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Theoretical justification of the assessment of contamination of surface water resources by underground runoff as a result of military operations

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Abstract. Military actions on the territory of Ukraine cause a negative impact on the quality of water resources due to the ingress of contaminated effluents into underground horizons due to the destruction and/or damage of treatment facilities. This work deals with the definition of theoretical approaches to the quantitative assessment of pollution entering surface water resources through underground feeding due to damage to protective screens in ponds, storage tanks of various types and tailings storage facilities. The spread of contamination in case of screen damage was noted in three stages: wetting of the aeration zone from the damaged lining to the surface of the underground flow; non-stationary rise in the groundwater level with the formation of a water dome; became filtering in the direction of discharge of underground flow. The problem of the loss of piezometric head during the passage of the filtration flow through the screen structure and the determination of the flow of polluted water from the specified structure based on this value are considered. An analytical solution to the problem of wetting the aeration zone from the damaged lining to the surface of the pressureless underground flow is given. Taking into account the increase in the permeability coefficient of the screen due to damage, increased cracking, gusts, it was established that if its value is greater than or equal to 1.0*10-2m/day, the effect of screen protection can be ignored, and the filtration costs can be calculated according to the well-known infiltration formulas from unlined sewage treatment plant. The proposed approaches at different stages of filtration losses from the sewage treatment plant may in the future form the basis of the development of methods for calculating the migration of pollutants, taking into account the various sources of their entry into the groundwater, depending on the degree of damage to the shielded sewage treatment facilities.

Keywords: influence of military operations, quality of water resources, underground power supply, screens of treatment facilities.

INTRODUCTION

Military actions on the territory of Ukraine have a negative impact on water resources, both surface water and underground. As a result, river basins and their quality are undergoing significant changes. As a result of the cessation of treatment facilities, the destruction of settling tanks, the destruction of sewage treatment facilities, collectors, drains, accumulators, sedimentation tanks, and tailings storage facilities, the environmental safety of water resources is deteriorating, both in controlled and uncontrolled territories [1,2, etc.]. According to regulatory documents, under normal operating conditions, the protective screens of these structures have filtration coefficients of $1.0*10^{-9}$ m/day, but due to numerous damages, cracking and gusts, the average filtration coefficient over the area of the structure is it increases by several orders of magnitude and can be $1.0*10^{-2}$ m/day - $1.0*10^{-4}$ m/day or more. Determining the amount of damages caused by pollution and/or clogging of surface waters as a result of military aggression according to the methodology for determining damages caused by pollution and/or clogging of waters, arbitrary use of water resources (Ministry of Environmental Protection and Natural Resources of Ukraine. Order No. 252 of 07/21/2022) requires instrumental and laboratory measurements, visual observation data, aerial photography, remote sensing of the Earth, state water monitoring, primary accounting of water use, calculation methods, development of expert assessments, etc. [3]. The methodology provides for one-time sampling in the case of instrumental laboratory control, which is insufficient for a full assessment of the quality of a water body after pollution has entered it due to underground feeding. There is a need for a theoretical justification and development of a methodology for assessing the transfer and transformation of pollutants by underground runoff due to the destruction and damage of treatment facilities.

THE AIM OF THE STUDY

The purpose of this work is to develop a theoretical justification for the quantitative assessment of pollution entering surface waters through underground supply as a result of damage to the screens of treatment facilities.

STATEMENT OF THE PROBLEM AND RESEARCH RESULTS

Contamination from underground runoff into surface waters as a result of hostilities in a certain territory can occur, among others, in the following ways:

- violation of the integrity of structures and destruction of the screens of sedimentation tanks, tailings storage facilities, infiltration basins with further advancement of contamination into the soil under the action of infiltration processes;

Secondly, the destruction of supporting structures, dams and flooding of a large area.

Destruction of protective screens of tailings and clarifiers reduces their protective effect, increases the conditional filtration coefficient through screened structures of treatment systems. It is known that the greatest loss of piezometric head during filtration from these treatment facilities occurs when the flow of contaminated liquid passes through the screen and its infiltration on the ground water surface. In this case, the wetting zone of the soil of the aeration zone does not go beyond the filtration zone with steady movement of the liquid.

According to the long-term research of the Institute of Hydromechanics of the National Academy of Sciences regarding the design of drainage protective structures, the following stages of filtration under the cladding can be considered:

- wetting of the aeration zone from the damaged lining to the surface of the pressureless underground flow;
- non-stationary rise in the groundwater level with the formation of a water dome as a result of infiltration to the surface from the damaged cladding;
- constant filtration flow after closing the dome of groundwater with the bottom of the damaged screen in the direction of discharge of the underground flow.

But it should be noted that in case of significant damage to the anti-filtration screen in the form of a separate crack or other significant damage, theoretical calculations for determining the flow of contaminated liquid into the soil should be carried out according to a separate algorithm, which assumes leakage from a separate source [4].

Analytical solution of the linear problem in the conditions of permanent supported filtration for melioration channels with lining on irrigation systems was considered. with the application of the method of filtering resistances in work [5]. Using this approach, it is possible to find the flow rate of the polluted flow coming from the destroyed sewage treatment plant to the aeration zone. At the first stage of soil wetting of the aeration zone and the rise of groundwater, we believe that the filtration flow is constant over time.

During the time interval *t*, *t*+d*t*, the flow will pass through the screen of width B:

$$Q = -k_{obl} B \frac{\partial h}{\partial x} \int_{t_1}^{t_2} \partial t \qquad (1)$$

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The amount of pressure lost at a given flow rate through the screen is:

$$\Delta h = h_k - h_{ost} \quad (2)$$

where:
h_{ost} - the value of the piezometric pressure under the destroyed cladding.

The quantity Q, which is necessary when passing through the screen, can also be represented in the form:

$$Q = \int_{x_1}^{x_2} \frac{n}{\delta} \Delta h(x) dx \quad (3)$$

Equating the right-hand sides of equations (2) and (3) and successively applying the theorem on the average and on finite increments, we obtain the following equation:

$$\frac{\partial}{\partial x}\left(K_{obl}\frac{\partial h}{\partial x}\right)\Big|_{\substack{x=x_4\\t=t_3}} = \frac{n}{\delta} \times \frac{\partial h}{ht}\Big|_{\substack{x=x_3\\t=t_4}}. \quad (4)$$

In equation (4) t_3, t_4 and x_3, x_4 – it's an intermediate points of arbitrary intervals t_1t_2 and x_1x_2.

When moving to expressions $x_1x_2 \rightarrow x$ and $t_1t_2 \rightarrow t$, equation (4) takes the form:

$$\alpha \times \frac{\partial^2 h}{\partial x^2} = \frac{\partial h}{\partial t}, \alpha = \frac{K_{obl}\delta}{n_{obl}}. \quad (5)$$

Boundary and initial conditions when solving this equation are represented by system (6):

$$h(-\delta, 0) = -h_K, \quad h(-\delta, t) = -h_K \quad (6)$$
$$\frac{\partial h(0,t)}{\partial x} = \frac{\delta + h_K}{\delta}.$$

The analytical solution of this equation assumes the following assumptions:

- constant gradient of pressure output through the damaged screen at x=0;
- the generalized value of the filtering coefficient $к_{обл}$. for the entire width of B.

For the Laplace image, the solution to equation (5) can be written as:

$$h_L(x,S) + \frac{h_K}{S} = A_1 l^{\sqrt{\frac{S}{\alpha}}x} + B_1 l^{-\sqrt{\frac{S}{\alpha}}x}. \quad (7)$$

The initial conditions in the images can be represented as:

$$h_L(-\delta, S) = -\frac{h_K}{S},$$
$$\frac{\partial h_L(0,S)}{dx} = \frac{\delta + h_k}{S\delta}. \quad (8)$$

A_1 i B_1 – constant values that can be determined from the initial conditions (8).

Transition to the original function according to [6] the pressure along the thickness of the destroyed lining with the generalized filtering coefficient can be written by the equation:

$$h(x,t)|_{0>x>\delta} = -h_K + (h_K + \delta)$$
$$\sum_{n=1}\left[\frac{2}{\mu_n^2}\cos\mu_n\frac{x}{\delta}\exp(-\mu_n^2\frac{\alpha t}{\delta^2}\right]$$
$$+2\frac{\delta + h_K}{\delta}\sqrt{\alpha t} \times ierfc\frac{(-x)}{2\sqrt{\alpha t}}. \quad (9)$$

According to the integral Laplace transform, the second term of the right-hand side of equation (9) is zero at $K_{obl} \leq 10^{-2}$ m/day. Such lining filtration coefficients are quite rare in the practice of construction of sewage treatment plants, but when these structures are damaged as a result of military operations, such values may occur.

The dependence for determining the final pressure under the cladding is determined from equation (9):

$$h_{ost}(0,t) = -h_K$$
$$+(h_K + \delta)\sum_{n=1}^{\infty}\left[\frac{2}{\mu_n^2}\exp\left(-\mu_n^2\frac{\alpha t}{\delta^2}\right)\right] \quad (10)$$

where:
μ_n – the root of the transcendental equation, which is equal to $\mu_n = (2n-1)\pi/2$.

According to this approach, it is possible to obtain pollution costs and concentrations of individual ingredients when they enter the soil.

When determining the formation halo of the area of pollution and the ways in which pollutants enter the filtration and migration flows, it is necessary to schematize the processes and conditions of mass transfer in aquifers depending on their hydrogeological characteristics [7,8]. In these works, based on the analysis of literary sources, it is concluded that the general mathematical model of migration consists of two interrelated blocks, namely, the hydrodynamic (filtration) block and the block of transformation (transformations) of pollutants in the aquifer. In order to assess pollution with a sufficient degree of accuracy for solving similar problems, geofiltration schematization and reduction of the filtration flow to two-dimensional, or even one-dimensional, is necessary. At the same time, it is desirable to use the materials of previous monitoring observations to test the assembled models.

The calculation formula for the running flow rate at the third stage of filtration after closing the dome of groundwater under the damaged screen in the direction of discharge of the underground flow is determined by the well-known formula (9,10):

$$q = \frac{TH_K}{F_{\text{K}} + F_{obl} + \sqrt{\frac{Tz_0}{\varepsilon_0}}}. \qquad (11)$$

where:

F_K i F_{obl} – filtering supports, which take into account the hydrodynamic imperfection of the structure and the filtering resistance of the screen of the damaged structure.

Value F_c we find according to the method described in detail in works [8-10], depending on the geological structure of the aquifer.

RESULTS OF THE DISCUSSION

The results of calculations of piezometric pressure values under the damaged structure with filtration coefficients of 10^{-2} m/day, 10^{-3} m/day and 10^{-4} m/day are presented in Table.

According to the values in table 1, it can be stated that in case of significant damage to the anti-filtration screen, as well as in estimation calculations with some margin of leakage from the sewage treatment plant, it is possible to neglect the residual effect of the screen and carry out calculations as in the case of open ground filtration.

Table. Calculations of piezometric head values under a damaged structure with a conditional head of 5 m

δ, m	h_k, m	K_{obl}, m/day	h_{ost} (0, $t_п$), m	$\Delta h = h_k - h_{ost}$, m
0,01	5,0	$1{,}67 \cdot 10^{-2}$	4,95	0,05
0,01	5,0	$0{,}67 \cdot 10^{-3}$	2,37	2,66
0,01	5,0	$1{,}06 \cdot 10^{-4}$	1,01	3,99

This approach can be used in the calculation of filtration losses of damaged open reclamation channels and collectors with lining.

The possibility and expediency of using the filtration resistance method is due to the limitation of the zone of sharp deformation of the filtration flow near the sump, which usually does not extend beyond one or two capacities of the aquifer. Under the condition B≥2m, where m is the capacity of the aquifer, according to the theory of filtration resistances, the calculation of the third stage of filtration can be carried out without taking into account the action of the damaged screen (F_{obl} =0). At this stage, there is a constant migration of pollutants towards the unloading of the underground flow.

In further research, based on the proposed approach, it is envisaged to develop methods for calculating the migration of pollutants, taking into account various sources of their entry into groundwater, depending on the degree of damage to shielded treatment facilities and the boundary conditions for applying the proposed approach.

CONCLUSIONS

Quantitative assessment of the transfer of pollutants by underground flow into surface water through underground supply due to damage to the screens of treatment facilities requires the development of reliable and substantiated mathematical models.

Previous studies have established that when treatment facilities are damaged, the processes

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of pollution migration can be considered in three stages, namely: wetting of the aeration zone; non-stationary rise in the groundwater level with the formation of a water dome; became filtering in the direction of discharge of underground flow.

With significant damage to the anti-filtration screen and an average filtration coefficient equal to $K_{obl} \geq 1.0*10^{-2}$ m/day, as well as in estimated calculations with some margin of leakage from the sewage treatment plant, it is possible to neglect the residual effect of the screen and conduct calculations as in the case of filtration in open ground.

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Теоретичне обґрунтування оцінки забруднення поверхневих водних ресурсів підземним стоком внаслідок воєнних дій

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Анотація. Воєнні дії на території України спричиняють негативний вплив на якість водних ресурсів внаслідок попадання забруднених стоків в підземні горизонти через руйнацію та/або пошкодження очисних споруд. В даній роботі розглянуті питання визначення теоретичних підходів до кількісної оцінки надходження забруднень до поверхневих водних ресурсів через підземне живлення внаслідок пошкоджень захисних екранів в ставках накопичувачах різного роду та водосховищах.

Відмічено розповсюдження забруднень при пошкодженні екрана в три етапи: промочування зони аерації з пошкодженого облицювання на поверхню підземного потоку; нестаціонарне підняття рівня ґрунтових вод з утворенням водного куполу; стала фільтрація в сторону розвантаження підземного потоку.

Розглянуто задачу втрати п’єзометричного напору при проходженні фільтраційного потоку через конструкцію екрана та визначення на основі цій величини витрати забруднених вод із зазначеної споруди. Приведено аналітичне рішення задачі промочування зони аерації з пошкодженого облицювання на поверхню безнапірного підземного потоку. З врахуванням збільшення коефіцієнту проникності екрану внаслідок пошкоджень, збільшення трещінуватості, поривів, встановлено, що при його значенні більше, або дорівнює $1{,}0*10^{-2}$м/добу, дію захисту екрану можна не враховувати, а витрати фільтрації розраховувати за відомими формулами інфільтрації із очисної необлицьованої споруди. Запропоновані підходи на різних стадіях фільтраційних втрат з очисної споруди в подальшому можуть лягти в основу розробки методів розрахунку міграції забруднень з урахуванням різних джерел їх надходження в грунтові води в залежності від ступеня пошкоджень екранованих очисних споруд.

Ключові слова: вплив воєнних дій, якість водних ресурсів, підземне живлення, екрани очисних споруд.