,200 stationary sources of potential groundwater pollution in the region. Of the entire mass of particularly dangerous waste generated, only about 2% is reused or disposed of. The lack of centralized points of storage, disposal, disposal and burial of hazardous waste contributes to their accumulation on the territory of industrial enterprises [1].

Almost 512,000 tons of toxic waste alone was generated in the region, of which 25 tons belong to the first class of danger, 4.29 thousand tons to the second class, which primarily included waste containing formaldehyde, petroleum compounds, polymer resins, etc. . Up to 70% of first-class waste was transferred to other enterprises for further use, and the rest was sent to organized storage facilities. Waste of the second class is less alarming, since most of it is neutralized, and the rest is sent to other enterprises for further use [2] .

The lion's share of toxic waste is made up of substances of the third (0.19 thousand tons) and fourth (507.0 thousand tons) hazard classes. The third class mainly includes "OPAK" oil from the production of adipic acid, to a lesser extent - sediments after dewatering sewage sludge, various solvents and dyes. The bulk of waste of this class (98%) is neutralized, the rest is transferred to other enterprises for further use or stored . Waste of the fourth class of danger is represented mainly by phosphorus oxides, which accumulate in phosphogypsum dumps located near the production site of OJSC " Rivneazot " [3] .

16.8 million tons are stored in the warehouses of the organized storage of enterprises of the region . toxic waste.

A special threat to the residents of Rivne and surrounding villages, as well as the basin of the Horyn River , is posed by phosphogypsum dumps located on the territory of Rivneazot OJSC , which is 20 km west of Rivne. 98.97% of all waste in the Rivne region is accumulated here. Therefore, solving the problem of industrial waste disposal in the region largely depends on how successfully this problem will be solved at this enterprise [4].

A comprehensive assessment of the state of the soil systems in the areas where waste is located at enterprises and a forecast of the effects of technogenic factors initiated by these objects on them were carried out at this object.

This choice is justified by the fact that the object is the most problematic from the point of view of the ecological situation - the largest repository of solid toxic waste in the Rivne region. This waste of the fourth class of danger is mainly represented by phosphorus oxides. Dumps of phosphogypsum are typical for other objects that pose a threat to soil and groundwater pollution and are suitable for field studies and solving scientific problems related to the prevention of soil and groundwater pollution. The results obtained during the research can be extrapolated to other objects that pose a threat to the environment.

2. Review of the methods of forecasting the migration of pollutants in the area of man-made dumps

According to the studies carried out in the works of such researchers as P. Ya. Polubarina -Kochyna and R. Collins , it is almost impossible to determine the distribution of velocities in the pore space, especially for heterogeneous media. When solving practical problems, it is enough to know only the flow rates, velocities and pressures of the liquid within small volumes, which at the same time are much larger than the pore sizes. For this, you can use the continuous filtration flow model, in which it is assumed that the liquid moves, filling the entire space: both pores and soil particles. Thus, the real liquid flow is replaced by its fictitious filtration flow, which completely fills the entire volume. The flow line of the filtration flow is a line whose tangent at each point coincides with the direction of the filtration velocity.

The basic law of filtration relates the fluid movement speed to the pressure difference H in the filtration flow. In the differential form, the law has the form

$$V = -KgradH. \quad (1)$$

The filtering coefficient K is determined by the formula

$$K = \frac{k\gamma}{\mu} = \frac{kg}{v}, \quad (2)$$

where μ and v are dynamic and kinematic viscosity; ρ - liquid density; k - medium permeability.

If compressibility is neglected, the equation of the filtration flow will be written down

$$\frac{\partial}{\partial x}\left(K\frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(K\frac{\partial H}{\partial y}\right) + \frac{\partial}{\partial z}\left(K\frac{\partial H}{\partial z}\right) = 0. \quad (3)$$

Polubarynoy-Kochynoy P.Ya. [7] considered in detail the nonlinear condition on the free surface. The author considered the filtration of a liquid with a free surface above an impermeable water barrier . The equation for the upper free $z=f(x,y)$ which has a slight slope is written in the form

$$\frac{\partial}{\partial x}\left(Kh\frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(Kh\frac{\partial H}{\partial y}\right) + \frac{\partial}{\partial z}\left(Kh\frac{\partial H}{\partial z}\right) + \varepsilon = n\frac{\partial h}{\partial t}. \quad (4)$$

For horizontal waterproofing $h = H$, then when $K = const$:

$$K\left(\frac{\partial^2 h^2}{\partial x^2} + \frac{\partial^2 h^2}{\partial y^2}\right) + 2\varepsilon = 2n\frac{\partial h}{\partial t}. \quad (5)$$

Analytical solution of the nonlinear equations (4) and (5) is faced with difficulties of a mathematical nature, although a number of exact solutions have been obtained for a number of one-dimensional problems Berentblatgom G.I. [8]. There are ways to linearize equation (5), for example V.I. Aravin , S.N. Numerov . [9] convert it to an equation of the heat conduction type.

Equation (4) is written for the case of an absolutely impermeable water stop. A "relative water resistance " occurs quite often , due to which a weak movement of liquid through cracks and pores is possible. Flow intensity ε_d through the lower boundary (sole of the aquifer) is due to the difference in pressure in the upper and lower - aquifers $\varepsilon_d = K_0 (H-H_1)/t_0$ (Fig. 1). Here H_1 *is* the pressure in the lower layer, K_0 is the filtration coefficient of the water resistance , t_0 is its thickness (power).

Taking into account the overflow, equation (4) will be written as follows

$$\frac{\partial}{\partial x}\left(Kh\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(Kh\frac{\partial H}{\partial y}\right)+\frac{\partial}{\partial z}\left(Kh\frac{\partial H}{\partial z}\right)+\varepsilon-\frac{K_0}{m_0}\left(H-H_1\right)=n\frac{\partial h}{\partial t}.$$

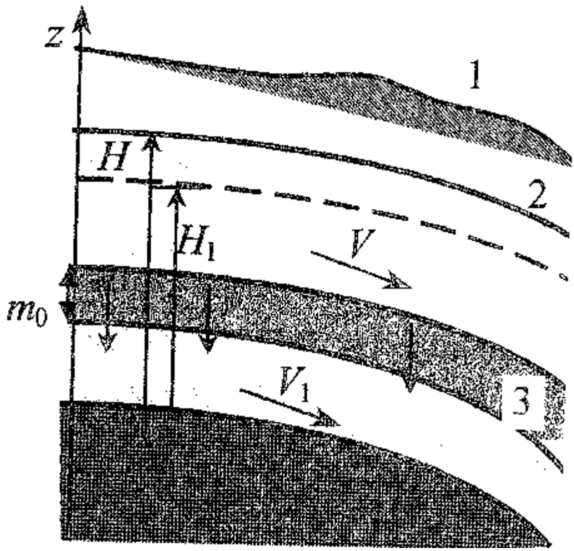

Fig. 1. Scheme of flow through a poorly permeable layer:
1 - ground surface; *2* - free surface; *3* - poorly permeable layer

Mass transfer in the filtration flow is a set of processes of mechanical transfer of dissolved or emulsified substances, their physical and chemical transformations, and mass exchange with the porous medium. The main factors of mass transfer are: 1) mechanical (forced) convection, 2) hydrodynamic dispersion (convective diffusion), 3) sorption and mass transfer, 4) physical and chemical transformations (decay, formation of new substances) [8].

Under the influence of forced convection, there is a mechanical movement of particles of matter in the form of solutions or colloids along the flow lines of the filtration flow. The speed of movement - of the substance front in the absence of mass exchange with the porous medium is determined by the filtration speed along the flow line $V(\xi)$ and the active porosity n_a : $d(\xi)/dt=V(\xi)$ here ξ is - a curvilinear coordinate measured along the flow line. A particle of matter will move along the streamline during the time interval $[t_1, t_2]$ by the distance $\xi_2 - \xi_1$, which is determined from the equation [8]

$$t_2 - t_1 = \int_{\xi_1}^{\xi_2} \frac{d\xi}{V^*(\xi)}, V^*(\xi) = \frac{V(\xi)}{n_a}.$$

The heterogeneity of the porous medium leads to the fact that forced convection is accompanied by the formation of a transition zone between the areas of the flow with maximum and minimum concentrations. The intensity of the formation of the transition zone is quantitatively characterized by the coefficient of hydrodynamic dispersion, which is a tensor of the second rank. In a homogeneous porous medium, the longitudinal (along the flow direction) and transverse (perpendicular to the flow) dispersion coefficients D_L and D_T are distinguished, m^2/day. It was experimentally established [9] that

$$D_t = D_0 + \delta_L |v|, \; D_T = D_0 + \delta_T |v|, \quad (6)$$

where δ_L and δ_T are parameters of longitudinal and transverse dispersion, m; D_0 ~ coefficient of molecular diffusion . Longitudinal dispersion, as a rule, is an order of magnitude greater than transverse. Since it is practically impossible to theoretically determine the value of the dispersion parameters, the results of experimental measurements D_L and D_T are used when solving practical problems .

Sorption (desorption) is a process of binding (release) of a substance on the surface of a porous medium. Sorption processes are caused by surface phenomena at the boundary of the "liquid-solid" separation. According to the Nernst model (diffusion boundary layer) [10], a thin (μm particles), practically immobile layer of liquid is formed on the surface of the sorbent grains , where particles of matter from the liquid medium are attracted and retained due to the difference in electric charge.

exchange capacity N_0 , mg-equiv-g $^{-1}$, which is defined as the mass of dissolved substance that can be bound (absorbed) by a sorbent weighing 1g. Due to the tortuosity of the pore channels, the presence of dead-end chambers at not the entire capacity is actually used in the exchange. When the particle size of the porous medium decreases, the parameter N_0 increases, reaching several tens of mg-eq /100 g of dry mass of the sorbent in clayey rocks [10].

The parameter of sorption kinetics is the mass transfer rate γ, day $^{-1}$, which is inversely proportional to the duration of the time interval during which equilibrium is established between the solution and the sorbent. During ion exchange, physical adsorption, equilibrium is reached within several hours, during sorption with the formation of chemical bonds - several days [10]. Therefore, mass transfer lasting - months and years is usually described using equilibrium sorption isotherms of the form $N=f(\varphi)$, where N is the concentration of the substance in the sorbent, φ is in the solution. At low concentrations, a fair linear dependence was obtained by A. B. Sytnikov [11].

Non-equilibrium mass transfer, which is described by differential equations of the form $dN/dt = f(\varphi, N)$, is generally nonlinear. At low concentrations, Henry's linear isotherm of the form $dN/dt = \gamma(K_d \varphi - N)$ can be used. When $\varphi > N/K_d$ ($dN/dt > 0$) sorption occurs, when $\varphi < N/K_d$ ($dN/dt > 0$) - desorption. Irreversible sorption with strong fixation of a substance by a sorbent can be described by the equation of the form $dN/dt = a\varphi$, dissolution and crystallization - by the equation $dN/dt=\gamma(\varphi_{max} - \varphi)N\beta$ where φ_{max} *is* the maximum - possible solubility of substances, *a*, *β, γ* are empirical parameters of these processes.

The sought-after functions when solving problems of mass transfer in filtration flows are the concentration of the substance in the pore solution φ and in the solid phase N. When studying the mass transfer of soluble substances in groundwater, along with the equations of filtration, the equations of transport and diffusion, as well as the mass balance of the substance in the elementary volumes of the porous medium.

For a filtration flow, the horizontal dimensions of which are one or two orders of magnitude larger than its vertical dimensions, which is the most common, Rudakov D.V. [10] averaged the concentration of the substance over the thickness of the aquifer and obtained a two-dimensional equation

$$\frac{\partial}{\partial x}\left(D_x\frac{\partial\bar{\phi}}{\partial x}-u\bar{\phi}\right)+\frac{\partial}{\partial y}\left(D_y\frac{\partial\bar{\phi}}{\partial y}-v\bar{\phi}\right)+\frac{q}{m}-q_M-q_d=(1-n_1)\frac{\partial N}{\partial t}+n\frac{\partial\bar{\phi}}{\partial t}. \quad (7)$$

where *t is* the flow depth (thickness of the aquifer); q_u, q_d - mass flows through its upper and lower boundaries; *u, v,* - filtration speed components; D_x, D_y - dispersion (diffusion) components; $\bar{\varphi}(x,y,t)=\frac{1}{m}\int_0^m\varphi(x,y,z,t)dz$ - vertically averaged concentration.

Among the problems of underground water dynamics, calculations of drains that intercept filtering (including polluted) groundwater flows have gained great practical importance.

Under the conditions of a steady two-dimensional flow of groundwater for a single well with a constant flow (flow rate) 0, located in a homogeneous layer of average thickness *t* and with a filtration coefficient *K* at a point with coordinates (x_0, y_0), the distribution of groundwater decline *H* is described by equation

$$Km\left(\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial y^2}\right)=Q\delta(x-x_0, y-y_{01}), \quad (8)$$

where $h=H_0-H_3$; H_0 - the level of groundwater formed without the influence of the well; H_3 - their reduced level.

The solution to equation (8), first obtained by Forchheimer for the semi-bounded region *x*>0*,* on the border of which *x*=0 a constant level (*h* = 0) is maintained, has the form

$$h(x,y)=\frac{Q}{2\pi Km}\ln\frac{\rho}{r}, \quad (9)$$

$$r=\sqrt{(x-x_0)^2+(y-y_0)^2}, \rho=\sqrt{(x+x_0)^2+(y+y_0)^2}$$

For a group of *n* arbitrarily located wells, the distribution of reduction in a semi-confined layer (*x*>0) is calculated by summing up the reductions from individual wells according to the formula

$$h(x,y)=\frac{1}{2\pi Km}\sum_{i=1}^{n}Q\ln\frac{\rho_i}{r_i}, \quad (10)$$

Unsteady filtration in the case of a single well is described by the equation

$$Km\left(\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial y^2}\right)-Q\delta(x-x_0, y-y_{01})=\sum\frac{\partial h}{\partial t}, \quad (11)$$

where $\Sigma = \beta \cdot m$ is the elastic capacity of the pressure layer. It is defined as the ratio of the change in water volume in the aquifer per unit area to the corresponding change in head. The solution of equation (11), first obtained by Theis for an unbounded layer, has the form

$$h(x,y) = -\frac{Q}{2\pi Km} Ei\left(-\frac{r^2}{4at}\right),$$

$$r^2 = (x-x_0)^2 + (y-y_0)^2 \qquad (12)$$

where $a=Kt/\lambda$. - coefficient of piezoconductivity of the layer, $Ei(\xi)$ - integral exponential function. For a semi-bounded region

$$h(x,y) = -\frac{Q}{2\pi Km}\left\{ Ei\left(-\frac{r_1^2}{4at}\right) - Ei\left(-\frac{r_2^2}{4at}\right)\right\},$$

$$r_{1,2}^2 = (x \pm x_0)^2 + (y-y_0)^2$$

The reduction calculation for a group of wells is performed similarly to formula (10).

In practice, both vertical and horizontal drainage systems are used. Depending on the dimensions of the solved problem, the drain is schematically shown as a point or linear drain [7]. Calculation formulas for linear flow are derived by integrating the corresponding solution for point flow along the drainage contour. For a horizontal drain, the contour of which is given by the equations $y=f(x)$ or $x=f(y)$, it is written

$$h(x,y,t) = \int_{x_1}^{x_2} Q_1(\xi) h(x-\xi, y-f(\xi), t) d\xi = \int_{y_1}^{y_2} Q_1(\eta) h(x-g(\eta), y-\eta, t) d\eta \qquad (13)$$

where $h(x,y,t)$ *is* the solution of the problem with respect to the decrease caused by the influence of a point flow of unit intensity; (x_1, y_1), (x_2, y_2) - endpoints of the contour; Q_1 - the specific flow rate of the drain, which can vary along it. Calculations of drainage under various conditions were considered in detail in many works, including V.I. Aravin , S.M. Numerov [9], F.M. Bochever , N.N. Lapshin, A.Ya. Oradovskaya [8], V. S. Usenko [12].

Formula (13) for linear drains is also used to predict flooding, which in urban conditions is often caused by leaks from water and heat supply systems. Then Q_1 means the intensity of leaks, and the equations $y=f(x)$ and $x=f(y)$ describe the position of the section of the water supply line where leaks occur.

When choosing a model for forecasting the spread of pollutants in groundwater flows, the following assumptions can be used. At low concentrations of pollutants, their transfer does not have a significant impact on the dynamics of the filtration flow, so the filtration problem can be considered independently of the migration problem. If the filtration flow is constant, then the migration problem can be solved separately on the basis of a predefined field of filtration velocities. For long-term migration predictions, sorption kinetics can be neglected, and at low concentrations, a linear sorption isotherm can be used to describe mass transfer with a porous medium. Depending on the volume of leaks of solutions containing pollutants, the sources of pollution in groundwater can be schematized as hydrodynamically active and passive. The most complete representation of the spread of pollution in groundwater is given by the field of filtration current velocities, on the basis of which the problem of mass transfer is solved

Preliminary estimates of the zone of groundwater contamination can be made using the "piston model" [9], in which the influence of diffusion is neglected. For a plane-parallel flow between intersections 1 and 2 (Fig. 2) with an average depth t, the horizontal components of the filtration rate are equal to

$$u = -K\frac{(H_2 - H_1)}{l} - \frac{Q_n}{mn} = const, \quad v = 0.$$

where Q_n *is* the filtration flow rate per unit of its width. If pollution begins to flow through section 1 after the moment $t=0$, then the length of the zone of pollution at the moment t_1 is $x_1 = Q_n t/(n_e m)$, and the time for the pollution front to reach point $x_ф$ is equal to $t_ф = (n_e m n x_ф)/Q_n$ Here the speed of migration $u_m = u/n_e$. The concentration at point x is equal to

$$\varphi(x,t) = \varphi_0(1 - \theta(t - t_ф)),$$

$$\theta(\xi) = \begin{cases} 0, t < 0, \\ 1, t > 0. \end{cases}$$

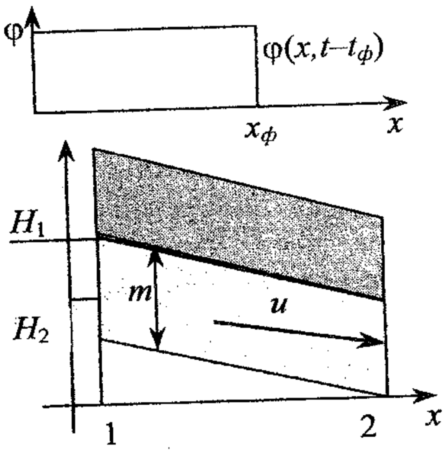

Fig. 2. Scheme of piston displacement in undisturbed unidirectional flow

The migration forecast based on the diffusion model takes into account the erosion of the contamination front. Most of the analytical solutions were obtained for simplified schemes of plane-parallel and radial flows.

A fairly common case is migration in a semi-infinite region, at the entrance boundary of which x=, the concentration φ_0 is set . The process of solute transport is described by a one-dimensional equation

$$D\frac{\partial^2\phi}{\partial x^2} - u\frac{\partial^2\phi}{\partial x} = n_e\frac{\partial\phi}{\partial t}. \tag{13}$$

The solution of equation (14) was first obtained by Samuelson [8] and has the form

$$\varphi(x,y) = 0.5\varphi_0\left\{erfc(\xi-\eta) + e^{4\xi\eta}erfc(\xi+\eta)\right\}, \tag{14}$$

$$\eta = \frac{u\sqrt{t}}{2\sqrt{Dn_e}}, \quad \xi = \frac{x}{2\sqrt{Dt/n_e}}$$

Numerical analysis [6] shows that when $D/(ux)<0.005$ the second term with an error of 4% can be rejected. The coordinate of a point with a concentration of $0.5\varphi_0$ moves with a constant speed u/n_e which corresponds to the scheme of piston displacement. When the pollution front moves, three zones are formed: 1) a zone of high concentrations close to φ_0 ; 2) the mixing zone, where the concentration changes from 0 to φ_0;

3) uncontaminated zone, where φ=0. The width of the mixing zone L between the points with a concentration of $0.99\varphi_0$ and $0.01\varphi_0$, which is 6.6 $\sqrt{Dt/n_e}$, increases over time.

To describe non-stationary mass transfer in two and three-dimensional plane -parallel flows in the presence of continuously operating plane sources of inflow of pollutants, the formulas obtained by F.M. Bochever [8] are used

$$\varphi(x,y,t)=\frac{1}{mn_e}\int_0^t q(t(1-\theta))\varphi_x(x,t\theta)\varphi_y(y,t\theta)d\theta,$$
$$\varphi(x,y,z,t)=\frac{1}{n_e}\int_0^t q(t(1-\theta))\varphi_x(x,t\theta)\varphi_y(y,t\theta)\varphi_z(z,t\theta)d\theta, \quad (15)$$

where φ_x , φ_y , φ_z - solutions of one-dimensional problems of mass transfer along the O_x, O_y, O_z axes after "instant" contamination of a local area.

For an unlimited aquifer in terms of φ_x an expression can be used

$$\varphi(x,t)=0{,}5\left\{erf\left(\frac{x-x_1-u^*t}{2\sqrt{D_x^*t}}\right)-erf\left(\frac{x-x_2-u^*t}{2\sqrt{D_x^*t}}\right)\right\}. \quad (16)$$

For φ_y , you can take the given formula by replacing the corresponding notations. In fig.3 shows an example of the distribution zone of the substance in groundwater, calculated according to the two-dimensional model.

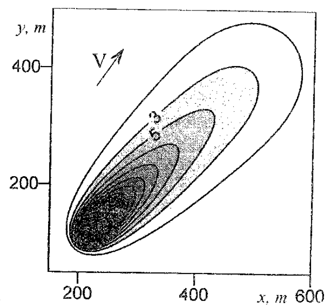

Fig. 3. Concentration distribution φ obtained according to the two-dimensional model for a certain moment in time

So, there is a well-developed mathematical apparatus for describing the migration of pollutants in the filtration streams of groundwater, but their use in each case requires adaptation of the approach to the boundary conditions and physico-chemical features of the object being studied.

3. Overview of technical pollution prevention systems in the conditions under study

Water filtration through the body of protective structures is always undesirable. With significant sizes, or when highly mineralized water is filtered, it can pose a serious threat to both the environment and the hydrotechnical structure itself.

A large number of hydrotechnical structures, which are intended for the protection of soils and groundwater, are built from permeable materials that are separated by structural or technological seams, or are placed on a filtering basis, so their integral structural part is anti-filtration devices, the role of which is to prevent penetration of water into the body of the structure or foundation, or to reduce filtration losses to acceptable safe limits.

Today, anti-filtration devices of various designs are used in production - screens, sumps, sheet pile walls, diaphragms, cores, linings, etc., and are made of various materials - clay, bitumen, wood, metals, reinforced concrete, rubber, etc. .

All traditional materials used for anti-filtration devices have one or another disadvantages. Constructions with their use are either time-consuming, complex and expensive, or limited by a narrow range of structures, conditions of their work and construction.

Polymer films as a material for anti-filtration devices of hydrotechnical structures have a number of advantages: practical impermeability of the material itself and high resistance of polyethylene and polynyl chloride films to the aggressive effects of common chemical reagents, high deformability of films, low material consumption and high manufacturability. The advantages of polymer films include the fact that the formation of waterproof elements in them depends little on local construction conditions.

At the same time, polymer anti-filtration devices have a number of disadvantages and features. This is primarily a tendency to aging, which proceeds at a sharply different speed depending on the conditions in which they are found, weak aggression towards other materials, a significant change in properties when the temperature changes, etc.

Film anti-filtration devices must be reliable in operation during the entire service life of the structure. Reliability of operation is determined primarily by the properties of the polymer film element. These properties should be such as to distinguish the types of influences (mechanical stress, water influence, temperature fluctuations, etc.), possible both during operational and construction periods, that would not cause changes in the material or its damage, unacceptable from the point of view of reliability anti-filtration device.

In buildings, for example, in which there should be no place for water loss (storage of aggressive liquids, etc.) , in film anti-filtration elements, not only punctures, cuts, but also changes that would lead to a violation of the integrity of the films and, hence, loss waterproofing in a period shorter than the service life of the structure.

In fig. 4. the scheme of protection of phosphogypsum dumps with a polyethylene diaphragm is shown.

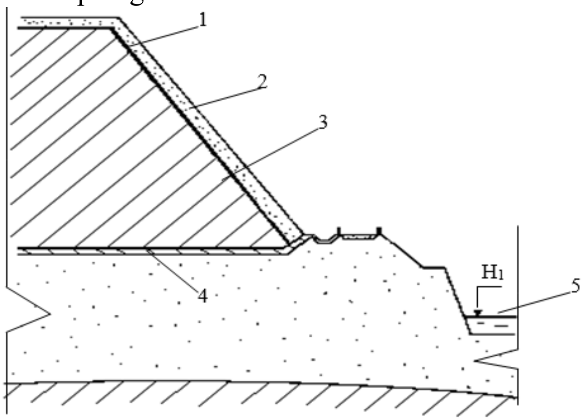

Fig. 4. Scheme of a protective structure with a polyethylene diaphragm:

1 - polyethylene diaphragm; *2* - loading layer of large stone; *3* - dumps of phosphogypsum; *4* – concrete curtain*;* *5* - fishing channel

In the absence of mechanical damage to the film due to its low porosity, the movement of water through the film is possible only in the form of diffusion of water molecules and substances soluble in it. Diffusion losses of water, however, are quite insignificant, but in some cases they have to be taken into account (for example, when designing storage facilities for highly toxic substances).

Since protective screens during operation can lose their protective functions due to soil deformation, erosion, suffusion, the main attention in the work is devoted to substantiating the parameters of drainage structures that will intercept the soil flow of highly mineralized water coming from the object of study.

In fig. 5 shows the scheme of interception of the soil flow from the massif of phosphogypsum dumps by one drainage line.

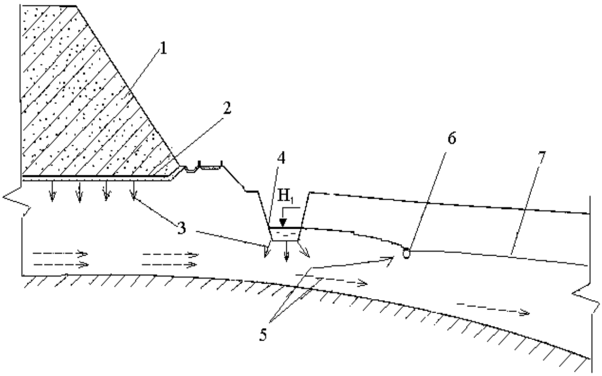

Fig. 5. Scheme of the arrangement of the drainage line for intercepting the soil flow from the massif of phosphogypsum dumps: *1* – phosphogypsum dumps; *2* – concrete curtain; *3* – migration flow; 4 – fishing channel; *5* – the direction of the filtration current; *6* - drain; 7 – the level of groundwater after installing drainage

It is possible to arrange *the nth* number of drains [1] (Fig. 6).

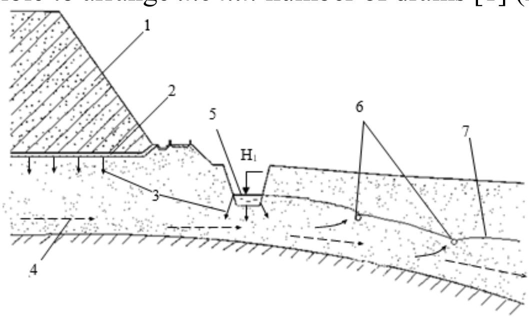

Fig. 6. Scheme of arrangement of the nth number of drains to intercept the soil flow from the massif of phosphogypsum dumps: *1* – phosphogypsum dumps; *2* – concrete curtain; *3* – migration flow; *4* – the direction of the filtration current; *5* – fishing channel; *6* - drain; *7* – groundwater level after drainage installation

In the practice of hydrotechnical construction, with the artificial interception of contaminated groundwater in order to prevent soil pollution, it is possible to apply a scheme for arranging a group of wells, the mutual location of which may be different.

The scheme of groundwater interception by a series of wells is presented in Fig. 7. In this case, the wells can be located in several rows after washing the contaminated object. The number of wells and their placement is optimized by appropriate hydrotechnical and migration calculations.

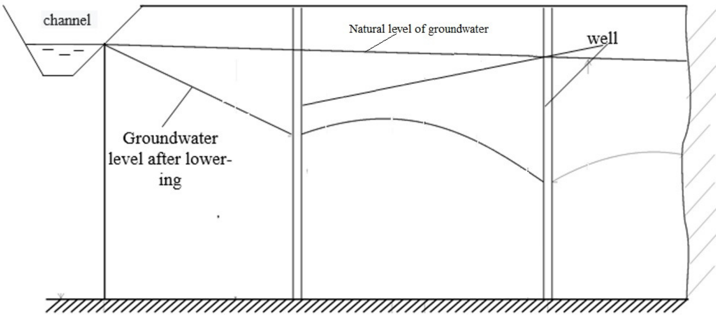

Fig. 7. Scheme of interception of the soil flow of contaminated water from the object of pollution by a series of wells

For more effective interception of groundwater, the horizontal drainage can be reinforced with vertical wells that will discharge into the drains (Fig. 8).

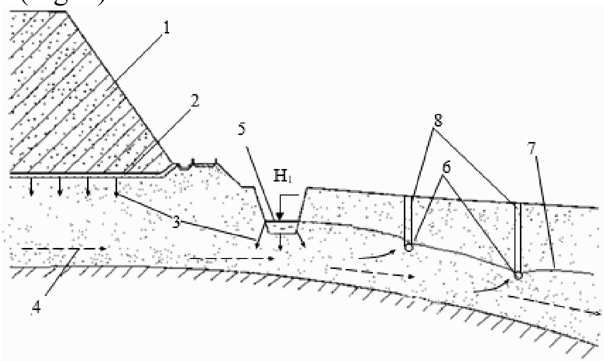

Fig. 8. Scheme of interception of polluted water by drainage reinforced with vertical wells: *1* – phosphogypsum dumps; *2* – concrete curtain; 3 – migration flow; *4* – the direction of the filtration current; *5* – fishing channel; *6* - drain; *7* – ground water level after installing drainage; *8* – well

Strengthening of drainage with vertical wells is recommended in the case when the soil massif from which the polluted water is drained is represented by soils with a low filtration coefficient.

One of the options for cleaning the water that is wedged out of the waste layer can be: cleaning the drains in 2-step biological ponds with natural aeration and aquatic vegetation; - interception of heavy metals from filtrates with the help of a natural sorbent in a geochemical screen (loam of a defined chemical and mineralogical composition, laid at the base of the catch channel); combination of the proposed combination of two cleaning methods - biogeochemical and geochemical.

The biochemical method involves the use of aquatic vegetation grown in ponds, at the base of which screens of rocks are placed. Based on the results of a comparative analysis of the accumulation of heavy metals in the system " aquatic deposits - aquatic vegetation", it was established that reed is a better natural sorbent than sedge and cattail for the following metal content: chromium >copper>nickel >cadmium>cobalt>manganese. The best sorbent that accumulates metals among studied aquatic plants is watercress. The accumulation coefficients, calculated as the ratio of the metal content in watercress to the metal content in water, range from 16,000 to 24,000 for manganese, and from 4,000 to 8,000 for iron. Since the main pollutant components for this object are iron, manganese, and chromium, then the combination of reed and duckweed allows to reduce pollution by the listed metals.

The main burden of reducing the content of pollutant components in the waters of the fishing channel is borne by the geochemical screen. Geochemical screens are used in the form of soil dams that enclose ponds. An anti-filtration tray is installed along the bottom and slopes of the dams. A geochemical screen made of natural sorption material is placed in the biopond of the second stage of purification . The filtrate, having passed through a layer of sorption material, enters the drainage layer and enters the biopond of the third stage through pipes , where it is further purified, after which the excess of purified filtrate is discharged into the drainage channel.

The scheme of the preliminary assessment of the validity of the geochemical screen is based on the determination of the value of the limit sorption capacity in relation to the pollutant components toxic for the given source for the specified type of rocks.

To reduce pollution of the fertile soil layer, you can use a layer of loess loam with a thickness of 0.5 m in combination with layers of chernozem of different thicknesses (30, 50, 70 cm). The conducted studies made it possible to conclude that the use of a shielding layer of loess loam reduces the entry of lead and zinc into the black soil by 2 times, copper, cobalt and cadmium - by 1.6 times. The concentration of iron, manganese and chromium in the soil in the contact zone with the loess rock does not change. A decrease in the number of mobile forms of metal entering the soil layer from the rock leads to a decrease in the content of metals in agricultural products.

In the reclamation of territories, carbonate loams are widely used both independently and together with sand as ameliorants . Carbonate ameliorant improves the chemical composition of rocks, increases the supply of fine soil , increases moisture capacity, porosity, water permeability.

Methodological approaches and criteria for evaluating geoecological indicators of safety and minimization of water and soil contamination by heavy metals in the territory of phosphogypsum dumps include:

- creation of geochemical screens;
- engineering and technical measures - installation of drainage structures to intercept polluted water coming from phosphogypsum dumps, installation of film screens;
- the use of perennial grasses (alfalfa and safflower) as test crops and buffer crops on reclamation sites;
- creation of a methodology for determining the parameters of absorption of heavy metals by soils and rocks and its implementation in the practice of predicting groundwater pollution;
- of highly mineralized waters discussed above are designed to intercept the flow of clean water. And we are dealing with a liquid that has a concentration different from the concentration of groundwater.

The schemes do not take into account diffusive transport, as well as sorption and desorption of the soils of the massif on which the studies are conducted.

4. Justification of the technological parameters of interception and removal of polluted waters

highly mineralized water from the territory of phosphogypsum dumps of JSC " Rivneazot " is filtered in the experimental area , which leads to soil, groundwater and Horyn River water pollution.

According to experimental research data, the source of pollution is not only the phosphogypsum dumps of JSC " Rivneazot ", but also the surrounding area. As a result of the spread of phosphogypsum by wind erosion and groundwater, the content of soil contamination in a radius of 1 km around the dumps exceeded the maximum permissible standards. The content of nitrates in the soil exceeds the maximum allowable concentration of MPC (45 mg/dm^3) and ranges from 30 to 90 mg/dm^3. The content of manganese in groundwater within the study area in all samples exceeds the MPC (0.1 mg/dm^3). An area with a manganese content in groundwater of 50-300 mg/dm^3 has been allocated directly on the territory of the solid household waste site. The content of iron in groundwater directly within the waste site is within 2000-1000 mg/kg (MPC-0.3 mg/dm^3). The content of lead, zinc, copper, cadmium, nickel, cobalt, and nitrites in groundwater everywhere exceeds the MPC. The results of chemical analysis of water samples taken from the site show that the water has a mineralization of 8.3 mg/dm^3. The content of total chromium exceeds the MPC (1.0 mg/dm^3) and is 3.0-6.0 mg/dm^3 .

To prevent the spread of pollution, we have developed and proposed an engineering network for the interception of highly mineralized waters from the territory of phosphogypsum dumps (Fig. 9). According to this scheme, it is proposed to arrange a network of drainage around the dumps, which will intercept and divert contaminated groundwater to the treatment facilities of OJSC " Rivneazot", located 5 km from the territory of the research object. Catch channels (3) are designed around the perimeter of the object to intercept the polluted water coming from the territory of the phosphogypsum dumps, which accumulates in the dumps due to atmospheric precipitation in the form of rain and snow. From the catch channels, the highly mineralized solution is fed by the pumping station (5) into the pond, which is located on top of the dumps (V=406,000 m^3). The installation of a settling tank on top of the dumps is due to the prevention of the highly mineralized solution from entering the soil and the further spread of groundwater pollution in the Horyn River.

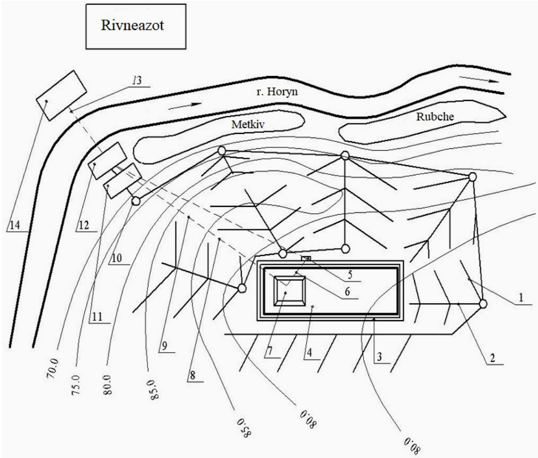

Fig. 9. Engineering network of pollution prevention within the influence of phosphogypsum dumps: *1* - drains; *2* - collective collector; *3* - fishing channels; *4* - dumps of phosphogypsum; *5* - pumping station*; 6, 13* - pressure pipeline; *7* - storage pool; *8, 9* - gravity pipeline; *10* - drainage well; 11 - collection pool; 12 - pumping station; *14* - treatment facilities

To evaluate the parameters of drainage systems for the localization of migratory currents, theoretical developments [2] were used to determine the one-way inflow to the drain by the point flow method and calculated dependencies to determine the parameters of the closed drainage. A sufficiently generalized version of the hydrodynamic scheme reflects the most common situation with layers differing in permeability and partial pressure (fig. 10), which, however, is easily simplified to a single-pressure scheme.

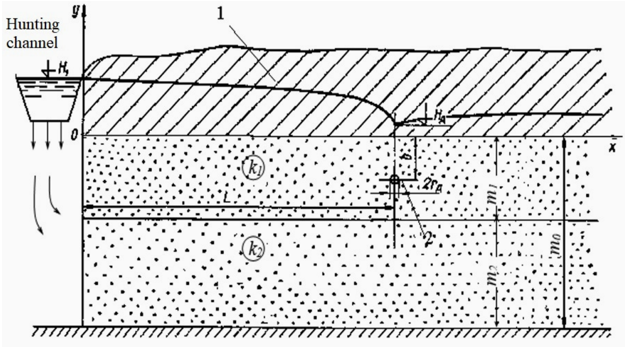

Fig. 10. Calculation scheme of one-way inflow to the drain:
1 depression curve; *2* - drain

The solution of the problem for the flow located at a point with coordinates (*L,-b*) and having a flow rate *q* is expressed by the equation

$$H(x,y)=\frac{q}{4\pi k_1}\{\ln[(x-L)^2+(y+b)^2]+\ln[(x-L)^2+(y-b)^2]\}+$$
$$+\frac{q}{4\pi k_1}\sum_{n=1}^{\infty}c'_n\{\ln[(x-L)^2+(y+2nm_0-b)^2]+\ln[(x-L)^2+(y+2nm_0+b)^2]+, \quad (17)$$
$$+\ln[(x-L)^2+(y-2nm_0+b)^2]+\ln[(x-L)^2+(y-2nm_0-b)^2]\}+C_1$$

The solution of the problem for a fictitious source located at the point (- *L* , *-b*) and which has a flow - *q* , will be as follows

$$H(x,y)=-\frac{q}{4\pi k_1}\{\ln[(x+L)^2+(y+b)^2]+\ln[(x+L)^2+(y-b)^2]\}-$$
$$-\frac{q}{4\pi k_1}\sum_{n=1}^{\infty}c'_n\{\ln[(x+L)^2+(y+2nm_0-b)^2]+\ln[(x+L)^2+(y+2nm_0+b)^2]+ \quad (18)$$
$$+\ln[(x+L)^2+(y-2nm_0+b)^2]+\ln[(x+L)^2+(y-2nm_0-b)^2]\}+C$$

Summing expressions (17) and (18), we find the level function for an arbitrary coordinate

$$H(x,y)=\frac{q}{4\pi k_1}\{\ln\frac{[(x-L)^2+(y+b)^2][(x-L)^2+(y-b)^2]}{[(x+L)^2+(y+b)^2][(x+L)^2+(y-b)^2]}+$$
$$\sum_{n=1}^{\infty}c'_n\ln\frac{[(x-L)^2+(y+2nm_0-b)^2][(x-L)^2+(y+2nm_0+b)^2]}{[(x+L)^2+(y+2nm_0-b)^2]+[(x+L)^2+(y+2nm_0+b)^2]}\times$$

$$\times \frac{\left[(x-L)^2+(y-2nm_0+b)^2\right]\left[(x-L)^2+(y-2nm_0-b)^2\right]}{\left[(x+L)^2+(y-2nm_0+b)^2\right]\left[(x+L)^2+(y-2nm_0-b)^2\right]}\Bigg\}+C \quad (19)$$

In order to satisfy the condition $H=H_1$ at $x=0$, the constant value C must be taken equal to $H_{1.}$ The pressure H_d on the contour of the tubular drain with a radius r_D we determine from expression (19), substituting $x=L\text{-}r_D$ and $y=\text{-}b$ into it

$$H_Д = \frac{q}{4\pi k_1}\Bigg\{\ln\frac{r_Д^2(r_Д^2+4b^2)}{(2L-r_Д)^2\left[(2L-r_Д)+4b^2\right]}+$$

$$+\sum_{n=1}^{\infty} c'_n \ln\frac{\left[r_Д^2+4(nm_0-b)^2\right](r_Д^2+4n^2m_0^2)^2}{\left[(2L-r_Д)^2+4(nm_0+b)^2\right]\left[(2L-r_Д)^2+4n^2m_0^2\right]}\times \quad (20)$$

$$\times\frac{\left[(r_Д^2+4(nm_0+b)^2\right]}{\left[(2L-r_Д)^2+4(nm_0+b)^2\right]}\Bigg\}+H_{1.}.$$

From formula (20), taking into account that $r_Д<m_1$ and $r_Д<<L$, we obtain for the consumption $q=q_Д$ per unit length of the drain

$$q_Д = 4\pi k_1(H_1-H_Д)\Bigg\{\ln\frac{16L^2(L^2+b^2)}{r_Д^2\ (r_Д^2+4b^2)}+ \quad (21)$$

$$+\sum_{n=1}^{\infty} c'_n\left[\ln(1+\frac{L^2}{(nm_0-b)^2}+2\ln(1+\frac{L^2}{n^2m_0^2})+\ln(1+\frac{L^2}{(nm_0+b)^2})\right]\Bigg\}^{-1}.$$

When $k_2=0$ and $k_1=k_2$ from the obtained formulas, the known dependences for head and linear flow in the case of a homogeneous pressure reservoir with capacities m_1 and m

$$q_Д = \frac{k_1(H_1-H_Д)}{\dfrac{L}{m_1}+\dfrac{1}{2\pi}\ln\dfrac{m_1}{2\pi r_Д\sin\dfrac{\pi(2b+r_Д)}{2m_1}}}, \quad (22)$$

When $k_2=0$

$$q_Д = \frac{k_1(H_1-H_Д)}{\dfrac{L}{m_1}+\dfrac{1}{\pi}\ln\dfrac{m_1}{\pi r_Д}}. \quad (23)$$

Consider the scheme of inflow to *the nth* number of drains (Fig. 11).

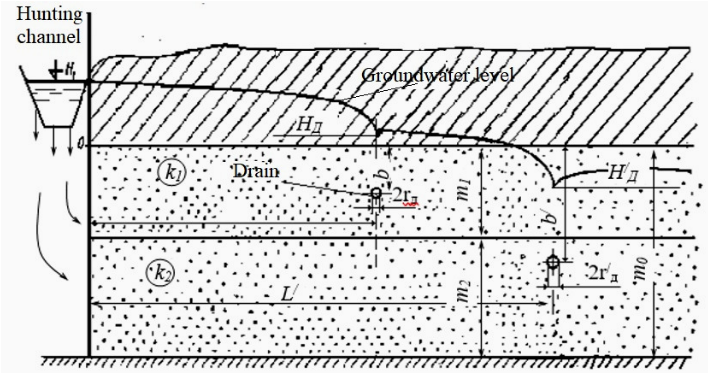

Fig. 11. Calculation scheme for interception of soil flow by the drain system

To solve problems of this type for the second drain, let's assume that the Y axis passes through the center of the first drain. Then it can be written when $k_1=k_2$

$$q'_Д = 4\pi k_1 (H_Д - H'_Д)\left(\frac{4\pi(L' - L)}{m_0} + \ln\frac{m_0}{2\pi r'_Д} - 2\ln\sin\pi B - 2\ln\frac{\sin\pi B}{4}\right)^{-1}; \quad (24)$$

$$B = \frac{2b' + r'_Д}{2m_0}$$

where $q'_Д$ is the flow intensity of the second drain, m^3 /s; $H'_Д$ - pressure over the second drain , m; $r'_Д$ - radius of the cross-section of the second drain, m; L'- distance from the second drain to the power source, m; b'- the depth of the second drain, m.

For complete interception of the soil flow, it is necessary that the condition $H'_Д$=0 be fulfilled, that is, the pressure above the drain should be equal to zero.

$$H'_Д = H_Д - \frac{4\pi k_1\left(\frac{4\pi(L' - L)}{m_0} + 2\ln\frac{m_0}{4\pi r'_Д} - 2\ln\sin\pi B - 2\ln\frac{\sin\pi B}{4}\right)^{-1}}{q'_Д} = 0; \quad (25)$$

For the *nth* drains dependence (25) can be rewritten

$$H_Д^n = H_Д^{n-1} - \frac{4\pi k_1 \left(\frac{4\pi(L^n - L^{n-1})}{m_0} + 2\ln\frac{m_0}{4\pi r_Д^n} - 2\ln\sin\pi B - 2\ln\frac{\sin\pi B}{4} \right)^{-1}}{q_Д^{/}} = 0; \quad (26)$$

performing the necessary mathematical operations in equation (26) we obtain

$$H_Д^{/} = H_Д - \frac{4\pi k_1 \left(\frac{4\pi(L^{/} - L)}{m_0} + 2\ln\frac{m_0}{4\pi r_Д^{/}} - 4\ln 2 \right)^{-1}}{q_Д^{/}} = 0; \quad (27)$$

$$H_Д^{/} = H_Д - \frac{4\pi k_1 \left(\frac{4\pi(L^{/} - L)}{m_0} + 2\ln\frac{m_0}{16\pi r_Д^{/}} \right)^{-1}}{q_Д^{/}} = 0; \quad (28)$$

$$H_Д^n = H_Д^{n-1} - \frac{4\pi k_1 \left(\frac{4\pi(L^n - L^{n-1})}{m_0} + 2\ln\frac{m_0}{16\pi r_Д^n} \right)^{-1}}{q_Д^n} = 0; \quad (29)$$

where $q_Д^n$ is the flow intensity of the *n* drain, m^3/s; $H_Д^n$ - pressure over the *n* drain, m; $r_Д^n$ - radius of the cross section of the *n* drain, m; L^n - distance from the *n* drain to the power source, m; b^n - the depth of the *n* drain, m.

To intercept highly mineralized water coming from phosphogypsum dumps, we will calculate the installation of a drainage line along the contour of the object under consideration. The drainage is arranged at a distance of 20 m from the fishing channel, the depth of which is 0.5 m. The calculation scheme is presented in fig. 12. For complete interception of contaminated water, the drain will be arranged on the sole of the waterproof layer at a depth of 5 m from the ground surface. The difference in pressure between the mark of laying the drain and the mark of the water level in the catch channel is 2 m. To prevent soil and groundwater contamination, the pressure above the drain *НД* should be equal to 0 .

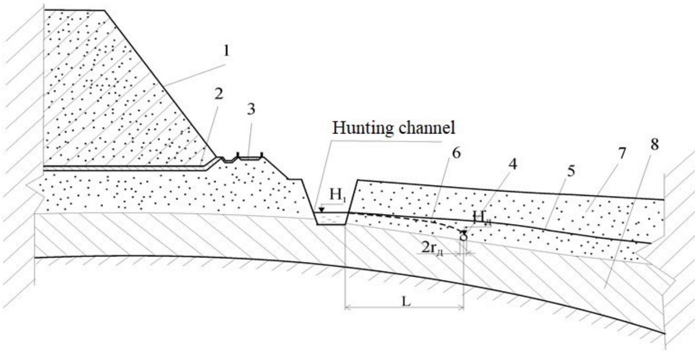

Fig. 12. Scheme for calculating the installation of a drainage line for intercepting soil flow from an array of phosphogypsum dumps: *1* – phosphogypsum dumps; *2* – concrete curtain; *3* – road; *4* – drain; *5* – natural level of groundwater; *6* – ground water level after installing drainage; *7* – sand; *8* – loam

In order to intercept the drainage water as much as possible, the radius of the drainage should be such that it can pass the drainage flow. To calculate the required radius of the drainage line, we will use dependence (23). After transformations, we get

$$r_{Д} = \frac{m_1}{\pi e^{\left(\frac{\pi k_1 (H_1 - H_{Д})}{q_{Д}} - \frac{\pi L}{m_1}\right)}}. \tag{30}$$

Fig. 13, 14 show the results of calculations for possible ranges of parameters in the form $r_{Д} = f(к_1; L; m)$.

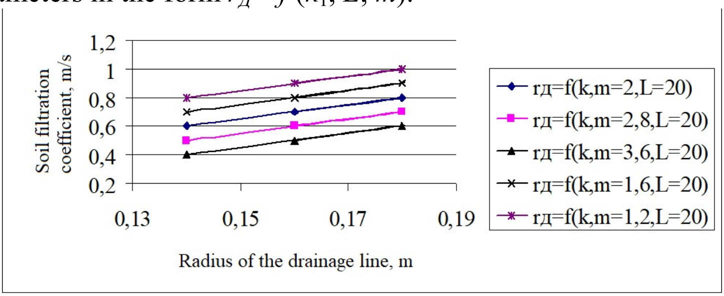

Fig. 13 Dependence of the drainage radius of the line on the filtration coefficient at different values of the capacity of the aquifer

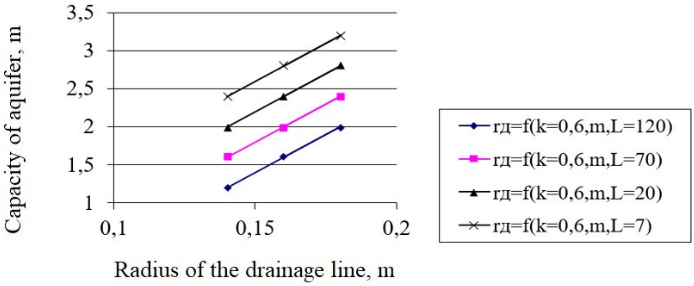

Fig. 14. Dependence of the radius of the drainage on the capacity of the aquifer at different values of the distance of laying the drainage from the catch channel

For more effective interception of groundwater, the horizontal drainage can be reinforced with vertical wells that will discharge into the drains (Fig. 15).

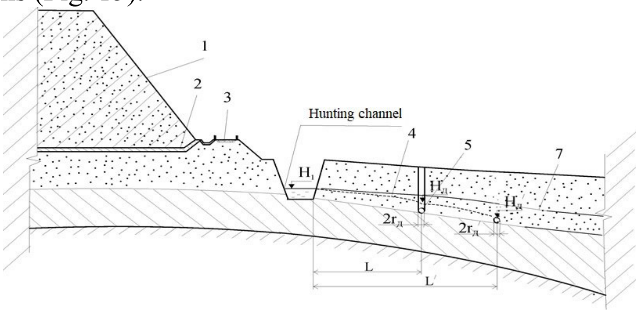

Fig. 15. Scheme of interception of polluted water by drainage reinforced with vertical wells: *1* – phosphogypsum dumps; *2* – concrete curtain; *3* – road; *4* – ground water level after installing drainage; *5* – drain; *6* – well; *7* – natural level of groundwater

To determine the diameter of the well, it is advisable to use the theoretical developments of M.M. Veregin on the lowering of groundwater.

In the case of one well, the pressure (water depth) h at any point of the soil flow is expressed by the following equation

$$h^2 = H_e^2 - \frac{q}{\pi k}\left[\ln\frac{\rho_k}{r_k} + 0{,}5\varsigma\left(\frac{l}{m},\frac{m}{r_k}\right)\right]. \qquad (31)$$

where *k is* the filtering coefficient.

Here we note only that at $l=m$ (perfect well), and also at $m/r_k \leq 1$ value $\sigma=0$.

Therefore, for the case when the well reaches a water-impermeable layer, dependence (31) can be rewritten

$$h^2 = H_e^2 - \frac{q}{\pi k}\left(\ln\frac{\rho_k}{r_k}\right). \quad (32)$$

The values ρ_k and r_k are expressed in the following way

$$r_k = \sqrt{(x-b-\rho)^2 + (y-\rho\sin\alpha)^2}, \quad (33)$$

$$\rho_k = \sqrt{(x+b+\rho)^2 + (y-\rho\sin\alpha)^2}\ . \quad (34)$$

ρ_k and r_k - bipolar coordinates of any point, correspondingly equal to its distance to the center of an arbitrary well and to its mirror image relative to the water cut; q - flow rate of the well.

The value of H_e is equal to the depth of water at any point in natural conditions (before the start of the wells). H_e =1 m - above the drainage line.

With the action of all n wells based on the principle of addition of currents, the pressure h at the same point will be expressed as follows

$$h^2 = H_e^2 - \frac{q}{\pi k}\left(\sum_{k=0}^{k=n-1}\ln\frac{\rho_k}{r_k}\right), \quad (35)$$

To determine the radius of the well, which is necessary for complete interception of the soil flow of contaminated water, we will use the dependence

$$H^2 - h^2 = \frac{Q}{\pi r}\ln\left(\frac{2l}{r_0}\right) \quad (36)$$

Taking h=0, we get r_0=0.1 m.

$$\ln r_0 = \ln(2l) - \frac{H^2 \cdot \pi r}{q}.$$

In fig. 16 gives the results of calculations for a possible range of parameters $r_D = f(L;l;r_0)$.

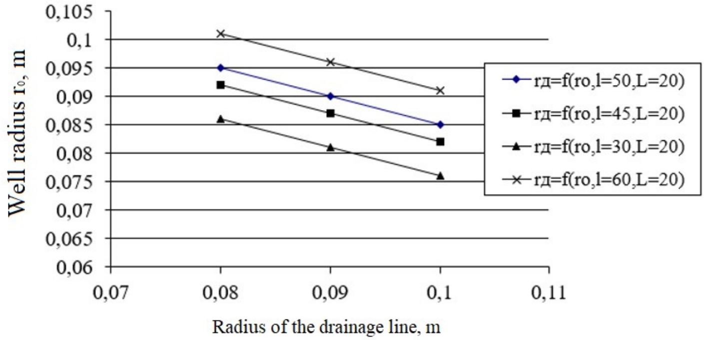

Fig. 16. Dependence of the drainage radius on the radius of the well at different values of the distance between the wells *l*

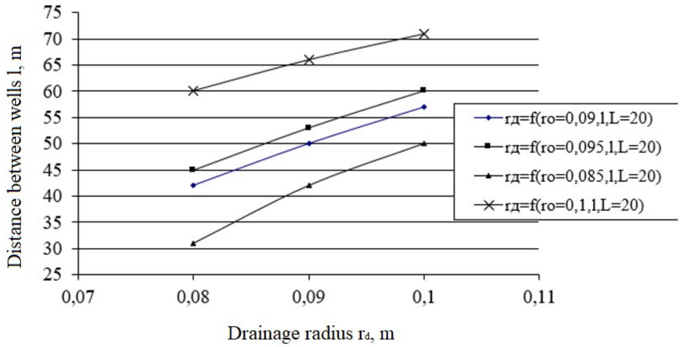

Fig. 17. Dependence of the drainage radius on the distance between the wells at different values of the well radius

Strengthening of drainage with vertical wells is recommended in the case when the soil massif from which the polluted water is drained is represented by soils with a low filtration coefficient.

5. Justification of optimal parameters of volumetric drainage filters for interception of polluted waters

When choosing the optimal parameters (thickness and density) of drainage filters, it is necessary to solve the technical and economic optimization problem. On the one hand, increasing the thickness of the filter makes it possible to increase the distance between the drains due to the reduction of filtration resistance, that is, to reduce construction costs per unit area. On the other hand, material costs for filter production are increasing. In addition, reducing the density of the filter allows you to reduce material consumption and increase the distance between the drains. But, with a certain load on the filter, it begins to deform, which reduces the intensity of drying. Therefore, among many values of different thickness, density, diameter of drains, type of filtration scheme, it is necessary to choose the most optimal option both from the point of view of economy and from the point of view of ensuring the required drainage effect.

Reducing the density of the filter allows you to reduce the consumption of material and increase the distance between the drains, but due to the load on the filter, it begins to deform. Therefore, among the many values of different filter thickness, density and diameter of drains, it is necessary to choose the option with the lowest costs for the construction of the drain, taking into account the cost of the filter material.

According to the methodology developed by L.F. Kozhushko [13], the criterion of optimality is the minimum capital investment in the construction of drainage with volumetric filters, with the mandatory provision of the calculated module of drainage flow

$$K=ZD+ZF \Rightarrow min, \quad (37)$$

where ZD - drainage construction costs without taking into account the cost of the filter, hryvnias/ha; ZF - filter manufacturing costs and material cost, hryvnias/ha

$$ZD=K_{ZD} \cdot L_0, \quad (38)$$

$$ZF=K_{ZF} \cdot P_0, \quad (39)$$

where K_{ZD} is the cost of construction of 1 m of drainage without a filter, determined by calculation, UAH/ha; K_{ZF} - the cost of the volumetric filter, taking into account the cost of the material and the costs of manufacturing the filter, hryvnias/ha; L_0 - length of drains per unit area, m/ha; P_0 - filter material consumption per unit area, kg/ha.

$$L_0 = \frac{10000}{E}, \quad (40)$$

$$P_0=\pi(t\,(D+t))\rho \cdot L_0, \quad (41)$$

where E is the distance between drains, m; t - filter thickness, m; D - diameter of drains, m; ρ - filter density, kg/m ^{3}.

The calculation is performed taking into account soil and hydrogeological conditions in the following sequence:

1. Given the known diameters of the drain and the type of filter

material, we set different values of the initial thickness of the filter: $t_1, t_2, \ldots t_n$ and the initial density: $\rho_1, \rho_2, \ldots \rho_n$;

2. For each of the values of t_{and} and ρ_i, determine the load of the backfill of the drainage trench per 1 p.m of the drain

$$P_i = \frac{2jHb}{\pi(D+2t_i)}, \tag{42}$$

where j is the volumetric mass of the backfill soil, kg/m ^{3}; H - trench depth, m; b - trench width, m.

3. Depending on the type of filtration material, its filtration coefficient is determined at $\rho=\rho_ф$;

$$k_ф = a \cdot \rho^b, \tag{43}$$

where a, c are empirical coefficients depending on the type of material, kg/m^3;

4. Determine the actual thickness of the filter, taking into account the deformation $t_ф$, and the actual density $\rho_ф$

$$t_ф = t_0\left(1 - a\frac{P^m}{P_0^n}\right), \tag{44}$$

$$\rho_ф = \rho_0 \frac{2t_0(D+t_0)}{t_0(D+2t_ф)+Dt_ф}, \tag{45}$$

where D is the pipe diameter, m; P - load, kg/cm ^{2}; m, n - empirical coefficients depend on the type of material.

5. At $t=t_ф$ and $\rho=\rho_ф$ we calculate the filtration resistance according to the nature of the opening of the aquifer Φ_i;

$$\Phi_i = 2\Pi \cdot K_{гр}^n \cdot \rho_ф^к (a_0 + a_1 t_ф + a_2 t_ф^2 + a_3 t_ф^3) - \ln 4H_д / D. \tag{46}$$

6. Taking into account the filtration scheme, we determine the general filtration resistances according to the degree and nature of the opening of the aquifer [13].

7. Determine the distance between the drains using the formulas:

a - when the water resistance is relatively shallow

$$B = 4(\sqrt{L_{нд}^2 + \frac{H_p T}{2q}} - L_{нд}) \tag{47}$$

the waterproofing is deep

$$B = \frac{2\pi K_{гр} H_p}{q(\ln(2E/\pi D) + \Phi_i} \tag{48}$$

where $K_{гр}$ - soil filtration coefficient, m/day; H_p - calculated pressure above the drain, m; q - inflow of water to the drain, m/day; $L_{нд}$ - total filtration resistance according to the degree and nature of formation opening ($\Phi_0+\Phi_ф$).

8. According to formula (40), the length of drains per 1 ha is determined and according to (45) at $t=t_ф$, $\rho=\rho_ф$ calculate ρ_0 ;

9. With the known values of ZD and ZF , we determine the value of the optimization criterion K by formulas (38) and (39);

10. According to the minimum value of the criterion, we determine the optimal initial parameters t and ρ_i , and the distance between the drains that corresponds to them .

According to this method, the optimal parameters of volumetric drainage filters are given (Tab. 1).

Table 1

Optimal parameters of volumetric drainage filters

Parameters	Filtering materials			
	straw	flax - kostrytsia	a mixture of firewood and sawdust	a mixture of straw and artificial fibers
Filter density, g/ cm^3	0.16-0.20	0.18-0.22	0.18-0.22	0.18-0.22
Filter thickness, mm	10-12	10-12	10-12	10-12

The use of volumetric filters made of organic materials allows to reduce the cost of drainage construction by 1.3-1.4 times compared to the option of a filter made of non-woven fabric [13].

5. Recommendations for environmentally safe operation and disposal of phosphogypsum dumps of JSC "Rivneazot"

After the analysis of the research object, which included topographic surveying, determination of the chemical and mechanical composition of the soil and groundwater, water-physical properties of the soil of the adjacent territory, three stages are proposed that will ensure the environmentally safe functioning of the phosphogypsum dumps of JSC "Rivneazot"[14].

At the first stage, in order to prevent the spread of pollution, a scheme for intercepting polluted waters from the territory of phosphogypsum dumps is proposed. In the territory around the dumps, it is necessary to install a collector and drainage network that will intercept and divert contaminated groundwater to the treatment facilities of OJSC "Rivneazot", located 5 km from the territory of the research object.

Remedial measures will intercept soil and surface flows of polluted water, which in turn will prevent their entry into the soil , groundwater, and in the Horyn River, drinking water wells in the village of Metkiv et al. Rubche.

At the second stage, it is recommended to cover the phosphogypsum dumps with a protective film followed by sprinkling with a fertile layer of soil with planting of vegetation, which will prevent wind erosion and contamination of the adjacent territories. Vegetation that is recommended for planting in a one-meter layer of soil - small bushes with herbs.

The third stage is designed for a longer perspective - it is the processing of phosphogypsum into building materials (wall blocks, floor panels, binder with strength greater than concrete grade 500) with simultaneous disinfection of phosphogypsum from harmful elements and extraction of rare earth metals that are part of phosphogypsum - up to 1%.

Conclusion

In the work, an actual scientific and practical task is solved, which consists in establishing the regularities of the distribution of pollution in the soil massif during the filtration of groundwater from the source of pollution, based on which methods of assessment and analysis of the impact of man-made objects on the environment and calculation of rational parameters of pollution localization have been created within the influence of phosphogypsum dumps, developed technological solutions for the localization of such pollution.

The implementation of these solutions will increase the level of environmental safety through the use of more reliable engineering systems for environmentally safe storage of phosphogypsum dumps and reduce the morbidity of the population living within the limits of the dumps.

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