THE POLLUTION PHENOMENON MODELLING OF THE UNDERGROUND WATER

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Abstract: The industrial waste deposits determine an increased pollution of underground waters. The paper presents the modeling of pollution phenomenon of underground water in an industrial waste deposit area. The pollution phenomenon is analyzed in time, during the period of the deposit exploitation and conservation. The results obtained through modeling allow the application of some environment protection measures. The numerical simulations achieved for different scenarios and for a certain period of time can appreciate the dispersion of a pollutant in a carrier of water. The numerical simulation used the FEFLOW program package. The simulation model through the FEFLOW program package has allowed the analysis and the methods of underground waters depollution for a certain determined period of time.

Introduction

Waste products represent one of the most acute problems of environment protection in the current stage of economic and social development. In Romania, large quantities of waste products are generated because of the economic development, growth of production and consumption.

The inappropriate management of industrial waste and their deposits determines numerous cases of air, soil and underground pollution, with a negative impact on the environment and population health. Of the total volume of waste produced in Romania, about 97.98 % is of industrial and agricultural type and only 2.3 % of such waste of other nature.

The mass of deposited waste represents the main source of pollution of soil, underground waters and surface waters in certain cases, from the area of the placement of deposits and industrial waste stock-piles, both directly, by changing

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the use of the occupied land, and indirectly, through the contamination of neighboring surfaces. The soil is the most stable environment factor, which keeps the traces of pollution for a long period of time. Soil pollution implicitly leads to the pollution of the underground water.

Waste disposal on land is the main solution found for waste disposal industry in Romania. Over 80% of wastes generated in Romania are stored each year. In time a large amount of waste accumulated in the existing landfills. Currently in Romania there are 951 industrial warehouses which occupy over 11,000 hectares [Balan, 2010].

Industrial landfills in the conservation and exploitation and to be designed or implemented must comply with European legislation transposed into the Romanian legislation.

1. Mathematic and hydraulic model of pollutants transport

Numerical simulation of the dispersion of pollutants in the landfill and adjacent aquifer consists of solving a 2D isothermal flow and transport in phase in an aquifer, the horizontal distribution of surface source of fluid and pollutant. Hypothesis implies that the aquifer water level does not exceed the upper surface which limits the aquifer [Balan, 20101].

We have chosen a model of pollutant transport type, applicable first of all to the flow processes through porous unsaturated/saturated media, in stationary / transitory regimes, and secondly to processes of miscible /non-miscible pollutants transport from porous unsaturated/saturated media, in transitory regime.

The mathematical model is customized according to the conceptual model and includes the specification of the area and its border, the basic equations of flow and transport of substances.These mathematic models consisted in:

- non-governing equations (also called basic) of the flow and/or transport processes;
- initial conditions (only for the processes dependent of the time *t*);
- contour conditions.

The equations governing the flow consist of the equations of the fluid mass balance – named also the continuity equation and, respectively, moment equation, the famous Darcy's equation, generalized to non-saturated porous media; these can be presented under the following general form [Voss, 1984]:

$$\frac{\partial\left(n\cdot S_w\cdot\rho\right)}{\partial t}=-\nabla\cdot\left(n\cdot S_w\cdot\rho\cdot\mathbf{v}\right)+Q_p\rho \tag{1}$$

$$\mathbf{v}=-\left(\frac{\underline{\underline{\mathbf{k}}}\cdot k_r}{n\cdot S_w\cdot\eta}\right)\left(\nabla p-\mathbf{g}\cdot\rho\right) \tag{2}$$

where the symbols present the following significations: $n = n\ (x,y,t)$ porosity; $\rho = \rho\ (T(x,y,t))$ water density, temperature dependency T; v = v(x,y,t) average speed vector of the fluid (water) through the pores of the porous medium; $Q_p = Q_p(x,y,t)$ the intensity of the distributed (punctiform) source of volume (specific debit) of fluid; $\eta = \eta(T(x,y,t))$ dynamic viscosity of water, dependent on the T temperature; $p = p\ (x,y,t)$ fluid pressure from the pores (the relative pressure in relation with the atmosphere pressure; the manometric pressure for $p \geq 0$ or the vacuum manometer pressure $p \leq 0$); g = g (x,y) vector of the gravitational acceleration.

The equations governing the flow and transport of substances result [Balan, 2010]:

- Darcy's equations

$$\bar{q}_x = -K\left(H - z_b\right)\frac{\partial H}{\partial x},\ \bar{q}_y = -K\left(H - z_b\right)\frac{\partial H}{\partial y} \tag{3}$$

- the equation of continuity

$$S\frac{\partial H}{\partial t} + \frac{\partial \bar{q}_x}{\partial x} + \frac{\partial \bar{q}_y}{\partial y} = \bar{Q}_\rho, \tag{4}$$

were the detailed specifications of the parameters is presented in [Balan, 2010].

Contour conditions were defined for the flow and pollutant transport. The definition relations for each of the classical types of contour conditions are:

1º *type 1 contour conditions* (Dirichlet), in which are given the values of the dependent H variable on the frontier,

$$H(x,y,t) = H_{\Gamma_1}(t),\ (x,y,t) \in \Gamma_1 \times \left[t_I, t_F\right] \tag{5}$$

2º *type 2 contour conditions* (von Neumann), in which are given the values of the H size flow, according to the ***n*** direction of the normal to the Γ frontier, flow marked with $q_{n_H}(x,y,t)$:

$$-e_{ij}\cdot\frac{\partial H}{\partial x_j}\cdot n_i = q^R_{H\_\Gamma_2}(t),\ (x,y,t) \in \Gamma_2 \times \left[t_I, t_F\right] \tag{6}$$

where, according to the rule of mute indices, for $i, j \in \left\{x, y\right\}$.

3° *type 3 contour conditions* (Cauchy), when the values of the flow $q_{n_H}(x,y,t)$ depend also on the H variable, according to a law considered as linear:

$$-e_{ij}\cdot\frac{\partial H}{\partial x_j}\cdot n_i = -\Phi_{H\_\Gamma_3}\left[H^R_{\Gamma_3}(t) - H\right],\ (x,y,t) \in \Gamma_3 \times \left[t_I, t_F\right] \tag{7}$$

The initial condition for the transport problem imply the knowledge of baseline $t = t_I$ (usually $t_I = 0$) the value of the dependent variable C at any point (x, y) in the field and are of the form [Balan, 2010]:

$$C\ (x, y, t) = C_I(x, y) \text{ for } t = t_I \text{ and } (x, y) \in \Omega. \quad (8)$$

where $C_I(x, y)$ is the initial distribution of concentration.

The initial conditions for the flow refers to piezometric H share knowledge in the baseline points (x, y) in the analysis domain.

$$H(x, y, t) = H_I(x, y) \text{ for } t = t_I \text{ and } (x, y) \in \Omega \quad (9)$$

For solving the proposed problems, we achieved a conceptual model, for which we elaborated a mathematic model of pollutants transport. The mathematic model represents the flow and transport of pollutants from one layer of underground water from the analysis field. In the analysis, we used a complex of basic data specific to the case study. The data introduced in the calculation model come from systematic measurement in 13 observation wells positioned in the location of the industrial waste deposit.

The numerical simulations achieved for different scenarios and for a certain period of time can appreciate the dispersion of a pollutant in a carrier of water.

For the numerical simulation, we used the FEFLOW program package.

2. Experimental results

We used in the analysis a complex of basic data specific to the case study (industrial waste deposit of the “Rulmenti Barlad”, fig. 1, 2 and 3). The observation period regarding the underground water layer was between 2005-2009. In this period, we collected data regarding the pollution phenomenon parameters. For the prognosis, we considered a period of 10 years, respectively 2010-2019. The analysis carried out on the main pollutant substances indicated for the first prognosis stage the consideration of the anion from the NH_4 ammonium.

The numerical simulation using the FEFLOW program package requires going through three distinctive stages [Luca, 2010]:

- pre-processing of the basic data,
- the effective processing of basic data,
- the post-processing of the resulting data.

We successively treated a flow problem in four scenarios and two flow and transport problems (in total 6 calculation variations):

1. The flow problem for the study duration, $t \in [0, 1825]$ days (01.01.2005 – 31.12.2009) in four scenarios regarding the functioning of drillings from the area of the closed deposit (for establishing the optimal scenario)

1.1. Without pumping;

1.2. With pumping from the drillings P1 (P.O. 14) and P2 (P.O. 15);

1.3. With pumping from the drilling E2 (P.O. 23);

1.4. With pumping from the drillings E1 (P.O. 24) and E2 (P.O. 24).

Fig. 1 - Deposit of industrial waste in conservation status.

Fig. 2 - New industrial waste deposit.

Fig. 3 - Observation well.

2. The flow and transport problem for the study duration, $t \in [0, 1825]$ days (01.01.2006-31.12.2009), in the scenario established as being optimal within the flow problem (for monitoring the pollution phenomenon in all the interest points from the domain Ω (fig. 4).

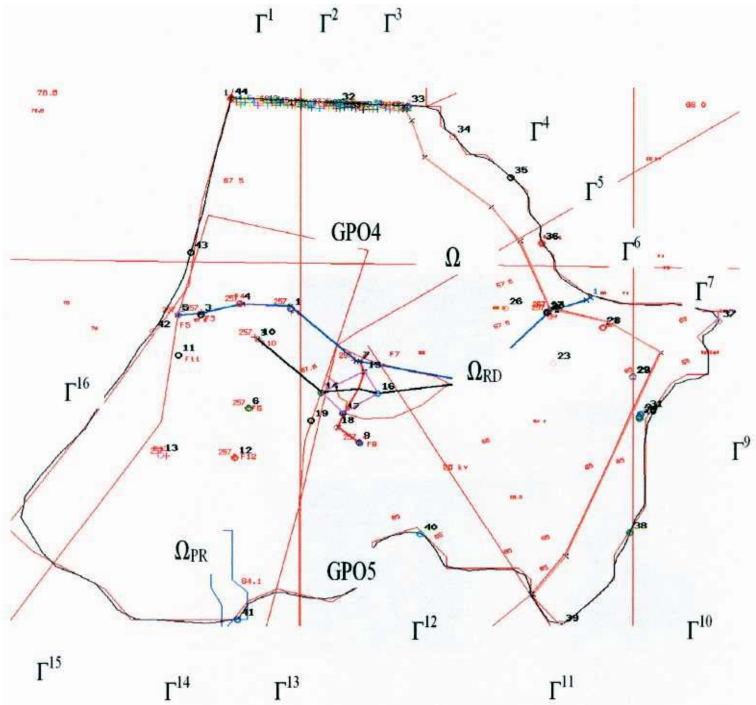

Fig. 4 - Domain of analysis Ω (with sub domains Ω_{PRB} and Ω_{RD}), domain boundary Γ (with divisions $\Gamma^1, \Gamma^2,\dots \Gamma^{16}$) and reference items: 44 point of observation, PO (1, 2, …, 44), 5 profiles-section (1-1, 2-2,…, 5-5) and 2 out of 9 groups of observation points, GPO (GPO.4 and GPO.5).

3. The flow and transport problem in the perspective of the following decade, $t \in [0, 1825]$ days (01.01.2010-31.12.2019), in the scenario established as being optimal within the flow problem 1 and through the simulation of the contour conditions and variation of the material parameters (for the prognosis of the evolution of the pollution phenomenon in all the interest points from the domain Ω).

The study data were pre-processed, regarding:

A. The natural environment (topographic – the layout plan of the study area; climatic – precipitations and evapo-transpiration; hydrological – levels and discharge rates in the hydrometric stations; hydro-geological – levels of the underground water and the depth of the basic layer, impermeable, of the carrier of water in the observation drillings and the material constants of the aquifer layer regarding the processes of mass flow and transport);

B. The analyses regarding the qualitative indicators of the soil and underground water and from the rivers;

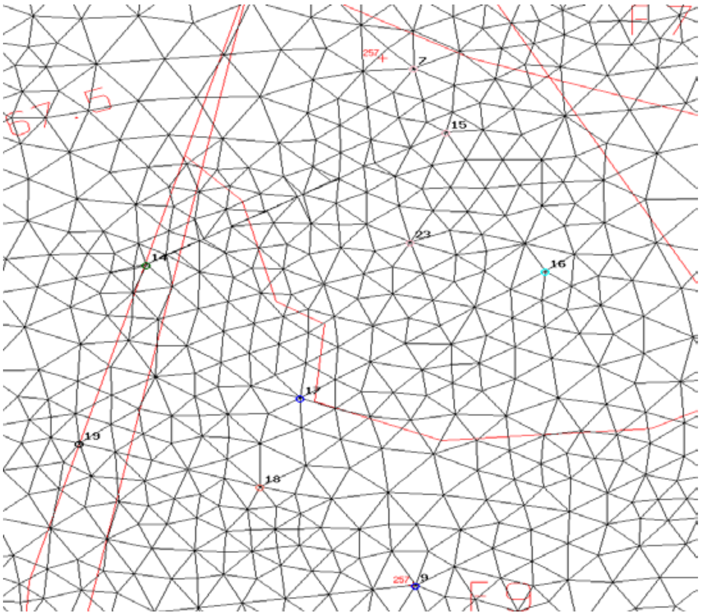

Fig. 5 - EF scheme in the study area waste industrial dump.

Tab. 1 - Fluid flows (water with dissolved pollutants) entry into and exit from the closed landfill area at time t=1825 days

No.	Interval time simulation problem (days)	Inflow (m^3/d)	Outflow (m^3/d)	Balance (m^3/d)
1	2	3	4	5=3x4
1	**1.1**, [0.1825]	26.791	15.029	11.762
2	**1.2**, [0.1825]	45.744	4.954	40.790
3	**1.3**, [0.1825]	94.984	1.732	93.252
4	**1.4**, [0.1825]	104.025	1.078	102.947

C. The quarterly rate of waste depositing (garbage, industrial non-recyclable wastes- emulsions, slime, ash, cinder etc.) and the monthly rate of sediment powders upon emission and their concentration in NH_4.

After pre-processing this study data, we determined the concrete numerical constants for the entry parameters and elaborated the input data files in the FEFLOW program package.

Data obtained and presented in figures allowed qualitative analysis and comparison of the four scenarios regarding the operation of the landfill closed wells and power lines in the spectrum of the area. The analysis show that in scenario d) flow out of the store is closed the lower intensity.

Comparing data from Table 1, column 4, results as optimal scenario the 1.4: the pumping of wells E1 and E2 [Balan, 2010].

For optimal scenario 1.4 were post-processed the data files on the computer program for the time period [0, 1825] and representative calculation times $t \in \{365, 956\}$. Numerical simulation results showed transport of pollutants in the analysis domain and the time considered (fig. 6 and 7).

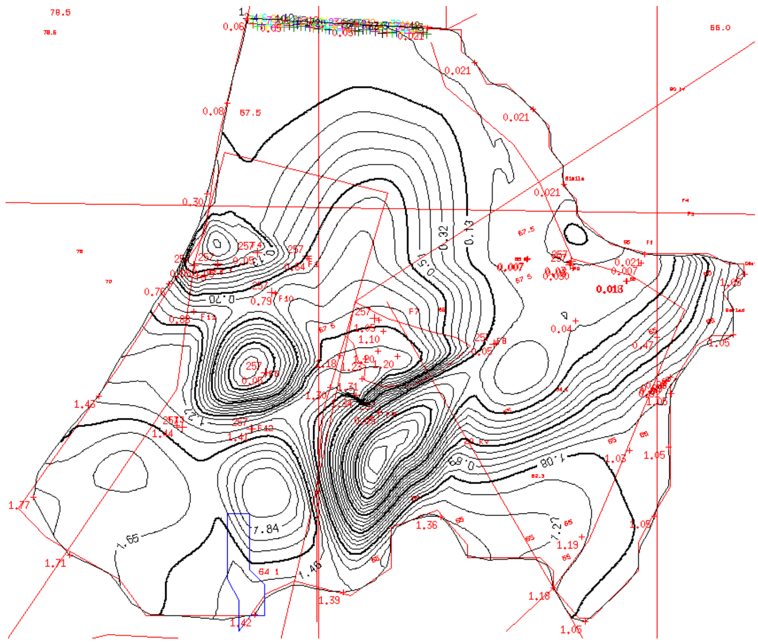

Fig. 6 - The NO_4 initial concentration (t = 365 days, on 01.01.2006) represented by isolines of equal concentration.

A part of the accidentally polluted water sources can be subject to a depollution process, of certain duration, in order to be reintroduced in the circuit of water supply for either industry or population.

Through the analysis and prognosis model conceived, we attempted a response to this problem that has been affecting, lately, the underground environment, more and more stringently.

In order to determine the evolution of the pollution process in the entire interest field, we can only make interpolations on bi-dimensional fields, according to certain mathematic techniques accepted in this field.

The intensity of the evacuation process of a pollutant soluble in water (NH4, in the present study), through pumping at a constant rate, decreases to the diminishment of its concentration in the carrier of water, and in order to obtain /maintain an acceptable intensity of this process, the pumped debit must be increased, or certain processes of the pollutant biotransformation be activated.

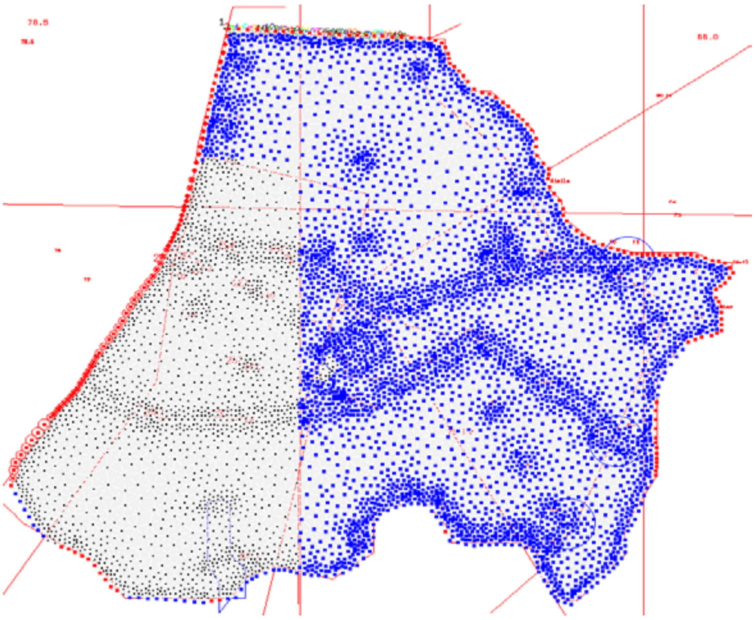

Fig. 7 - The balance of fluid flows (water dissolved pollutants), complex and domain boundaries *t* = 365 days (in red – the input streams and blue – flows out).

Similarly post processing was performed for flow and transport problems 2, 3 and 4. The obtained results revealed the best scenarios for each case analyzed.

The method of recovery of groundwater quality parameters (pumping wells) involves little investment. Remediation requires a minimum number of wells on the site.

Conclusions

The interpretation of the data obtained allows the enunciation of the following general conclusions:

1. The simulation model elaborated allows the analysis of the pollutant transport in the area of underground waters by emphasizing the variation of concentrations in time and space.

2. The simulation model through the FEFLOW program package has allowed the analysis and the methods of underground waters depollution for a certain determined period of time.

3. Using the numerical simulation techniques, we can solve both the problems regarding the monitoring of the pollution process for the entire duration of the experimental measurements (approached problems, but insufficiently solved through the current monitoring techniques), but also the future evolution, on the extended periods, in different scenarios, of the pollution and/or depollution processes.

4. Groundwater remediation can be achieved by hydraulic methods (pumping wells) in a period of time.

5. The simulation model can also be generalized for similar situations in the industrial waste deposits.

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