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Research on Shaping the Water Flow and Transport into the Soil

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Abstract: Groundwater flow and transport into heterogeneous porous media implies knowing all the hydrogeological parameters of the aqueous stratum. The paper presents the results of a survey conducted in the village of Podişu, Bălţaţi, the county of Iaşi. The values obtained were input data for the BIOF&T program, which allowed shaping the water flow and transport processes of the groundwater in a tridimensional system.

Keywords: ground water, soil, flow, shaping;

1. GENERAL ASPECTS REGARDIND THE MODEL WE USED

For the flow and transport processes shaping as components of ground water flow into heterogeneous porous media, we used the BIOF&T program, which is a model for 3-D and 2-D analysis of finite tridimensional and bidimensional elements for water flow and aqueous phase transport of pollutants into soil. BIOF&T can make 3-D representations both for saturated and unsaturated areas under very complicated circumstances, as well as simulations of flow transport both vertically along with the migration of leachate and horizontally along with its interfering with the side flow of ground water. This program allows extremely accurate representation of irregular ground boundaries, uneven ground surface as well as deep soil and groundwater geology (Technical Documentation, 2005).

The BIOF&T program uses two methods to account for permeability and pressure: the first model is van Genunchten, and the other model of formation is a linear model;

The relations among the limits, saturation and relative permeability for the first model of formation are expressed by the relations below:

$$\overline{S_w} = [1 + (\alpha\psi)^n]^{-m}$$

(1)

$$k_{rw} = \overline{S_w}^{0.5}[1 - (1 - \overline{S_w})^{1/m}]^2$$

(2)

where: $\overline{S_w} = \dfrac{S_w - S_m}{1 - S_m}$ - effective water saturation;

S_m - irreducible water saturation, α [L^{-1}] and n[-] are porous medium parameters and m = 1-1/n.

For the second model of formation, the linear one, water saturation, permeability and limit are expressed by the relations:

$$k_{rw} = \frac{S_w - S_m}{1 - S_m}$$

(3)

$$\frac{\psi - \psi_a}{\psi_m - \psi_a} = \frac{1 - S_w}{1 - S_m}$$

(4)

where: ψ_a is the air entry pressure [L]; ψ_m is the head [L] corresponding to the irreducible water saturation.

The BIOF&T program shapes the aqueous phase transportation up to five species in variable saturated porous media. The unsaturated area and groundwater aquifers are considered as part of granulometric and/or fractionated media. The dissolved phase flow and the transport into the saturated area are shaped as a 2-D area or a 3-D phenomenon. They are used to define the contaminant loading to groundwater during the simulation of the aqueous phase transport into the saturated area.

A typical subsurface transport media has five distinct regions:

1) air-filled pores;
2) mobile water located within the pores or the mineral particles;
3) stationary water located mainly within the pores of the mineral particles or within the porous medium surrounding the granulometric fractions;
4) a dynamic region of the soil in equilibrium with the mobile phase and
5) a stagnant region of the soil where mass transfer diffusion is limited;

Van Genunchten and Wierenga, 1976, expressed the general transport relationship as:

$$\frac{\partial}{\partial t}(\theta_m C_{wm}) + \frac{\partial}{\partial t}(\theta_{im} C_{wim}) + \frac{\partial}{\partial t}(f\rho P_{wm}) + \frac{\partial}{\partial t}[(1-f)\rho P_{win}] =$$

$$= \frac{\partial}{\partial x_i}(\theta_m D_{ij} \frac{\partial C_{wm}}{\partial x_i}) - \frac{\partial}{\partial x_i}(q_i C_{wm}) - q_s C_{ws}$$

(5)

where: θ_m, θ_{im} are the fraction of the soil filled with mobile and immobile water; C_{wm}, C_{wim} are the concentration [ML^{-3}] of species ω in the mobile and

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immobile water respectively; q_i is the Darcy velocity [L/T]; P_{wm}, P_{wim} are adsorbed phase concentration of species ω in the mobile and immobile phase [M/M]; f is the fraction of the sorption sites which is in direct with the mobile liquid, ρ is soil bulk density [ML^{-3}]; q_s - is the volumetric flow rate of fluid injection (or withdrawal) per unit volume of the porous medium; C_{ws} is the concentration of species ω in the injected fluid and D_{ij} is the hydrodynamic dispersion tensor defined as:

$$\theta_m D_{ij} = d_L |q| \delta_{ij} + (d_L - d_T)\frac{q_i q_j}{|q|} + \theta_m \tau D_c \delta_{ij}$$

(6)

where: d_L, d_T are the longitudinal and the transverse dispersivity; δ_{ij} is the Kronecker delta; τ is tortuosity; D_c is the coefficient of molecular diffusion; $|q|$ is the absolute value of the Darcy velocity;

Using the continuity equation for water flow:

$$-\frac{\partial qi}{\partial xi} = \frac{\partial \theta_m}{\partial t} - q_s \qquad (7)$$

and assuming linear adsorption $(P = K_d C)$ equation 2 can be written as:

$$\frac{\partial C_{wm}}{\partial t}(\theta_m + f\rho k_d) + \frac{\partial C_{wim}}{\partial t}[\theta_{im} + (1-f)\rho k_d] = \\ = \frac{\partial}{\partial x_i}(\theta_m D_{ij}\frac{\partial C_{wm}}{\partial x_i}) - q_i \frac{\partial C_{wm}}{\partial x_i} - q(C_{ws} - C_{wm}).$$

(8)

The mobile and immobile phases concentrations are related as:

$$\frac{\partial C_{wim}}{\partial t}[\theta_{im} + (1-f)\rho k_d] = x(C_{wm} - C_{wim})$$

(9)

where: x is a mass transfer coefficient [T^{-1}] for diffusive mass exchange between the mobile and immobile phases.

Incorporating decay losses λ_{wm} and contaminant loading from a hydrocarbon source to the mobile phase H_w, in equation (6) and (7) gives:

$$\frac{\partial C_{wm}}{\partial t}(\theta_m + f\rho k_d) + \frac{\partial C_{wim}}{\partial t}[\theta_{im} + (1-f)\rho k_d] =$$

$$= \frac{\partial}{\partial x}(\theta_m D_{ij}\frac{\partial C_{wm}}{\partial x_i}) - q_i \frac{\partial C_{wm}}{\partial x_i} - q(C_{ws} - C_{wm}) - \lambda_{wm} + H_w$$

(10)

$$\frac{\partial C_{wim}}{\partial t}[\theta_{im} + (1-f)\rho k_d] = x(C_{wm} - C_{wim}) - \lambda_{wim}$$

(11)

For transport analysis, additional input data for a saturated medium are: dispersivity, porous media fractions (necessary for the disturbed medium analysis), solubility, diffusion coefficient, mass transfer coefficient, etc. The variables used by BIOF&T model for heterogeneous porous media is based on porosity approximation.

To achieve effective results, BIOF&T uses discretization in horizontal layers which are individually addressed in order to reduce the size of the matrix. The layer solution is implemented through an iterative approach. This leads to a considerable saving of time which allows tackling the most difficult problems (Technical Documentation, 2005).

2. METHOD OF STUDY AND EXPERIMENTS

The site covered by this study is located in the village of Podişu, Bălţaţi, the city of Târgu Frumos, county of Iasi, parcel 1A, plot 2, cadastral number 60 116.

The relief of the area is comprised within the Moldavian Plateau and it is predominantly a hilly relief with altitudes between 200 - 300 m, being located in the South West of the Moldavian Plain, near its area of contact with the North West sector of the Central Moldavian Plateau and the South East sector of Suceava Plateau (Posea, 1982).

From a geographical and geomorphologic perspective, the village of Podişu, Bălţaţi, falls in the "Moldavian Plateau", the regional subdivision of "Moldavian Plain", the "Plain of the Jijia River Lower Course", the "Bahluieţ Corridor" subunit (Posea, 1982).

In terms of geology, the site is located on the west side of the Podolia Platform. The immediate geological foundation of the area is sparse Sarmatian marly clay. It has thin intercalations of fine sands. The relief of the region where Bălţaţi is located dates since the Quaternary Age (Crupa, 2010).

The lithological composition of the various forms of relief is varied and the following areas can be identified: Pleistocene alluvial terraces, Holocene alluvia of the Bahluieţ river Valley and of its affluents, the river slopes consisting of proluvio-colluvial and deluvio-colluvial deposits.

The fineness of the granulated material rises towards the surface. The distribution of sand and gravel layer is very uneven depending on the relief of the marly clay. Loess deposits are composed of layers of clay and clay dust. Their thickness is at its maximum at the transition between the terraces. Sarmatian rocks comprise a sequence of marls and sandstones with south-western gradients, generally.

From a hydrological point of view, Târgu Frumos is located in the hydrographic basin of the Prut River (Cadastral Code XIII-1), Bahluieț watercourse (Cadastral Code XIII 1.15.32.12) and its affluent, river Rediu (Cadastral Code XIII 1.15.32.12.04) and the uncoded affluent Valea Adâncată River (Cadastral Atlas of Waters in Romania, 1992).

The groundwater in this area can be divided into two main categories:

- captive stratification aquifer layers;
- ground water aquifer layers;

The waters in the first category are found in crystalline, Silurian, Miocene, Cretaceous and Sarmatian deposits. All of them have an ascending level and they are mineralized.

Groundwater can be found in: the Bahluieț River terraces, the deluvio-colluvial slopes and the Bahlui River plain. Waters in the terraces of the surrounding hills can be found in the layers of gravel and sand that are not genetically related to the sands and gravel of the Bahluieț plain. From this point of view, we can speak of the existence of superior terraces and inferior terraces.

In the slopy area the hydrogeological situation is more complex, several factors of high variability on the slope surface contributing to it, such as: the depth and gradient of the foundation formation which can be the bed aquifer, the thickness of the deluvium and its permeability where there is clay within the interspaces, the size of the supply basin area, etc. Under the circumstances, the hydrostatic level displays great variation of the surface; also, it has a seasonal character on an extensive area depending on the precipitation pattern (Crupa, 2010).

There are two types of sites in this area:

- a site which is characteristic to the slopy area of transition between the Bahluieț River terrace where water is confined to a depth of about 12 m in the granular layer.
- a site characteristic to the terrace area which is litho-structurally made of a Quaternary layer which covers the Sarmatian crystalline marly-clay bedrock, and which extends to approximately 10-12 m in thickness, being made, from the surface to the depths, of: topsoil, clay, dusty loess sequence, under which there are cross structure sands and pebble lenses of 2-5 meters thick where the aquifer is also confined (Crupa, 2010).

The hydrogeological perimeter was investigated by a boring of Ø 4" performed at a depth of 7.00 m. The rate at the drilling entrance was determined by interpolation. Exploration carried out allowed the collection of soil samples, on which research was conducted in the laboratory, where they determined the main physical-chemical characteristics of them. We are citing from the granulometric data sheets that were made the following specify the following figures related to the soil composition: colloidal clay: 31-36%, clay: 11-17%, dust: 38-44%, sand: 8-14%.

3. RESULTS AND DISCUSSION

Following the exploration work carried out, the following lithological succession of soil stratifications was determined:

- topsoil between 0.40 m and 0.70 m in thickness;
- dusty clay-loess with a thickness ranging from 4.60 to 4.80 m.
- purple-brownish clay, with dust diffusions covering medium to coarse sand with gravel and shell fragments;

The loess sequence consisting of dusty clay alternating with purple clay has an average thickness of about 11.00 m; if deeper than 8.00 m, it has an additional specific compaction pressure by soaking of 3 daN/cm^2 – i_{m3}, not exceeding 2%. (Crupa, 2010).

Tables 1 and 2 highlight the hydrogeological and geotechnical characteristics of the aquifer under analysis. These values were set and stored in the pre-processor of the BIOF&T program to create data files containing: control parameters, initial conditions of work, species properties and the lower area of the aquifer.

Water circulation in soils depends on its texture, structure, porosity, degree of aeration, compaction, etc. The higher the porosity and the larger the pores are, the higher the permeability will be. During the entry of water into the soil, permeability does not remain the same. Thus, starting from a dry soil, the permeability is high at the beginning and then it rapidly decreases until the soil is saturated with water; from this moment on, the quantity of water that penetrates the soil is constant.

Water circulation in soils occurs according to Darcy's law:

$$Q = K \cdot S \cdot \frac{H+L}{L}$$

(12)

where: Q is the quantity (flow) of filtered water (cm^3); S - soil column section which filters water (cm^2); H - thickness (weight) of water layer above the soil column (cm); L - soil thickness of the layer that filters water (cm); K - a constant of proportionality whose size depends on soil properties and filtering water. The ratio (H + L)/L is the hydraulic gradient is reprezented by I.

Although originally designed for water circulation in saturated soils, it has been extended by Richards for the conditions of unsaturation, too, indicating that now hydraulic conductivity is a function of matrix suction:

$$q = -K(\Phi)\cdot\nabla H$$

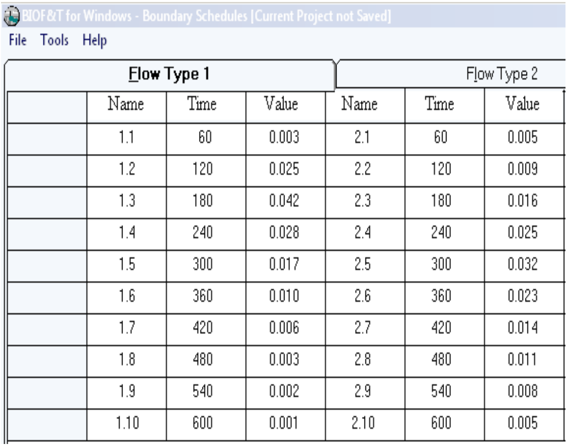
(13)

where: ∇H is the gradient of hydraulic potential, which can include both suction and gravitational components.

The simulation of the flow process was conducted on two cylindrical soil samples, with a length of 20 cm; the total time of application was 10 minutes. We used a constant time measure of 1 minute on a 2 cm remote node. Figure 1 shows Darcy’s velocity values for the two types of flow associated with soil samples

1 and 2, each having 10 nodes; time was expressed in seconds.

Fig. 1 Darcy's velocity values for water flow associated with the analysed soil samples



	Name	Time	Value	Name	Time	Value
	1.1	60	0.003	2.1	60	0.005
	1.2	120	0.025	2.2	120	0.009
	1.3	180	0.042	2.3	180	0.016
	1.4	240	0.028	2.4	240	0.025
	1.5	300	0.017	2.5	300	0.032
	1.6	360	0.010	2.6	360	0.023
	1.7	420	0.006	2.7	420	0.014
	1.8	480	0.003	2.8	480	0.011
	1.9	540	0.002	2.9	540	0.008
	1.10	600	0.001	2.10	600	0.005

Table 1. The shape of the hydrogeological drilling F1 Ø 4"
(Data cited from "A Hydrogeological Study", the village of Podişu, Bălțați, town of Târgu Frumos, 2010)

Field rate	Layer depth	Groundwater rate	Stratification	Layer – name and features	Sample no.	Sample rate	Lower plasticity limit (W_P)	Upper plasticity limit (W_L)	Plasticity index (Ip)	Natural humidity (W)	Granulometric composition			
											Colloidal clay	Clay	Dust	Sand
m 0.0	m 0.0	m 0.0				m	%	%	%	%	%	%	%	%
5.0	4.4			Wet dusty loess clay powder, with average plasticity and plastic consistency	1	1.0	20.3	43.2	23.0	24.7	36	11.5	43	9.5
					2	2.0	19.1	37.9	19.7	25.2	44.5	8.5	38.5	8.5
					3	3.0	19.0	40.3	21.4	25	41	11	38.5	9.5
					4	5.0	18.5	45.3	27.0	19.8	35.4	11.4	39.2	14
7.0	2.0			Purple-brownish clay with average plasticity and plastic consistency	5	5.5	17.8	42.7	24.9	19.9	34.7	12.2	43.4	9.7
					6	6.5	18.7	39.8	21.0	18.9	31.3	16.3	41.5	10

Table 2. Determinant geotechnical indices
(Data collected from "A Hydrogeological Study", village of Podişu, Bălțați, town of Târgu Frumos, 2010)

No.	Name	Symbol	U.M.	Value calculation
1.	Lower plasticity limit	Wp	%	20 - 22
2.	Upper plasticity limit	WL	%	38 - 41
3.	Plasticity index	ip	%	16 - 19
4.	Humidity	W	%	24 - 25
5.	Consistency index	»c	-	0.6 – 0.89

6.	Clay	A	%	38
7.	Dust	P	%	43
8.	Sand	N	%	19
9.	Volume weight	y	kN/m^3	15.8
10.	Volume weight in a dry state	Yd	kN/m^3	14.2
11.	Porosity	n	%	50
12.	Pore index	e	-	1
13.	Humidity degree	sr	-	0.64 – 0.76
14.	Type of linear deformation	E	kPa	30 - 37
15.	Angle of internal friction	*	grade	15^0
16.	Cohesion	c	kPa	8
17.	Volume weight	y	kN/m^3	15.8

Fig. 2 3-D Shaping of groundwater flow

Figure 2 represents the tridimensional shaping of groundwater flow for the two soil samples taken into account. The 10 nodal distances are represented on the Ox axis, their total length being equal to that of the soil samples. On the Oy axis, Darcy's velocity values are represented for two types of flow related to the soil samples, while the Oz axis shows the dispersion variation of water across the width of the soil column.

It appears that for sample 1, Darcy's velocity reaches a peak of 0.042 cm/sec and for sample 2, its maximum value is 0.032 cm/sec. It gradually decreases on the length of the soil column.

Water moved in the soil from the sections with higher hydraulic potential to the sections with lower hydraulic potential, and the driving force of the movement was determined by the water potential gradient in the soil.

The results of these simulations were carried out in stages and then printed. The BIOF&T program can create additional files that can be used to define the initial conditions for the next phase.

4. CONCLUSION

Taking into account the hydrogeological characteristics of the drilling work carried out, we conclude that the area has a lithological sequence made of wet dusty loess clay powder and purple-brownish clay at the bottom. In the analysed samples, the hydrodynamic level was identified at a depth of 7.0 m.

Ground water flow shaping was performed using the BIOF&T program, which is a 3-D and 2-D analysis model of tri- and bi- dimensional finite elements, and where the pedologic and geological data were entered as well as the hydrogeological and hydraulic parameters of two soil samples collected from depths of 5.0 m and 7.0 m in the area analyzed.

Calculation of effective solutions was obtained by discretizing the solution in horizontal layers. This resulted in reduced computational time and accurate representation of tridimensional shaping of ground water flow in a porous and heterogeneous medium.

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