MODELING OF THE CONTAMINANTS DIFFUSION IN GROUNDWATERS IN THE AREA OF TMFS

Sotir Plochev*,Anatoliy Angelov*,Svetlana Bratkova* and Rosen Ivanov*

** - University of Mining and Geology "St. Ivan Rilski", Department of Engineering Geoecology, 1700 Sofia, Bulgaria, e-mail: plo4ev@mail.bg*

ABSTRACT: Mathematical model studies were provided for the area of TMF(tailing management facility) for mining wastes located in a real mining site in the central part of Bulgaria. It was developed a current hydrogeological three-dimensional (3D) model for the contaminants migration conditions in the subsurface area and groundwaters. Through the designed 3D model is performed a medium-term forecast of dynamics, scope and intensity of groundwater pollution with typical anthropogenic pollutants - sulphates (SO_4), chloride (Cl), iron (Fe), copper (Cu), cadmium (Cd), nickel (Ni) and arsenic (As). Based on the predicted results from the model was possible to assess the natural protection and self-cleaning abilities of the geological environment and the environmental risk of permanent contamination of aquifers.

KEY WORDS: groundwater pollution, 3D model

1. INTRODUCTION

The studied area is in the central part of the Zlatishko-Pirdopska valley. The mine is situated in the south slopes of the Balkans, and on the north part of the Zlatishko field, part of the Zlatishko-Pirdopska valley. The waste water dump is built about 4 km south of the main constructions. The valley in the studied area is about 5 km wide and has inclination from north to south, towards the river Topolnica. The object is entirely in the water collecting area of river Topolnica, and this river is collector for all surface waters and groundwaters. Another river near the studied area is the river Vozdol. It flows in south direction and mixes with river Topolnica at height of 520 m. The rivers Ilindenska, Begleshka and Ravnishka flows into river Vozdol at height of 800-900 m on the south slopes of the mountain. In the lower Zlatishko field some other rivers pours in Vozdol (Mezerlak dere, Chugovishko dere, Gagalkovo dere).

The ground waters in the region are stored in the cracks of the under laying rocks and in the overlaying pores of the soil. The water collecting rock bed is silicate which means that the waters are ultra fresh (0,1-0,7 g/l) with neutral or slightly acid reaction . The major ions in the water are, SO_4, Ca and Na, and the gas composition includes nitrogen and oxygen.

The main task of the study is to create mathematical model for the area, which will show the ecological impact from the mine.

2. MATERIALS AND METHODS

The basic filtration model can be created with software – MODFLOW. This software was developed by U.S. Geological Survey and by Environmental Protection Agency, USA (McDonald and

Harbaugh, 1988; Harbaugh et al., 2000). This program use approximated decision of the basic equation of the filtration:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_z \frac{\partial h}{\partial z}\right)-W=S_S \frac{\partial h}{\partial t}$$

kx, ky, and kz – filtration coeff. to the three axis [m.T^{-1}]; h - head [m]; W – discharge for unit of volume (gives the source and outflow quantities) [T^{-1}]; S_S – coeff. of elasticity [L^{-1}]; t - time [T].

The created model determinates the elements of the filtration field – the head, the gradients and the speed of filtration v:

$$v_x=-k_x \frac{\partial h}{\partial x}, \quad v_y=-k_y \frac{\partial h}{\partial y}, \quad v_z=-k_z \frac{\partial h}{\partial z};$$

The real speed of the groundwater is $u_x = v_x/n_0$; $u_y = v_y/n_0$; $u_z = v_z/n_0$; n_0 - active porosity.

The migration models can be created with a software made by U.S. Geological Survey и Environmental Protection Agency, USA - MT3D-MS (Zheng and Wang, 1998). The program use numerical decision of the basic equation:

$$R_f \frac{\partial c}{\partial t}=\frac{\partial}{\partial x_i}\left(D_{ij} \frac{\partial c}{\partial x_j}\right)-\frac{\partial}{\partial x_i}\left(u_i . c\right)+\frac{q_s}{n_0} c_s-\gamma\left(c+\frac{\rho_b}{n_0} \bar{c}\right)$$

c – concentration of the pollutants in the groundwater [M.m^{-3}]; ĉ – concentration of the pollutants adsorbed by the media [MM^{-1}]; c_s – concentration of the pollutants in the source and the outflow of the modeled area [M.m^{-3}]; u_i – real speed of the groundwater [m.T^{-1}]; q_s – discharge for unit of volume (gives the source and outflow quantities) [T^{-1}]; t - time [T]; x_i – distance taken from the coordinate axis [m]; D_{ij} – tensor of hydrodynamic dispersion [m^2T^{-1}]; n_0 – active porosity; ρ_b – density of the soil [M.m^{-3}]; γ – coeff. of decaying and disintegrating [T^{-1}]; R_f – delaying factor:

$$R_f = 1+\frac{\rho_b}{n_0} . \frac{\partial \bar{c}}{\partial c}$$

If the eliminating goes according to Henry isotherm, R_f can be found by:

(5) $n_s = n_0 + \rho_b K_d = n_0 + k = n_0 R_f$;

k – parameter of equilibrium sorbtion; n_s – sorbtion porosity; n_0 – active porosity; K_d - coefficient of distribution [m^{-3}M].

3. RESULTS AND DISCUSSION

The prediction model is based on calibrated variants for every one of the pollutants. The forecast is made for 50 year period of time.

The basics simplify for the model are:

- The liquid pollutants enters through the whole bottom of the TMF.
- The pollutant infiltrates without any obstacles.
- The mathematical simulation is made according to the processes of convective movement, reversal elimination (sorbtion), dispersion, molecular diffusion and mixing.

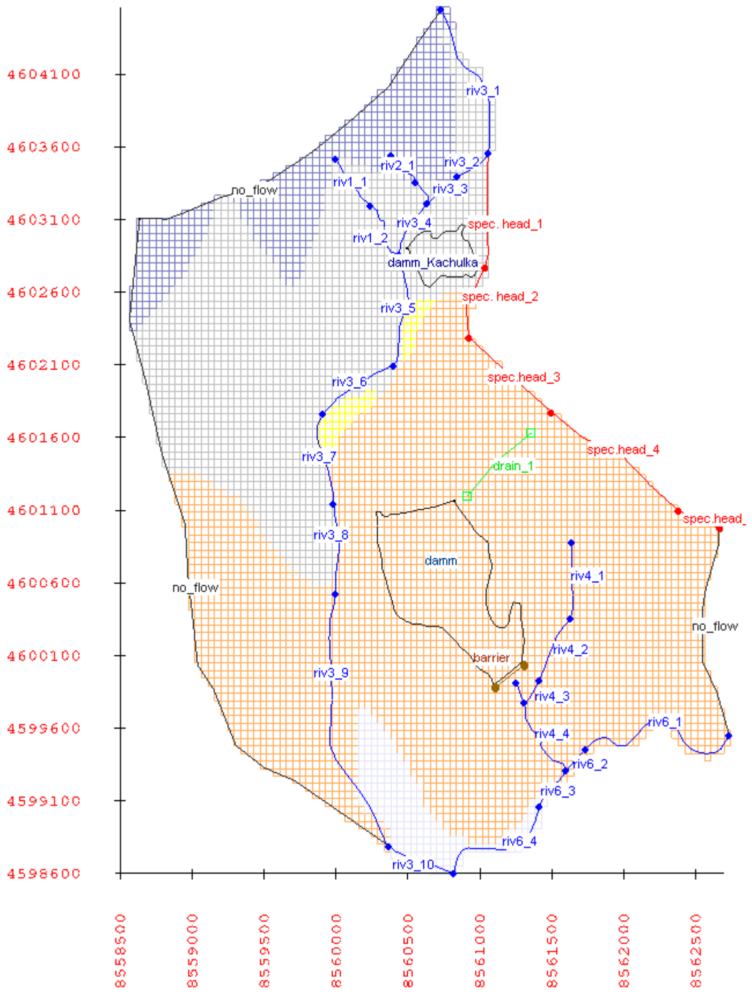

Figure 1. Boundary conditions and internal sources and outflows.

The result of the modeling shows:

- The pollutants migrate in plan (area) and in depth.
- The direction and speed of migration processes are controlled by the structure of the filtration field (the dimensional distribution of the hydraulic heads and gradients). The front of the pollution is moving to south-southwest, following the natural direction of the groundwater.
- In cross-section the vertical movement of pollutants is determined from the concentration gradients (the density differences between the polluted waters and the overlaying pure waters).
- The simulation with the model pollutants (Cl, SO_4, Fe, Cu, Cd, Ni and As) demonstrates very big differences in their behavior. According to their migrating capabilities (mobility) and their dimensional distribution they are separate in three basic groups:

  a) High mobile pollutants (Cl, SO_4);

b) Low mobile pollutants (Fe, Cu, Cd);
c) Very low mobile pollutants (Ni, As)

The first group of pollutants (Cl, SO_4) in practice do not get in contact with the ground particles and are moving with the speed of the filtration flow. The boundaries of the polluted areas are changing fast and can get significant in size. So they mark the maximal possible polluted area – about 1100 m in south-southwest direction from the source. In the same time the biggest level of concentrations are near the source of the pollution, and 200 m from there the concentrations are with legal levels according to the water regulations. The second group of pollutants (Fe, Cu, Cd) are very reactive, they actively interact with the ground and migrate relatively slowly. The areas polluted by them are with smaller sizes and reaches 400-500 m from the polluting source. The third group (Ni, As) are almost entirely held by the filtration media, which predetermine their reduced migration capability. The data from the computer models shows that the polluted areas with those type of pollutants are minor.

4. CONCLUSION

The basic mechanism of the pollutant disperse is the convective movement, but the processes of hydrodynamic dispersion and molecular diffusion are also significant. The pollutants (Cl^- and SO_4^{2-}) do not interact with the ground particles and they move with the same speed as the groundwater flow. The other pollutants (Fe, Cu, Cd, Ni and As) migrates much slower. These characteristics are simulated in the model by entering certain parameters (delaying factor, coefficient of distribution, disperse, coefficient of molecular diffusion), which accurately describes the behavior of each one of the pollutants.

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