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Simulation of the groundwater level fluctuations in riparian lowlands

Part Two

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Abstract. The part 2 of the paper is focused on rising of the groundwater table caused by rainfalls, superimposed on the influence from the changing water level in the neighbour river. The WAVE model is used that simulates the 1-D unsaturated water flow in the soil profile. The lower boundary condition is obtained from the quasi-2D groundwater flow model described in part 1 of the paper. By additional post-processing of the results from the WAVE model, the water flow velocity in the unsaturated zone at different distances from the riverbank is defined as a function of time. Two periods are identified: (1) initial period when the water flow in the vadose zone is downward but the precipitation water does not reach the groundwater level, and (2) the next period when the precipitation water reaches the boundary between the vadose and saturated zones and leads to the water table rise. The parameters of the model are from the Bulgarian Baley-Kudelin lowland near the Danube River.

Keywords: unsaturated zone, groundwater level, lowland, WAVE model

1. INTRODUCTION

Groundwater level fluctuations in riparian lowlands are of special interest due to real threat of flooding. Lowlands are widespread in Bulgaria – they are located near to the Danube River. They are protected by dikes from the direct flooding from river waters. Yet the rising of the water level in the Danube River leads to subsequent rise of the

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groundwater levels, and to a real threat of swamping from groundwater. The likelihood of flooding is higher during the rainfalls.

The aim of the study is to analyze the behavior of the groundwater level under impact of fluctuations of the water level in a neighbor river in combination with rainfalls, based on the WAVE model (1-D unsaturated flow) in combination with the quasi-2D groundwater model described in the part 1 of the paper.

2. MODELING WATER FLOW IN THE VADOSE ZONE

2. 1. Water flow in the vadose zone

The one-dimensional water flow in unsaturated zone is described by equation:

$$C(h)\frac{\partial h}{\partial t} = \frac{\partial}{\partial z}\left[K(h)(\frac{\partial h}{\partial z}+1) \right] \tag{1a}$$

where h is the hydraulic head, K is the hydraulic conductivity, z is the vertical coordinate defined as positive upward, t is time. The differential water capacity C(h) is a relation (θ is the volumetric soil moisture):

$$C(h) = \frac{\partial \theta}{\partial h} \tag{1b}$$

Equation (1) is applicable both for unsaturated and saturated media. To solve this equation, two functions should be defined: (1) the soil moisture retention characteristic and (2) the hydraulic conductivity relationship.

For the soil moisture retention characteristic, the relationship proposed by Van Genuchten (1980) is used in this study:

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{[1+(\alpha|h|)^n]^m} \tag{2}$$

where θ_s is the saturated volumetric soil water content, θ_r – is the residual saturated volumetric soil water content, α is the inverse of the air entry value, and n and m are shape parameters.

The hydraulic conductivity relationship used in this study is after the hydraulic conductivity model of Gardner – power function (1958):

$$K(h) = \frac{K_{sat}}{1+(\beta|h|)^{N}} \tag{3}$$

where K_{sat} is the saturated hydraulic conductivity, β and N are parameters.

2. 2. Brief overview of the WAVE model

The WAVE model (Water and Agrochemicals in the soil, crop and Vadose Environment) describes the transport and transformations of matter and energy in the soil, crop and vadose environment. The model was developed at the Institute for Land and Water Management of the Katholieke Universiteit Leuven, Belgium (*Vanclooster at al., 1994*).

WAVE is essentially a 1-D model for the description of matter and energy flow in the soil and crop system. The model may use time step smaller than a day but the model input is specified on a daily basis.

In the vertical direction, the soil layers are subdivided in space intervals called the soil compartments. The solution of the differential equations in the unsaturated zone is realized by means of the finite difference method.

The WAVE model has been applied successfully by the authors of the present study in implementation of the INCO-Copernicus Project "Development of tools, needed for an impact analysis for groundwater quality due to changing of agricultural soil use" (*Mioduszewski et al., 2005*) and in several other publications (*Diankov, Stefanova, 2011a, 2011b; Diankov et al., 2010; Nitcheva et al., 2010*).

2. 3. Input data

Input data are from the Baley-Kudelin Danube lowland (*Diankov and Velkovski, 1990*). The workflow is carried out in several stages: 1) preparation of input data for the model; 2) obtaining of the results (output files from the WAVE model), and 3) additional post-processing of the results.

For the purposes of the study, the Water Transport Module of the model is used. The input data are stored in three files:

1. file CLIMDATA – data on precipitation, irrigation and evapotranspiration during the simulated period;
2. file WATDATA for the soil characteristics data and boundary conditions;
3. file GENDATA with general information such as simulation period, time step, and parameters concerning printing of the results.

The adopted parameters for the soil moisture retention characteristic in equation (2) are: $\theta_s = 0{,}469$; $\theta_r = 0{,}08855$; $\alpha = 0{,}00216$ cm^{-1}; n = 0,4988 and m = 1. For the hydraulic conductivity relationship (3), the adopted parameters are: $K_{sat} = 40$ cm/d, $\beta = 1{,}33$ cm^{-1} and $N = 1{,}51$ (*Diankov and Velkovski, 1990*). The thickness of the soil compartments is 10 cm. The lower boundary conditions for the sections located at different distances from the riverbank are obtained from the quasi-2D groundwater flow model described in part 1 of the paper.

Alluvial sediments in the lowland are presented by a two-layered system. The thickness of the upper and the lower layers is 5 m and 12 m, and the hydraulic conductivity is 0,4 m/d and 100 m/d respectively. Typical value of the specific yield μ for the area is equal to 0,06.

The modeled area is 1000 m long transverse to the Danube River. Elevation of the terrain surface is 17 m, and of the crest of the dam – over 22 m. The initial water level (and hydraulic head) in the river as well as in the total area is set at 15,5 m.

The boundary conditions in the river are as follows:

- Period 1 with duration 8 days – constant hydraulic head 15,5 m.
- Period 2 with duration 14 days – linear increase up to 19,0 m (rate 0,25 m/day).
- Period 3 with duration 4 days – constant hydraulic head 19,0 m.
- Period 4 with duration 16 days – even decrease up to 19,0 m (rate 0,25 m/day).
- Period 5 with duration 13 days – constant hydraulic head 15,0 m.

The total simulated period is 55 days.

3. RESULTS

3. 1. Defining flow rate in the unsaturated zone

As a result of rising water level in river, water table in riparian lowland may reach the land surface and produce flooding. To define the depth to the groundwater level in the lowland, the 1-D unsaturated flow is simulated for several distances from the river.

The reporting of the calculated results is done in the WAT_SUM.OUT file. The data on the volumetric soil moisture θ, the hydraulic head h and the unsaturated hydraulic conductivity k for the 10-cm soil compartments are of special interest for the objectives of this work. The output data are used to evaluate the rate of the vertical water flow and the depth to the water table in the lowland.

As an example, data for a section at a distance $X = 450$m are presented in Table 1 that refer to for the 10th day from the start of simulation. To calculate the values of the hydraulic gradient and flow rate between neighbor soil compartments, two columns are inserted (after the CONDUC column) for additional processing of data. The negative values of the flow velocity mean the downward flow.

For the hydraulic conductivity between the nodal points, the arithmetic mean is taken.

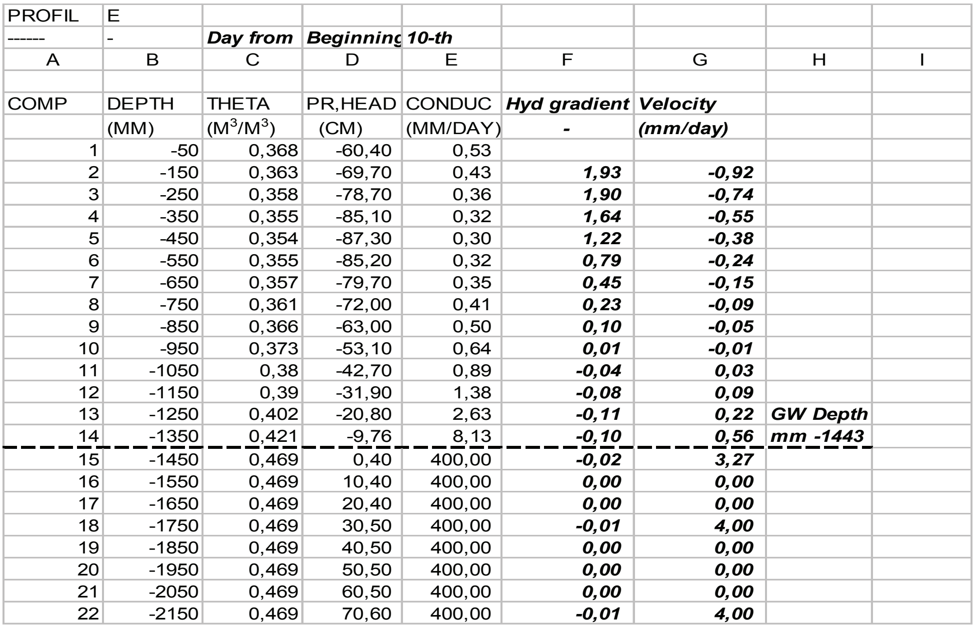
According to the data in Table 1, the simulated values of the flow velocity for the day 10th are negative up to the depth of 0,95 m. This means that the downward flow reaches only this depth and does not cross the water table at depth of 1,443 m. This example show the possibility to define the water flow in the vadose zone based on the results from the WAVE model.

Two main periods of the soil moisture distribution under influence of precipitation are identified: (1) initial period when the water flow in the vadose zone is downward but the precipitation water does not reach the groundwater level, and (2) the next period when the precipitation water reaches the boundary between the vadose and saturated zones and leads to the water table rise.

Two examples for distribution of the water flow velocity for the initial period are shown in Table 2 – for days 15th and day 20th from the beginning of the simulation period (at distance of 450 m from the river).

The results for days 45th and 50th from the beginning of the simulation period refer to the second period, when the downward flow reaches the saturated zone (Table 3).

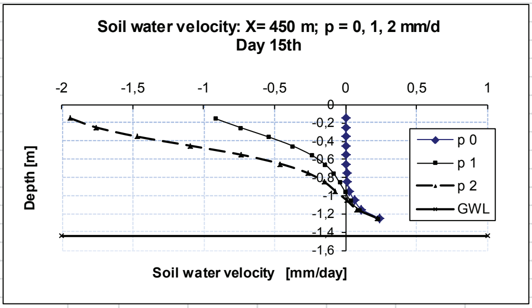
Table 1. Determination of the flow velocity between the soil neighbor compartments in the vadose zone from the WAT_SUM.OUT data



PROFIL	E							
------	-	***Day from***	***Beginning***	***10-th***				
A	B	C	D	E	F	G	H	I
COMP	DEPTH	THETA	PR,HEAD	CONDUC	***Hyd gradient***	***Velocity***		
	(MM)	(M^3/M^3)	(CM)	(MM/DAY)	***-***	***(mm/day)***		
1	-50	0,368	-60,40	0,53				
2	-150	0,363	-69,70	0,43	***1,93***	***-0,92***		
3	-250	0,358	-78,70	0,36	***1,90***	***-0,74***		
4	-350	0,355	-85,10	0,32	***1,64***	***-0,55***		
5	-450	0,354	-87,30	0,30	***1,22***	***-0,38***		
6	-550	0,355	-85,20	0,32	***0,79***	***-0,24***		
7	-650	0,357	-79,70	0,35	***0,45***	***-0,15***		
8	-750	0,361	-72,00	0,41	***0,23***	***-0,09***		
9	-850	0,366	-63,00	0,50	***0,10***	***-0,05***		
10	-950	0,373	-53,10	0,64	***0,01***	***-0,01***		
11	-1050	0,38	-42,70	0,89	***-0,04***	***0,03***		
12	-1150	0,39	-31,90	1,38	***-0,08***	***0,09***		
13	-1250	0,402	-20,80	2,63	***-0,11***	***0,22***	***GW Depth***	
14	-1350	0,421	-9,76	8,13	***-0,10***	***0,56***	***mm -1443***	
15	-1450	0,469	0,40	400,00	***-0,02***	***3,27***		
16	-1550	0,469	10,40	400,00	***0,00***	***0,00***		
17	-1650	0,469	20,40	400,00	***0,00***	***0,00***		
18	-1750	0,469	30,50	400,00	***-0,01***	***4,00***		
19	-1850	0,469	40,50	400,00	***0,00***	***0,00***		
20	-1950	0,469	50,50	400,00	***0,00***	***0,00***		
21	-2050	0,469	60,50	400,00	***0,00***	***0,00***		
22	-2150	0,469	70,60	400,00	***-0,01***	***4,00***		

Table 2. Simulated results for days 15th and 20th

day	DEPTH	Velocity	Velocity	Velocity
15	m	mm/day	mm/day	mm/day
COMP		p 0	p 1	p 2
1	-0,05			
2	-0,15	0	-0,922	-1,938
3	-0,25	0	-0,742	-1,755
4	-0,35	0	-0,549	-1,468
5	-0,45	0	-0,377	-1,095
6	-0,55	0,002	-0,244	-0,734
7	-0,65	0,003	-0,149	-0,458
8	-0,75	0,007	-0,087	-0,268
9	-0,85	0,013	-0,045	-0,149
10	-0,95	0,028	-0,006	-0,071
11	-1,05	0,061	0,031	0,008
12	-1,15	0,113	0,091	0,081
13	-1,25	0,240	0,221	0,227
GWL	**-1,443**			



day	DEPTH	Velocity	Velocity	Velocity
20	m	mm/day	mm/day	mm/day
COMP		p 0	p 1	p 2
1	-0,05			
2	-0,15	0	-0,938	-1,975
3	-0,25	0	-0,829	-1,911
4	-0,35	0	-0,701	-1,780
5	-0,45	0	-0,552	-1,576
6	-0,55	0,020	-0,415	-1,314
7	-0,65	0,024	-0,285	-1,005
8	-0,75	0,055	-0,169	-0,702
9	-0,85	0,119	-0,043	-0,431
10	-0,95	0,249	0,131	-0,162
11	-1,05	0,528	0,422	0,166
12	-1,15	1,029	0,896	0,661
GWL	**-1,307**			

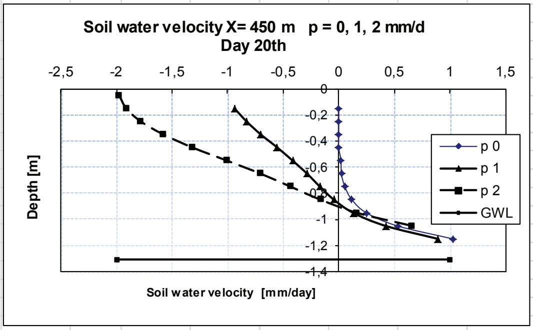
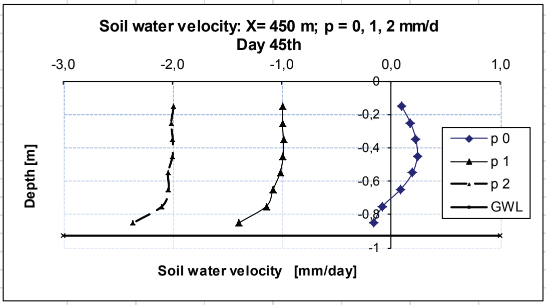
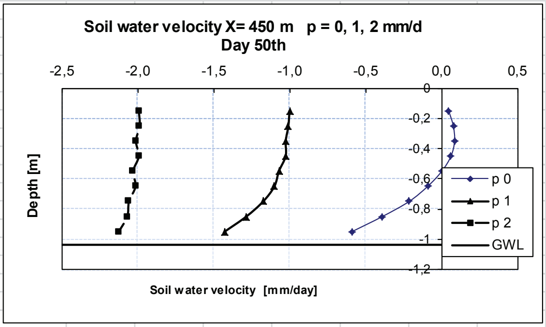


Table 3. Simulated Processes for day 45th and day 50th

day	DEPTH	Velocity	Velocity	Velocity
45	m	mm/day	mm/day	mm/day
COMP		p 0	p 1	p 2
1	-0,05			-3,515
2	-0,15	0,094	-0,992	-1,989
3	-0,25	0,176	-0,996	-2,014
4	-0,35	0,225	-0,988	-2,000
5	-0,45	0,238	-0,990	-2,002
6	-0,55	0,195	-1,017	-2,043
7	-0,65	0,085	-1,082	-2,039
8	-0,75	-0,078	-1,143	-2,097
9	-0,85	-0,164	-1,395	-2,361
GWL	**-9,27**			



day	DEPTH	Velocity	Velocity	Velocity
50	m	mm/day	mm/day	mm/day
COMP		p 0	p 1	p 2
1	-0,05			
2	-0,15	0,046	-1,003	-1,995
3	-0,25	0,076	-1,010	-1,989
4	-0,35	0,084	-1,028	-2,014
5	-0,45	0,061	-1,028	-1,995
6	-0,55	0,000	-1,073	-2,032
7	-0,65	-0,093	-1,102	-2,017
8	-0,75	-0,215	-1,176	-2,060
9	-0,85	-0,392	-1,287	-2,071
10	-0,95	-0,592	-1,430	-2,127
GWL	**-1,037**			



3.2. Rising of the groundwater level in response to recharge from precipitation

In periods when rainfall water does not reach the surface of the saturated zone, the groundwater level is formed only under the influence of the variations of the river water level. In cases when precipitation water reaches the saturated zone, the WAVE model allows two possibilities for the processes in the vadose zone depending on the boundary conditions.

Boundary condition 1: constant head boundary at the bottom. In this case, the water table change with time $\Delta H_k = 0$.

Boundary condition 2: zero flux at the bottom. This condition leads to the groundwater level rise for the time interval *K* according to equation:

$$\Delta H_k = \Delta t \frac{v_k}{\mu}, \tag{4}$$

where v_k is flow rate he saturated zone and μ is the specific yield, also known as the drainable porosity, with adopted value of 0,06.

3.2.1. Calculation scheme

The contribution of precipitation water to the groundwater level rise (when it reaches the saturated zone) is represented schematically on Fig. 1. The modelled period is divided in K time intervals from the beginning of the simulation with time step Δt = 5 days (K = 11).

The sequence of the data processing according to this scheme (Fig. 1) is shown in Table 3. It is assumed that the precipitation water reaches the saturated zone for the first time during the *j*th 5-day interval from the beginning of the simulated process. During this interval (with number K), the groundwater level rises with a value of

$$\Delta H_k = \Delta t \frac{v_k}{\mu}.$$

In the end of the first 5-day interval (K_1) it rises up to $Z_1 = Z^{0,0} + \Delta H_1$, where $Z^{0,0}$ is the water table unaffected by precipitation. During the next time interval K_2 the rising starts from the previous value Z_1.

The variations of the groundwater level unaffected by precipitation are taken into account. It is supposed that the effects on the groundwater level from precipitation and from fluctuations of the water level in the river are independent, and the total effect is calculated by the mathematical principle of superposition. For the end of the second interval the groundwater level is $Z_2 = Z^{0,2} + (Z_1 - Z^{0,1}) + \Delta H_2$.

The general recurrent equation (for time interval *K*) for the groundwater level is as follows:

$$Z_K = Z_{K-1} + (Z^{0,K} - Z^{0,K-1}) + \Delta H_K \, . \qquad (5)$$

The computation details are presented in Table 3, including the interval *K* of the first contact of the water flow that reaches the groundwater level (influenced only by the hydrological regime in the river). Two variants are described with different rainfall intensity *p*: 1 mm/d and 2 mm/d (*p1* and *p2* respectively). The computed depth of the groundwater level is presented in the last row of Table 3.

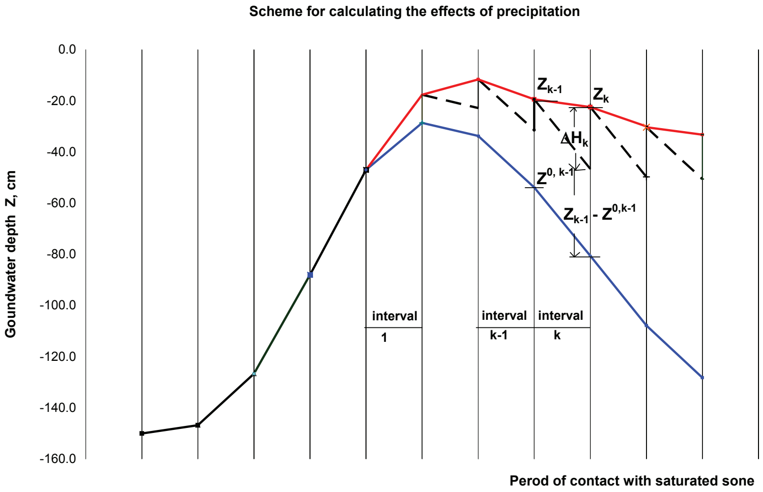


Fig. 1. Scheme for calculating the effect from precipitation

Table 3. Computations of the groundwater level depth (examples for distance of 450 m)

X=450 m													
p = 1 mm/d													
Interval (j)		0	1	2	3	4	5	6	7	8	9	10	11
Day		**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**
Z^0 без валеж p=0 от WAVE,WATSUM_OU)	450 p0	-2	-1,5	-1,47	-1,44	-1,31	-1,1	-1	-0,846	-0,848	-0,927	-1,037	-1,151
Compartment reached								**0**	**5**	**10**	**15**	**20**	**25**
Flow rate V_k, mm/day								0	0,22	0,94	1,39	1,43	1,5
$\Delta h_k = V_k/\mu$, mm/d								0	3,67	15,67	23,17	23,83	25,00
$\Delta H_K = 5 * \Delta h_k$								0	18,33	78,33	115,83	119,17	125,00
Groundwater level $Z_k = Z_{k-1} + (Z_{ok} - Z_{o(k-1)}) + \Delta H_k$	**450 p1**	**-2**	**-1,5**	**-1,5**	**-1,5**	**-1,5**	**-1,5**	**-1,5**	**-1,481**	**-1,403**	**-1,287**	**-1,168**	**-1,168**
X=450 m													
p =2 мм/d													
Interval (k)		0	1	2	3	4	5	6	7	8	9	10	11
Day		**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**
$Z_{0\,k}$ without rainfall from WATSUM_OUT	450 p0	-2	-1,5	-1,47	-1,44	-1,31	-1,1	-1	-0,846	-0,848	-0,927	-1,037	-1,151
Compartment reached									**8**	**8**	**9**	**10**	**12**
Flow rate V_k, mm/day								0	2,01	2,06	2,36	2,126	2,35
$\Delta h_k = V_k/\mu$, mm/d								0	33,50	34,33	39,33	35,43	39,17
$\Delta H_K = 5 * \Delta h_k$								0	167,50	171,67	196,67	177,17	195,83
Groundwater level $Z_k = Z_{k-1} + (Z_{ok} Z_{o(k-1)}) + \Delta H_k$	**450 p2**	**-2**	**-1,5**	**-1,47**	**-1,44**	**-1,31**	**-1,1**	**-1**	**-0,679**	**-0,509**	**-0,391**	**-0,324**	**-0,242**

Variations of the groundwater levels as a result of recharge from precipitation with different intensity are presented on Fig. 2 (for the same distance 450 m).

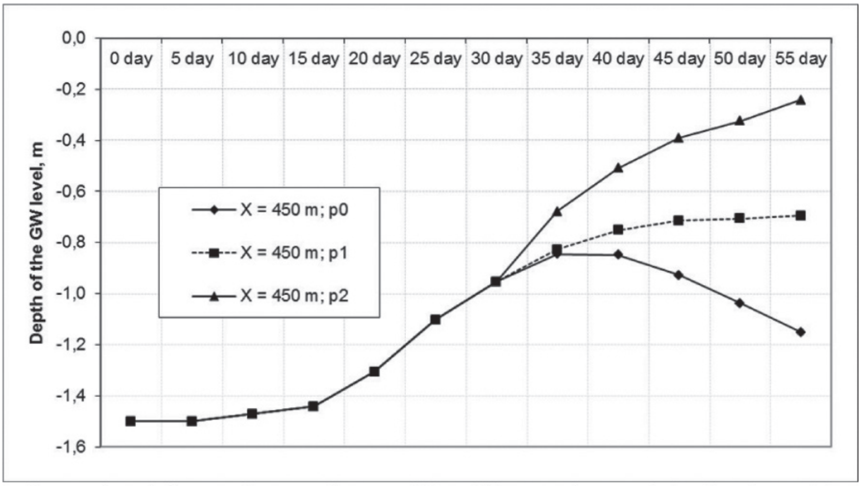


Fig. 2. Groundwater level fluctuations at distance X = 450 m under precipitation intensities p0, p1 and p2. GWL influenced by rainfall since day 30th.

It is shown in Fig. 3 that under precipitation intensity p = 3 mm/d the groundwater level "crosses" and swamps the land surface after the 37th day from the beginning of the process, for intensity $p0$ = 4 mm/d – after the 32nd day, and for intensity p = 5 mm/d – after the 28th day.

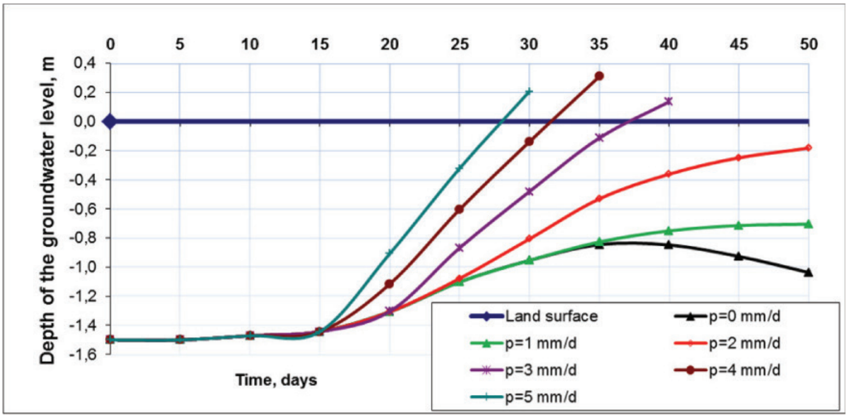


Fig. 3. Variations of the water table depth at distance 450 m from the river under different rainfall intensity values.

Really, the long term precipitation with intensity values higher than 2 mm/d is unlikely event and the respective modeled examples during the 55-day period serve for demonstration purposes only.

3.2.2. Impact of precipitation on the groundwater level rise

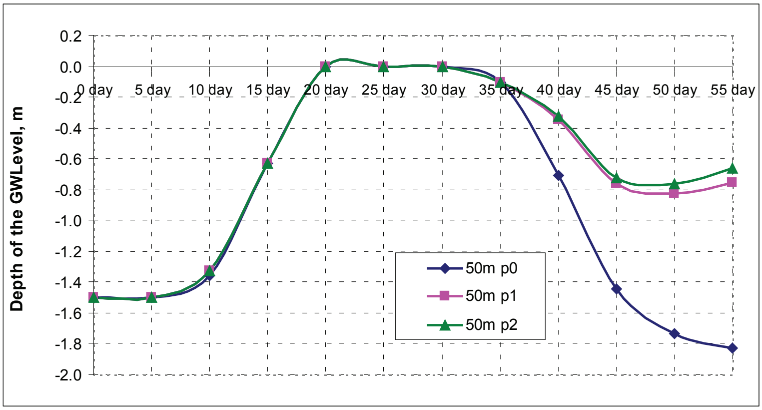
The obtained results describe variations of the groundwater level influenced both from the hydrological regime in the river and precipitation. As an example, in Table 4 are presented results on the evolution of the hydraulic heads for different distances under precipitation intensity values: 0, 1 and 2 mm/d (*p0*, *p1* and *p2* respectively).

The data in Table 4 are base for the analyses for the groundwater level fluctuations both in time and in space (for different distances from the riverbank).

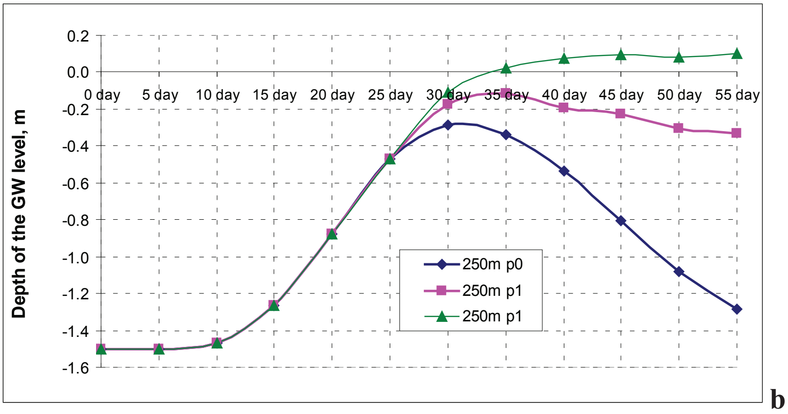
Table 4. Evolution of the hydraulic heads (in cm) for the defined depths as a result of recharge from rainfalls with intensity values: p0 = 0; p1 = 1 and p2 = 2 mm/d

	X, m	**day 0**	**day 5**	**day 10**	**day 15**	**day 20**	**day 25**	**day 30**	**day 35**	**day 40**	**day 45**	**day 50**	**day 55**
p0	**50**	-150	-150	-132,6	-63	0	0	0	-10,3	-70,8	-144,5	-173,1	-183
p0	**250**	-150	-150	-146,6	-126,7	-88,03	-47,08	-28,633	-33,8	-53,7	-80,7	-107,9	-128,2
p0	**450**	-150	-150	-147,1	-144,3	-130,7	-110,2	-95,4	-84,6	-84,8	-92,7	-103,7	-115,1
p0	**750**	-150	-150	-149,9	-149,4	-147,0	-142,4	-136,3	-130,7	-126,7	-125,3	-126,1	-128,5
p0	**850**	-150	-150	-149,9	-149,6	-148,6	-146,3	-142,8	-139,4	-136,9	-135,5	-135,6	-136,7
p0	**950**	-150	-150	-149,9	-149,9	-149,6	-148,9	-147,8	-146,7	-145,8	-145,3	-145,2	-145,5
p1	**50**	-150	-150	-132,6	-63	0	0	0	-10,3	-35,0	-76,5	-82,9	-75,8
p1	**250**	-150	-150	-146,6	-126,7	-88,0	-47,1	-17,7	-11,7	-19,5	-22,5	-30,3	-33,3
p1	**450**	-150	-150	-147,1	-144,3	-130,7	-110,2	-95,4	-82,8	-75,1	-71,5	-70,5	-69,4
p1	**750**	-150	-150	-149,9	-149,4	-147,0	-142,4	-136,3	-129,7	-122,3	-115,0	-108,4	-103,3
p1	**850**	-150	-150	-149,9	-149,6	-148,6	-146,3	-142,8	-138,9	-132,7	-125,7	-118,4	-111,6
p1	**950**	-150	-150	-149,9	-149,9	-149,6	-148,3	-146,0	-142,3	-137,2	-131,0	-125,0	-117,4
p2	**50**	-150	-150	-132,6	-63	0	0	0	-10,3	-32,8	-72,3	-76,5	-66,1
p2	**250**	-150	-150	-146,6	-126,7	-88,0	-47,1	-11,2	2,3	7,3	9,5	7,9	10,3
p2	**450**	-150	-150	-147,1	-144,3	-130,7	-110,2	-95,4	-67,9	-50,9	-39,1	-32,4	-24,2
p2	**750**	-150	-150	-149,9	-149,4	-147,0	-140,5	-125,7	-105,4	-85,1	-67,0	-51,0	-32,4
p2	**850**	-150	-150	-149,9	-149,6	-148,6	-144,1	-132,3	-114,9	-95,8	-77,1	-60,4	-44,0
p2	**950**	-150	-150	-149,9	-149,9	-148,5	-144,5	-135,1	-120,0	-102,2	-84,5	-66,9	-49,8

Temporal variations of the water table at different distances from the riverbank are presented on Fig. 4abc. The areas close to the riverbank are the most threatened from swamping. For example, at a distance x = 50 m from the bank (Fig. 4a), the land surface is flooded even in the absence of precipitation during the period from the 20th to the 30th day. At the distance of 250 m the flooding would occur only under rainfall rate of 2 mm/d from the 35th day up to the end of the modelled period. Without any rainfall, at the same distance the groundwater level would show gradual decline from 0,3 m up to 1,28 m below the land surface.



a



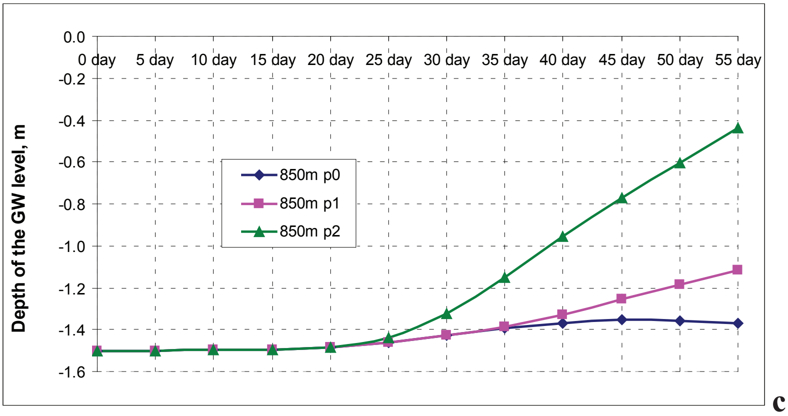
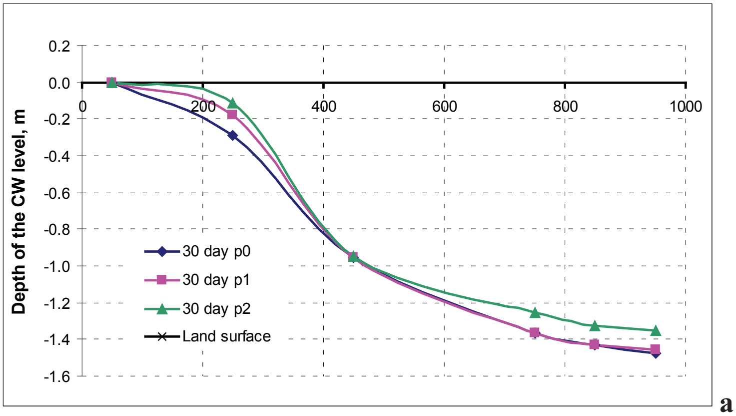


Fig. 4abc. Groundwater level fluctuations at different distances from the riverbank: a) X = 50 m; b) X = 250 m; c) X = 850 m



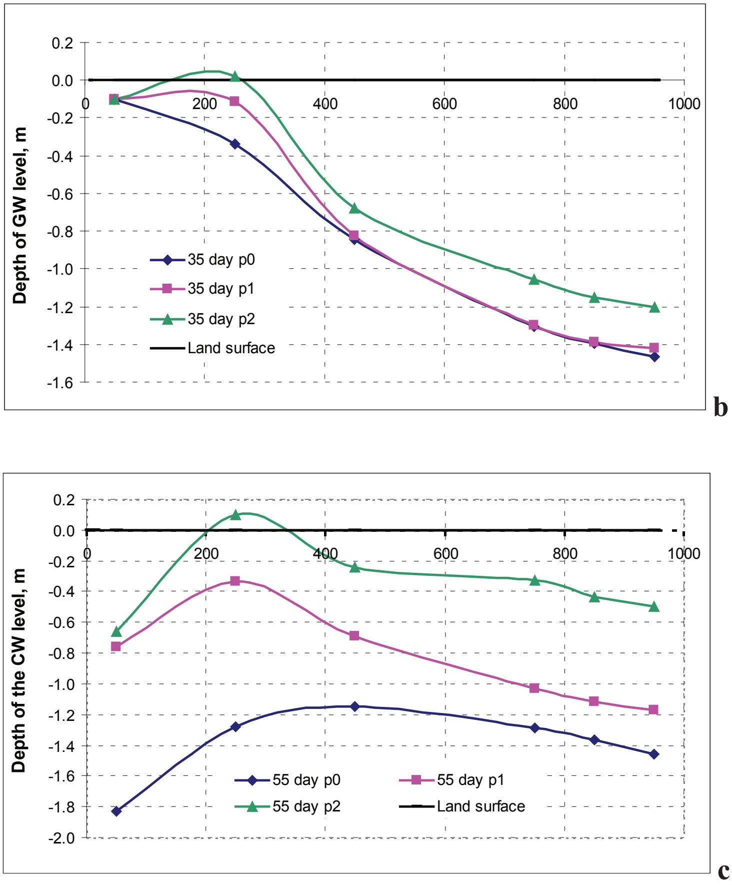


Fig. 5abc. Groundwater level as a function of the distance for various rainfall intensity values: a) for day 30th; b) for day 35th; c) for day 55th.

Figures 5abc show the groundwater levels as a function of distance from the river for various rainfall intensity values. They allow to assess the impact on the water table from precipitation and to compare the groundwater levels affected by rainfalls with the intensity 1 mm/d and 2 mm/d to those without any rainfall. The propagation of the wave inside the lowland gradually attenuates towards the drainage canal. This manner of presentation most possibly is the best to express more clearly the set objectives of modelling.

4. SUMMARY AND CONCLUSIONS

The behavior of the groundwater level in riparian lowlands is an issue of significant practical interest related to management of these areas. The necessity of protection of the lowlands from flooding and swamping should be based both on *in-situ* observations and measurements and theoretical considerations including simulation.

The groundwater level in riparian lowlands is influenced by changing water level in a river, recharge from precipitation and irrigation and evapotranspiration.

In this study the major factors affecting the groundwater fluctuation are examined and simulated based on both the WAVE model for 1-D unsaturated water flow and the quasi-2D groundwater flow model. For this purpose a series of model experiments is run with different rainfall rates. The hydrogeological parameters used are from the Baley-Kudelin lowland and are typical for a number of riparian Bulgarian lowlands near to the Danube River.

A 55-day period has been simulated, which includes gradual rising and lowering of the water level in the river and a period of constant head.

The combined effect from hydrological regime in the river and precipitation on the groundwater level is analyzed based on model experiments. Additional processing of data from the output file (WAT_SUM.OUT) allowed quantifying the rate of the water flow in unsaturated zone as a result of precipitation in lowland affected by hydrological regime in the river. The visualization of the results clearly shows the general features of the temporal and spatial variations of the groundwater level.

The applied methodical approach could be used in practice for solving various engineering problems under specific natural conditions.

The presented case studies demonstrate the power and usefulness of the model WAVE to describe the flow processes in riparian lowlands. In addition to the simulated impacts from variable water level in the river and precipitation, the WAVE model allows modeling of the root water uptake from plants and the plant growth. Furthermore, the program WAVE includes the solute transport and the nitrogen fate modules that are important for agricultural studies.

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