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Optimization of hydrogeological monitoring in the coal-mining region of Western Donbass

Halyna Yevhrashkina[1], Mykola Kharytonov[2,4], Elena Shikula[3] and Svitlana Lemishko[2]

[1]Oles Honchar Dnipro National University, Haharin Ave., 72, Dnipro, 49010, Ukraine
[2]Dnipro State Agrarian and Economic University, Serhii Yefremov Str., 25, Dnipro, 49600, Ukraine
[3]State University of Telecommunications, Solomenska Str., 7, Kyiv, 03680, Ukraine

[4]Corresponding author: kharytonov.m.m@dsau.dp.ua

Abstract. The results of the solutions for assessing the degree of reliability compared with the results of regime observation network, water balance hydrogeological stations and key sites created for it. Epignous tasks occupy a special place in the optimization of hydrogeological monitoring of coal-mining regions. The "disordered dispersion" scheme should recognized as the most reliable after numerous numerical experiments to solve the problems of assessing the technogenic pollution of groundwater in the conditions of Western Donbas. The direct forecasting problem for various periods before the stabilization time was determined and solved at the final stage.

1. Introduction

Numerical models are powerful tool to solve the number of ground water related problems associated with mining and mine closure [1]. However, specific features require a deep understanding of the mining environment [2].

Several models developed for the task of simulating the flooding of large underground mines and the associated rebound of the groundwater table [3]. It concluded that groundwater modelling based on realistic assumptions on hydrogeological structure, boundary conditions, recharge and discharge areas can used as valuable tool for verification of the conceptual models accepted. There are four different process models, which integrate ground and surface water processes [4]. These models were compared based on own data requirement, desired complexity level, their ability to simulate relevant hydrologic and hydraulic processes. The MODFLOW program based on the finite difference method [5] and the FEFLOW program based on the finite element method [6] used the most extensively in mining hydrogeology. Meantime the numerical flow modelling has become an important tool to estimate the groundwater inflows into coalmines [7-8]. The key problem in numeric modelling is the parameters in case of lack of field data. The groundwater management model of a coal mining area developed to optimize mine life cycle [9]. The results of this case study show that the economic - hydraulic management model can be useful in solving the multi-factor problems of mine drainage, water supply and environmental protection for coalmines. The well-known classification of hydrogeological forecasts made according to their destination and has a hydrogeological - meliorative orientation [10]. The proposed classification include next kinds of hydrogeological forecasts: a) the forecast for the zone of azation and complete water absorption belonging to the object of research; b) the forecast by the type of hydrogeological process (moisture transfer, filtration, mass transfer); c) short-term and long-term forecasts by the duration of the predicted processes in time; d) the forecasts according to the spatial characteristics of the studied territory within the zone of influence of one regime of the disturbing object and quantitatively characterizing the total impact of all technogenic factors of the mining region. The forecasts for operating and projected man-made objects were distinguished by the method of obtaining the initial data. A feature of predicting the regime of groundwater in the zone of influence of operating technogenic objects is the possibility of using regime observations to determine hydrodynamic and migration parameters due to lack of initial information. The most relevant problems in the Western Donbass coal-mining region are the rise in the level of underground waters, their pollution, flooding of settlements and productive land [11]. The main difficulties making complicated accurate comparisons between calculated and field data are following: a) changes in parameters of mining and pumping rates of water used for local needs; b) hydrological changes including formation of new channels, bed deformation; c) transformation of the monitoring network; d) increasing leakage through the clayey bottom of the ponds. The main objective of this study was to work out the bases for optimization of hydrogeological monitoring in the coal-mining region of Western Donbas.

2. Methods

The scheme of a regime observation network, consisting of observation wells (1-2-3), based on a hydrodynamic grid, was proposed to assess the impact of the "Balka Stukanova" mine water storage pond on the environment conditions (figure 1).

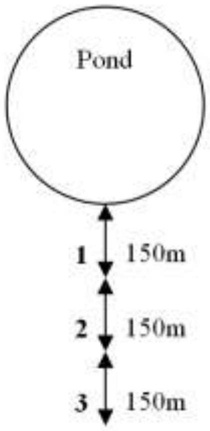

Figure 1. The scheme of the regime observation network.

Hydrogeological monitoring is a complex, dynamic, multi - stage, spatio - temporal, natural - technical system of control and management of the groundwater regime with feedback between control and management. This system includes several sections as following:

a) observations in space and time for the regime of underground waters of technogenically disturbed territory;

b) solution of all types of hydrogeological problems for the scientific substantiation of a complex of hydrogeological environmental protection measures based on specially created mathematical models of changes in hydrogeological conditions;

c) development of a complex of environmental protection measures based on the analysis of the results of solving predictive hydrogeological problems;

d) implementation of environmental protection measures;

e) evaluation of the effectiveness of environmental protection measures and their adjustment;

f) repeated control of their sufficiency and effectiveness or the implementation of feedback between control and management.

The minimum number of wells is one. A single regime well characterizes a natural or disturbed hydrogeological process in time only at one point of the study area. However, a single observation is not informative for the following reasons. It does not characterize movement in space and cannot recreate one that describes a hydrogeological process. A straight line drawn from two observations in space. A straight-line depression curve is a dubious or even improbable variation of a natural hydrogeological process. The structure of the regime observation network should ensure the control of the groundwater regime and the use of observation results to determine the hydrogeological parameters used as initial data in solving forecast problems with the maximum degree of reliability.

The complex of hydrogeological calculations is the second part of a permanent regional, multifunctional task, limited in space and infinite in time. Epignosis is a characteristic of the hydrogeological process in the past tense, determined by regime observation. An epignosis procedure is necessary to confirm its correctness or to question it, and then clarify the information (boundary conditions, hydrogeological parameters), which will be used as initial data for a predictive assessment of development in time and space for the current hydrogeological situation.

3. Results and discussion

Geofiltration and migration processes in natural and antropogenically disturbed conditions described by differential equations of the second order in partial derivatives of elliptic (Laplace, Poisson) and parabolic (Fourier) types. They determine the shape of the depression curve to characterize the development of a hydrogeological process in space with such a mathematical description.

The number of observation wells within each selected landscape element along the flow of groundwater should be at least three and across the flow, if the presence of anisotropy is proven. This criterion preserved even in the simplest hydrogeological conditions when determining the geofiltration and migration parameters.

An example considered for a parabolic equation:

$$T\frac{\partial^2 H}{\partial X^2}+\varepsilon=\mu\frac{\partial H}{\partial t}, \tag{1}$$

where T is the water conductivity, m^2/day; H – hydrodynamic head, m; x – spatial coordinate, m; ε – infiltration nutrition, m/day; μ – coefficient of hydrocapacity, unit fraction; t – time coordinate, days. Parameters and hydrodynamic heads in wells 1, 2, 3 are determined in the first section. Infiltration nutrition must be determined for it. In this regard, we write equation (1) in finite differences:

$$T\frac{H_1^\tau-2H_2^\tau+H_3^\tau}{(\Delta x)^2}+\varepsilon=\frac{\mu\cdot\left(H_2^{\tau+1}-H_2^\tau\right)}{\Delta t}. \tag{2}$$

In equation (2) – time indices of the previous and next time point. Initial data: $H_2=73.7$ m; $H_3^\tau=70.2$ m; $\Delta x^\tau=1000$ m; $\Delta t=30$ day; $\mu=0.1$; $H_2^{\tau+1}=74.4$ m; $T=80$ m^2/day.

Determination of infiltration recharge in the second part of hydrogeological monitoring is an inverse problem. The second mandatory inverse task of the second part is to determine the filtration rate using Darcy's law. Wells with conditional numbers 1, 2, 3 are located on a flow line directed from the centre of the dam and flowing into the "Mala Ternivka" river at a right angle at a water surface elevation of 63.45 m. The filtration coefficient was determined in the field by the Pavlograd geological exploration expedition. The formula for Darcy's law is:

$$V=k\cdot I, \tag{3}$$

where V is the filtration rate, m/day; I – pressure gradient, dimensionless value, k – filtration coefficient, m/day.

$$I=\frac{H_1-H_2}{\Delta x},\ \text{or}\ I=\frac{\partial H}{\partial x}, \tag{4}$$

Thus, $V = 0.0064$ m/day. The groundwater contamination as a result of filtration losses of highly mineralized mine waters of the processing plant is relevant for this territory. Regime observations for three wells, which quantitatively characterize the change in groundwater salinity, make it possible to determine an important parameter of mass transfer following the analytical dependence of Verygyn [12]. It looks like this:

$$D = \frac{V \cdot \Delta x}{\ln(\bar{c} - 1)}; \quad (5)$$

where $D-$ the macrodispersion coefficient, m^2/day; $\bar{c}-$ normalized concentration of groundwater salinization:

$$\bar{c} = \frac{c_1 - c_3}{c_1 - c_2}, \quad (6)$$

where c_1, c_2, c_3 – are the mineralizations of groundwater at three points of the underground flow, located at a distance from each other (g/dm^3).

$D = 10.6$ m^2/day, because of substitution of all initial data in formula (5) which corresponds to the calculated migration scheme "disordered dispersion". This scheme gives reliable results if the fundamental solution of Karslow - Yeager used in the direct problem [13], which ensures the best agreement of the calculation results with the regime observations. The results of solving the epignous problem shown in figure 2.

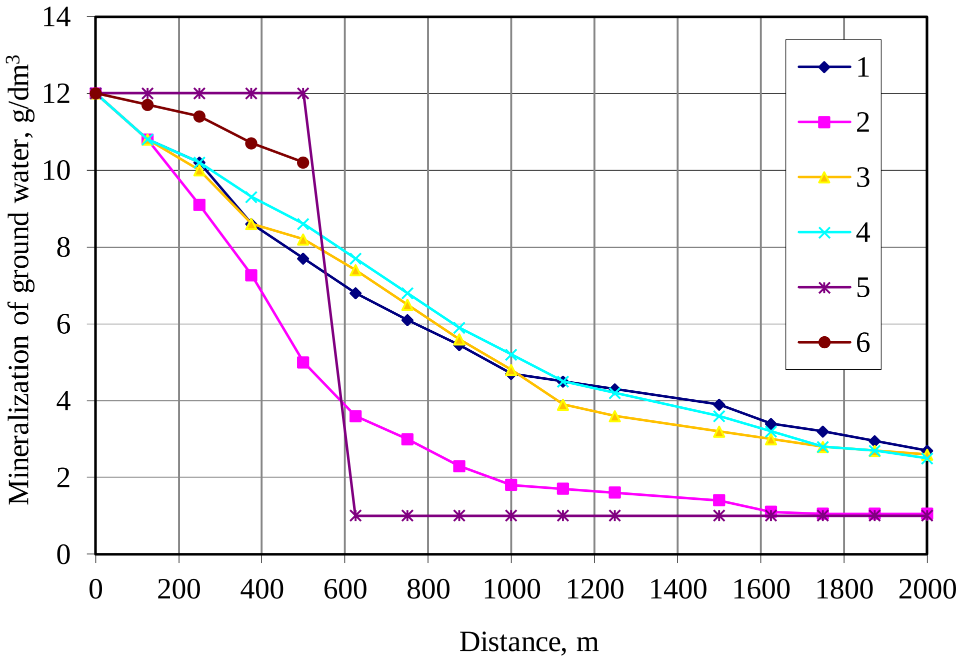

Figure 2. Epignous calculation along the alignment of the pond "Stukanova Balka" - the "Mala Ternivka" river: 1 – regime observations; 2 – $D = 3.0$ m^2/day; 3 – $D = 25.0$ m^2/day; 4 – $D = 30.0$ m^2/day; 5 - piston displacement; 6 - Loverier scheme at microdispersion coefficient $Dm = 5 \cdot 10^{-5}$ m^2/day.

It follows that the schemes of "piston displacement" and Loverier for the study area are inappropriate to use according to the results of solving the inductive problem. The direct task in mining regions consists of two parts: forecasting the regime of the groundwater level and pollution or changes in their mineralization and chemical composition over time under the influence of a complex of technogenic factors. An analytical solution by the method of superposition of a parabolic equation most often use to predict the groundwater level regime.

In particular, the Fourier equation describes the movement of groundwater in a homogeneous aquifer in an unsteady filtration regime in the absence of additional internal sources of power or unloading. In a one - dimensional version, it looks like:

$$\frac{\partial^2 H}{\partial x^2} = \frac{1}{a} \cdot \frac{\partial H}{\partial t}, \quad (7)$$

where $H-$ is the absolute value of the hydrodynamic head, m; $x-$ spatial coordinate in the Descartes system, the distance of the calculated point from the origin of coordinates, m; $a-$ conductivity level coefficient for free flow, m^2/day; $t-$ forecast period, days.

Equation (7) has several analytical solutions for various hydrodynamic schemes. For the design scheme "semi - boundary layer", the analytical solution obtained by the superposition method and has the form:

$$\Delta H = \Delta H^0 \operatorname{erfc} \frac{x}{2\sqrt{a \cdot t}}, \quad (8)$$

where $\Delta H = \Delta H_1 - \Delta H_2$, m; ΔH_x – increment of hydrodynamic head at the design point, m; ΔH^0 – the difference in the absolute values H_1 of the hydrodynamic heads in the feeding area and the unloading area H_2, m; H_1, H_2 – respectively, the absolute elevation of the water surface in the mine water storage pond and the "Mala Ternivka" river at the point where it crosses the current line with three observation wells 1-2-3 (see figure 1). This mark is located in the centre of the study area with the origin at the middle of the dam. The calculation results shown in figure 3.

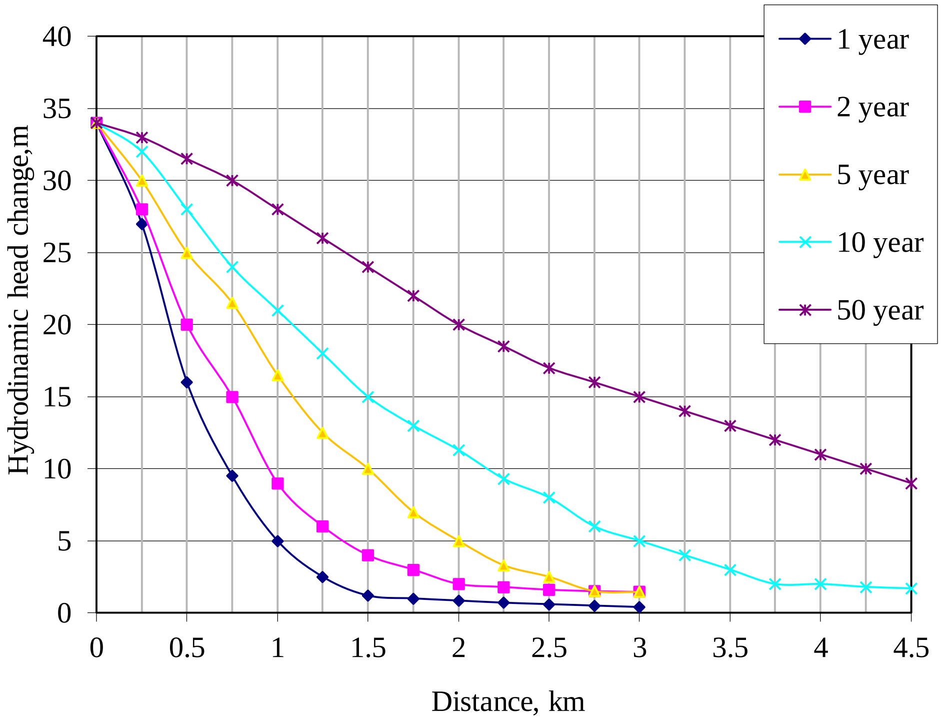

Figure 3. Results of the forecast of the groundwater level regime.

From the results of the calculation it follows that the salty water from the storage pond "Balka Stukanova" will begin to flow into the "Mala Ternivka" river after five years of operation. The maximum period of forecast calculation of 50 years is equal to the duration of the planned operation of this mine water accumulator.

The filtration and migration models were tested to assess changes in the hydrogeological conditions in the area of local man-made objects impact: ponds - mine water accumulators, a processing plant, mine dumps in the conditions of the coal - mining region of Western Donbas [14].

Several types of hydrogeological problems were solved for these arias. The inverse problem is associated with the determination of hydrogeological parameters from the data of regime observations. An inductive model using for multivariate calculations of analytical or numerical solutions of differential equations of filtration and mass transfer allows the most reliable description of the hydrogeological process in the study area. The first most realized part of hydrogeological monitoring - the regime observation network at the beginning is only one component. The principles of its placement and functioning at various objects of anthropogenic impact are descriptive [15-17]. A stochastic justification of the number and optimal location of observation wells has been proposed using variograms and interval correlation [18]. The results of the solutions for assessing the degree of reliability are compared with the results of regime observations. The calculation errors were estimated. Epignous tasks occupy a special place in the optimization of hydrogeological monitoring of coal-mining regions. They are solved if there is no doubt about the correctness of the choice. Epignous is a characteristic of a hydrogeological process in the past tense, already studied by regime observations. The coincidence of the results is a reliable argument for the high reliability of subsequent forecast calculations and control [19]. Inverse problems, following the epignous ones, make it possible to refine the boundary conditions. The direct forecasting problem for various periods before the stabilization time was determined and solved at the final stage.

4. Conclusions

Hydrogeological monitoring for each mining region has own characteristics. Solving the problems of vertical mass transfer is not relevant for areas where flooding is the main problem. In this case, it is enough to solve this case study using the filtration mathematical model. Well theory can be effectively used to calculate mine drainage.

The most reliable as a result of numerous numerical experiments of the task of assessing the technogenic pollution of groundwater in the conditions of Western Donbas should be recognized as the "disordered dispersion" scheme. The "disordered dispersion" scheme should be recognized as the most reliable after numerous numerical experiments to solve the problems of assessing the technogenic pollution of groundwater in the conditions of Western Donbas.

References

[1] Surinaidu L, Gurunadha Rao V V S, Srinivasa Rao N and Srinu S 2014 *Water Resources and Industry* **7-8**
[2] Surinaidu L, Gurunadha Rao V V S and Ramesh G 2013 *Arabian J. Geosci.* **6** (4)
[3] Rapantova N, Grmela A, Vojtek D, Halir J and Michalek B 2007 *Mine Water Environ* **26**
[4] Waseem M, Kachholz F, Klehr W and Tränckner 2020 *J. Apl. Sc.***10** 1281
[5] McDonald M G and Harbaugh A W 2003 *Groundwater* **41**
[6] Diersch H J G 2014 *Mass and Heat Transport in Porous and Fractured Media* (Berlin, Germany: Springer)
[7] Yonger P L and Harbourne H J 1995 *Water Environ. Manage.* **9** (4)
[8] Sherwood J M and Younger P L 1997 Modeling groundwater rebound after coalfield closure *Groundwater in the Urban Environment* (Problems, Processes and Management, vol. 1) ed P J Chilton et al.
[9] Wu Q, Hu B X, Wan L and Zheng C 2010 *Hydrological Sciences Journal – Journal des Sciences Hydrologiques* **55** (4)

[10] Zhernov I Ye, Sytnykov A B and Muromtsev N N 1972 Metodyka y resultaty polevykh issledovaniy usloviy vlagoperenosa na oroshaeyemom uchastke. *Mater. mezhvedomstv. sovesch. po meliorativnoy gydrogeologogii i inzhenernoy geologyi.* Moskva **2** 42-7

[11] Yevgrashkina G P, Rudakov D V, Kharytonov M M 2009 Environmental Protection Measure Assesment in Affected Area of Ponds Collecting Waste Mine-water in Western Donbass *Optimization of Disaster Forecasting and Prevention Measures in the Context of Human and Social Dynamics* ed I Apostol et al. (Amsterdam - Berlin - Tokyo - Washington, DC: IOS Press) pp 122-9

[12] Verygyn N N, Vasylyev S V, Sargsyan V S, Serdjukov B S 1979 *Metody prognosa solevogo rezhima pochv y podzemnykh vod* (Kolos)

[13] Karslow G K and Yeager D 1964 *Teploprovodnost Tverdykh Tel* (Moskva: Nauka Press)

[14] Ognyanyk N S 1983 *Postoyanno deiystvuyschie modely hydrologycheskykh protsessov (na prymere yuga Ukrainy)* (Kyiv: Naukova dumka)

[15] Gamburtsev A G 1994 Kontsesptsiya monitoringa prirodo-tekhnicheskikh system *Geoekologiia* (Moskva: Nauka) pp 12-9

[16] Yevgrashkina G P 2003 *Vplyv gyrnychovydobuvnoyi promislovosti na gydrogeologychny ta gruntovo –klioratyvny umovy terytoryi.* (Dnipropetrovsk: Monolyt)

[17] Perkova T I and Rudakov D V 2014 *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu,* **5** 5-10

[18] Navarro A A 1993 *Boletín geológico y minero* **104** 3

[19] Kharytonov M, Pashova V, Lemyshko S, Yevgrashkina G and Titarenko O. 2021 Geospatial Assessment of the State of the Samara River Floodplain in the Area of Coal Mining in Western Donbas. *Agrology* **4** 2 93-7