Bulgarian Journal of Meteorology and Hydrology

Bulgarian Academy of Sciences

National Institute of Meteorology and Hydrology

Bul. J. Meteo & Hydro 21/1-2 (2016) 108-115

Simulation of the groundwater level fluctuations in riparian lowlands

Part One

Zdravko Diankov[*], **Sashka Stefanova**

National Institute of Meteorology and Hydrology BAS, 66 Tsarigradsko shose Blvd., BG-1784

Abstract. This part one of the paper describes the groundwater level fluctuations under influence of the hydrologic regime in the neighbour river based on model experiments. The processes within saturated zone result from distribution of the hydraulic head within the highly permeable layer that transmits groundwater inside the lowland. The changes of the hydraulic head are simulated by quasi-2D groundwater model. After discretization of the domain, the respective set of discrete equations is solved numerically. For this purpose, program MATLAB is used, and the results are presented in Excel format for further processing. The model experiments are performed under boundary condition in the river presenting both the rising and falling branches for the period of 55 days, and the model parameters are from the Baley-Kudelin lowland. The groundwater level fluctuations in respect to time as a function of the distance from the riverbank are presented and analysed.

Keywords: groundwater level, hydraulic head, quasi-2D groundwater model, riparian lowland

1. INTRODUCTION

Areas with pronounced flat character are usually formed around the middle and lower stretches of the river courses. In Bulgaria, 13 lowlands with total area of 68000 hectares are identified along the Danube River.

In riparian lowlands protected by dikes from direct flooding the attention is focused on the groundwater level variations under influence of hydrologic regime of the river and

---

[*] corresponding author, e-mail: zdiankov1@gmail.com

recharge from precipitation and irrigation. In general, the groundwater level in riparian lowlands is very close to the land surface, and its rising may lead to waterlogging and swamping of the area, irrespective of the drainage canals.

The influence of the changing water level in the Danube River on the groundwater level fluctuations has been analyzed for the Bulgarian lowlands based on observations in wells (*Spasov and Mollov, 1964; Spasov, 1979* as examples).

The aim of the paper is to present the results of model experiments (based on the quasi-2D groundwater flow model) to define the groundwater level fluctuations for Bulgarian lowlands near the Danube River (with parameters of the Baley-Kudelin lowland).

2. DESCRIPTION OF THE MODEL

2. 1. Groundwater flow in riparian lowlands

Groundwater flow in Bulgarian lowland near to the Danube River occurs under influence of several factors: changing water level in the river, precipitation, irrigation and evapotranspiration (*Diankov, 1981*). In this study the two-dimensional flow is considered transverse to the river flow, as the aquifer is under strong influence of the hydrologic regime in the Danube River.

The quasi-2D groundwater flow in riparian zone is described by equation:

$$\mu \frac{\delta h}{\delta t} = -T \frac{\delta^2 h}{dx^2} + w \tag{1}$$

where h is the hydraulic head, μ is the specific yield, T is the transmissivity of the aquifer, x is the distance; w is the groundwater recharge, and t is time. The hydraulic head in the aquifer as a function of time and distance from the river is described by solving this equation.

2. 2. Conceptual model

The conceptual model (2D) is presented in Fig. 1, and the input data are from the Baley-Kudelin lowland (*Diankov and Velkovski, 1990*). The horizontal extent of the model (1000 m) spans the distance from the riverbank to the drainage canal.

The upper layer is low permeable with hydraulic conductivity K_1 = 0,4 m/d and thickness T_1 = 5 m. The lower layer is characterized with high hydraulic conductivity K_2 = 100 m/d and thickness T_2 = 12 m.

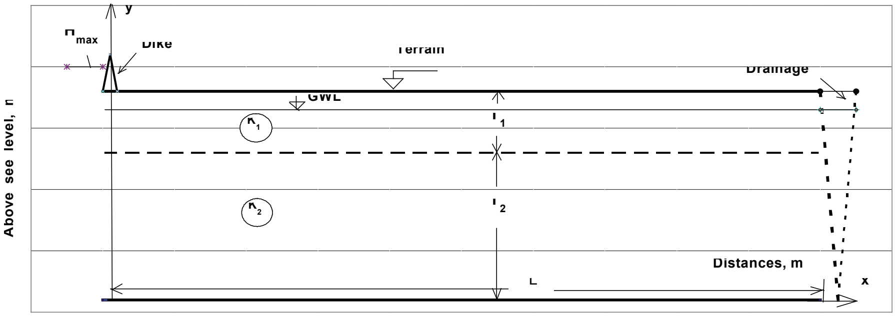


Fig. 1. Conceptual model of the 2D groundwater flow in riparian lowland

Elevation of the terrain surface is 17 m, and the protective dike at the riverbank with crest elevation is over 22,0 m.

Transient groundwater flow is considered, and a value of 0,06 is adopted for specific yield μ (typical for the Danube lowlands).

2. 3. Initial and boundary conditions

The initial condition (h_0 = 15,5 m) provides equilibrium state of the system with groundwater level depth 1,5 m below the land surface.

The boundary condition in the river (Table 1) describes both the rising and falling branches for the model experiments. The total duration of the studied process is 55 days within the cold period (evapotranspiration is not taken into account).

In the drainage canal, the boundary condition is specified constant hydraulic head (h_L = 15,5 m).

Table 1. Boundary condition – water level in the river

Period N	**Duration days**	**Boundary conditions of the river level**	**Days from the start**
1	8	Constant 15,5 m	8
2	14	Increasing level with a rate of 0,25 m/day, up to elevation 19,0 m	22
3	4	A constant level of elevation 19,0 m	26
4	16	Even decrease with a speed 0,25 m/day up to elevation 15,0 m	42
5	13	Constant water level at 15,0 m	55

2. 3. Space and time discretization

For numerical solution of the equation (1), discretization in space and in time is applied (Fig. 2), and a set of discrete equations is written.

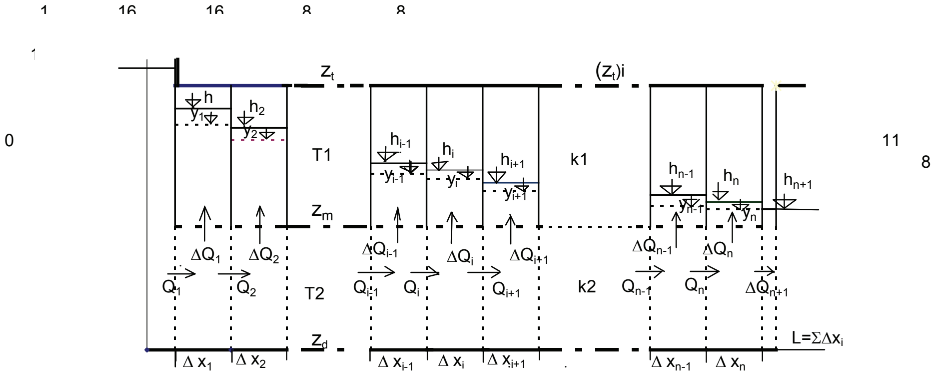


Fig. 2. Groundwater flows in elementary sections of the modelled domain

With the designations introduced in Fig. 2, the finite difference approximations of the balance equation (the inflow, outflow and the storage change) for the i-th section are as follows:

$$Q_i - Q_{i+1} = \Delta Q_i \,, \tag{2}$$

where:

$$Q_i = (k2)_i (T2)_i \frac{(h_{i-1} - h_i)}{(\Delta x_{i-1} + \Delta x_i)/2} = (a1)_i (h_{i-1} - h_i) \,, \tag{3}$$

$$Q_{i+1} = (k2)_{i+1} (T2)_{i+1} \frac{(h_i - h_{i+1})}{(\Delta x_i + \Delta x_{i+1})/2} = (a2)_i (h_i - h_{i+1}) \,, \tag{4}$$

$$\Delta Q_i = (k1)\Delta x \, \frac{(h_i - y_i)}{(y_i - z_{mi})} = b_i (h_i - y_i) \quad . \tag{5}$$

Here y_i is the initial elevation of the groundwater level for the time period Δt and z_{mi} is elevation of the boundary between the two layers (here equal to 12 m).

Equations (2) - (5) may be written in the form:

$$(a1)_i h_{i-1} + [\; a1)_i + (a2)_i + b_i]h_i + (a2)_i h_{i+1} = -b_i y_i, \tag{6}$$

or after combining the coefficients $a1_i$, $a2_i$ and b_i in a single coefficient $A_i = (a1)_i + (a2)_i + b_i$, the water balance equation for the i-th section is as follows:

$$(a1)_i h_{i-1} - A_i h_i + (a2)_i h_{i+1} = -b_i y_i. \tag{7}$$

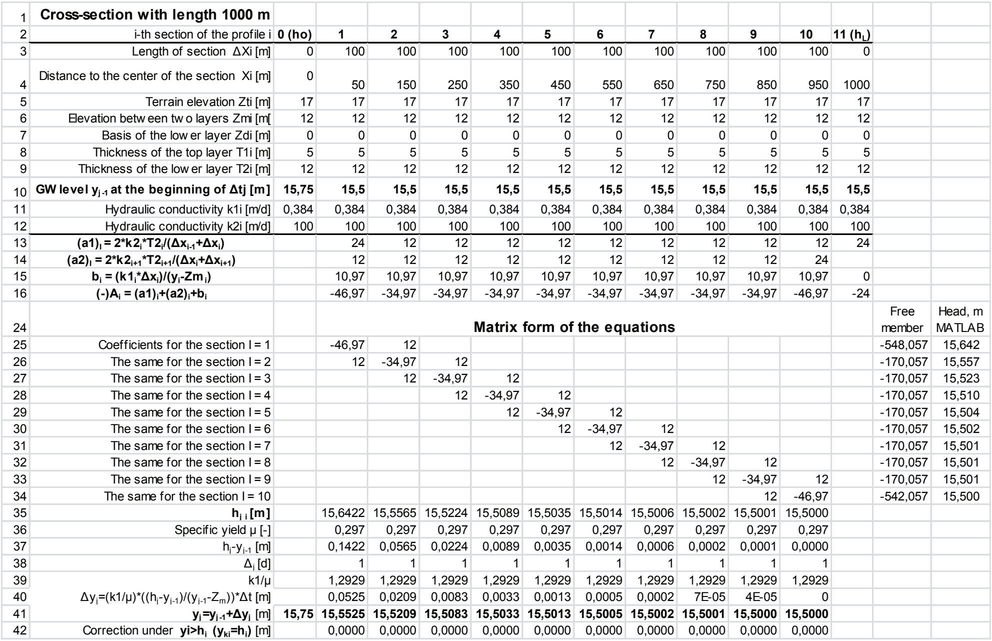
The increase of the groundwater level for the i-th section Δy_i for the time interval Δt is defined by equation:

$$\Delta y_i = \frac{\Delta Q_i . \Delta t}{\mu_i} = \frac{(K1)_i . \Delta x_i}{\mu_i} \frac{(h_i - y_i)}{(y_i - zm_i)} \Delta t. \tag{8}$$

2. 4. Numerical solution

The finite-difference method is chosen for solving the set of equations (7) with the specified initial and boundary conditions. For this purpose, the MATLAB program is used, and the results are presented in Excel format. The time step is equal to 1 day.

Table. 2. Procedure for solving the set equation (7) – example for the first day of simulation



1	**Cross-section with length 1000 m**														
2	i-th section of the profile i	**0 (ho)**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11 (h_L)**		
3	Length of section ΔXi [m]	0	100	100	100	100	100	100	100	100	100	100	0		
4	Distance to the center of the section Xi [m]	0	50	150	250	350	450	550	650	750	850	950	1000		
5	Terrain elevation Zti [m]	17	17	17	17	17	17	17	17	17	17	17	17		
6	Elevation between two layers Zmi [m[	12	12	12	12	12	12	12	12	12	12	12	12		
7	Basis of the lower layer Zdi [m]	0	0	0	0	0	0	0	0	0	0	0	0		
8	Thickness of the top layer T1i [m]	5	5	5	5	5	5	5	5	5	5	5	5		
9	Thickness of the lower layer T2i [m]	12	12	12	12	12	12	12	12	12	12	12	12		
10	**GW level y_{j-1} at the beginning of Δtj [m]**	**15,75**	**15,5**	**15,5**	**15,5**	**15,5**	**15,5**	**15,5**	**15,5**	**15,5**	**15,5**	**15,5**	**15,5**		
11	Hydraulic conductivity k1i [m/d]	0,384	0,384	0,384	0,384	0,384	0,384	0,384	0,384	0,384	0,384	0,384	0,384		
12	Hydraulic conductivity k2i [m/d]	100	100	100	100	100	100	100	100	100	100	100	100		
13	**$(a1)_I = 2*k2_i*T2_i/(\Delta x_{i-1}+\Delta x_i)$**		24	12	12	12	12	12	12	12	12	12	24		
14	**$(a2)_I = 2*k2_{i+1}*T2_{i+1}/(\Delta x_i+\Delta x_{i+1})$**		12	12	12	12	12	12	12	12	12	24			
15	**$b_i = (k1_i*\Delta x_i)/(y_i-Zm_i)$**		10,97	10,97	10,97	10,97	10,97	10,97	10,97	10,97	10,97	10,97	0		
16	**$(-)A_i = (a1)_i+(a2)_i+b_i$**		-46,97	-34,97	-34,97	-34,97	-34,97	-34,97	-34,97	-34,97	-34,97	-46,97	-24		
24			**Matrix form of the equations**											Free member	Head, m MATLAB
25	Coefficients for the section I = 1		-46,97	12										-548,057	15,642
26	The same for the section I = 2		12	-34,97	12									-170,057	15,557
27	The same for the section I = 3			12	-34,97	12								-170,057	15,523
28	The same for the section I = 4				12	-34,97	12							-170,057	15,510
29	The same for the section I = 5					12	-34,97	12						-170,057	15,504
30	The same for the section I = 6						12	-34,97	12					-170,057	15,502
31	The same for the section I = 7							12	-34,97	12				-170,057	15,501
32	The same for the section I = 8								12	-34,97	12			-170,057	15,501
33	The same for the section I = 9									12	-34,97	12		-170,057	15,501
34	The same for the section I = 10										12	-46,97		-542,057	15,500
35	**$h_{j\ i}$ [m]**		15,6422	15,5565	15,5224	15,5089	15,5035	15,5014	15,5006	15,5002	15,5001	15,5000			
36	Specific yield μ [-]		0,297	0,297	0,297	0,297	0,297	0,297	0,297	0,297	0,297	0,297			
37	h_i-y_{i-1} [m]		0,1422	0,0565	0,0224	0,0089	0,0035	0,0014	0,0006	0,0002	0,0001	0,0000			
38	Δ_i [d]		1	1	1	1	1	1	1	1	1	1			
39	k1/μ		1,2929	1,2929	1,2929	1,2929	1,2929	1,2929	1,2929	1,2929	1,2929	1,2929			
40	$\Delta y_i=(k1/\mu)*((h_i-y_{i-1})/(y_{i-1}-Z_m))*\Delta t$ [m]		0,0525	0,0209	0,0083	0,0033	0,0013	0,0005	0,0002	7E-05	4E-05	0			
41	**$y_i=y_{j-1}+\Delta y_i$** [m]	**15,75**	**15,5525**	**15,5209**	**15,5083**	**15,5033**	**15,5013**	**15,5005**	**15,5002**	**15,5001**	**15,5000**	**15,5000**			
42	Correction under **$yi>h_i$ ($y_{ki}=h_i$)** [m]		0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000			

The calculation procedure is presented in Table 2 for the first day of the simulation (t = 1 day). The groundwater level for the new time step *j* is done in the row before last.

The example presented in Table 2 shows how the change of the boundary condition in the river results in subsequent redistribution of the hydraulic heads in the area and changes of the groundwater level.

3. RESULTS

3. 1. Modelled results for the groundwater level fluctuations

The results obtained from the simulation are processed to analyze variations of the groundwater level in respect to time and distance from the riverbank.

The graphs shown in Fig. 3 clearly demonstrate the influence of the changing water level in the river on the groundwater levels in riparian lowland as a result of the distance from the river and time.

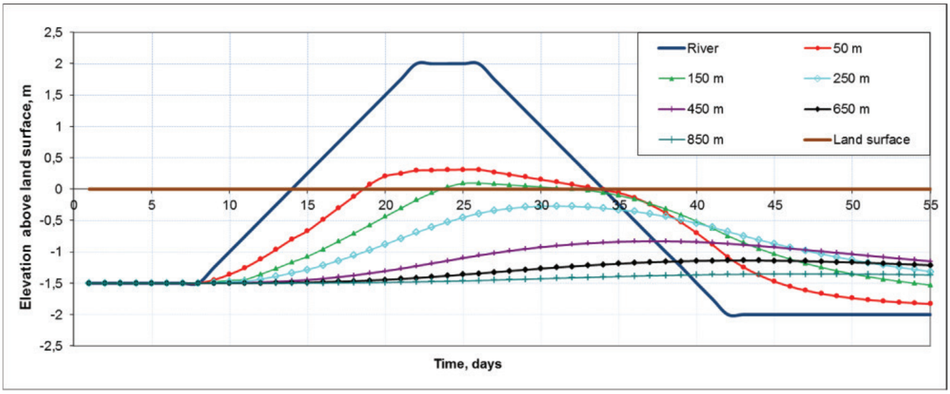


Fig. 3. Groundwater level for different distances from the river as a function of time

The high water level in the river causes temporary flooding from the groundwater, even in absence of precipitation. For example, at a distance of 250 m, the modelled results show flooding of the land surface for a period of two weeks (Fig. 3).

The graphs (shown in Fig. 4) present the groundwater level in a longitudinal section transverse to the river for different time from the beginning of the simulation. Such type of graphs is useful to define the flooded area.

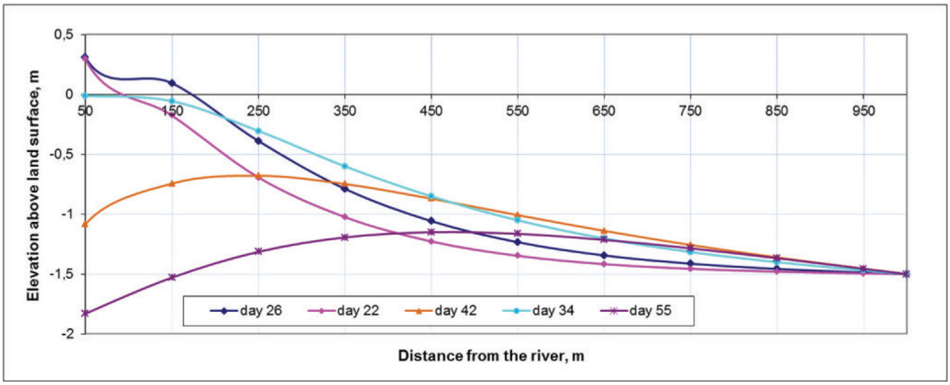


Fig. 4. Groundwater level as a function of the distance from the river

The role of the boundary conditions including the drainage canal with constant head is evident especially on Fig. 4.

3.2. Impact of the time step on the accuracy of the results

The impact of the time step on accuracy of the results concerning the groundwater level fluctuations is evaluated. It is established that the time step of one day produces satisfactory degree of accuracy in all modelled domain, compared to the obtained results with time steps $\Delta t = 0{,}5$ day. The respective comparisons are not presented for brevity.

With the time step of two days the calculation is faster, but on the account of inaccurate results (especially near the riverbank) that could lead to erroneous conclusions. For this reason the model is run with the time step of 1 day for the entire period of 55 days.

4. CONCLUSIONS

General features of the groundwater level fluctuations in the Baley-Kudelin lowland are analyzed based on model experiments. The changes of the hydraulic head are simulated by quasi-2D groundwater model. Numerical solutions of the equations are obtained with the aid of the program MATLAB. The model experiments are performed under boundary condition in the river presenting both the rising and falling branches for the period of 55 days.

The presented results clearly demonstrate the changes of the groundwater level depending on the distance from the riverbank and time. The amplitude of the groundwater level gradually attenuates with the distance from the river and depends on the hydraulic head in drainage canal.

The applied method could be used for other riparian lowlands based on their specific parameters and boundary conditions. Particularly, it is useful to define the areas prone to flooding by groundwater under specific hydrologic regime in the river.

REFERENCES

Diankov, Z. (1981) Filtration in riparian lowlands – methods of modeling. Sofia, Publ. House of BAS, (in Bulgarian, with English summary).

Diankov, Z., G. Velkovski (1990) Effect of the groundwater level on productive soil moisture in a root zone. Proceeding of the Czechoslovak-Polish seminar “Soil water physics”, Stara Lesna, 15-18 May 1990 (in Russian).

Spasov, V., D. Mollov (1964) Groundwater regime in the Karaboaz lowland and its protection from the flooding in case of construction of a dam on the Danube River. Works on the geology of Bulgaria. Series Eng. geology and hydrogeology, III: 5 -23 (in Bulgarian).

Spasov, V. (1979) Determining of hydrogeological parameters along the banks of the Danube River using data from groundwater regime. Eng. geology and hydrogeology, 8-9: 32-43 (in Bulgarian).