Surface and Ground Water Regime in Biđ-field Soils

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Summary

The aim of this work was to determine, through several-years stationary investigations, the water regime of soils in the Biđ-field district. Investigations were carried out during a three-year period (2001-2003) on 8,700 ha of agricultural areas. Detailed hydropedological investigations were done in 2000 and a soil map of the district (scale 1:10,000) was produced. Five pedosystematic units were detected: semigley, pseudogleyed, eugley hypogley, eugley amphigley, humogley, and drained soils. Based on three-year continuing monitoring of surface and ground waters the following main types of moistening of the soils were identified: eugley-pseudogley, hypogley, amphigley and drained. Stochastic relation between the Sava and Biđ water levels and groundwater in the agrological profile of studied soils was determined by cross-correlation with one decade shifts (c = 1). It was found that the ground waters in the profiles of studied soils communicate more intensively with the River Biđ water (r = 0.65-0.69) compared to the River Sava water (r = 0.23-0.69). This especially applies to ground water of hypogley soils, which cover 57% of the studied area. Marked vertical communication of ground water in the deep aquifer with water of the shallow soil aquifer was detected, indicating that the surface layer, mainly made up of silty clayey loams, is not impervious.

Key words

soil, water regime, Biđ-field, ground water, cross-correlation

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Introduction

Biđ-field is a part of the large Sava valley, defined by the river Biđ catchment area. In the wider physiographic sense, the studied region lies in the transition area from the central to the lower Sava valley, which coincides with the Biđ–Bosut field or the so-called Bosut Sava Valley (Tomić et al., 2003). The first hydrogeological investigations of the Sava alluvial aquifer in this region were done in the 1970s. These investigations revealed fairly thick, coarse clastic Quaternary beds at Županja, formed by the river Bosna deposits (Urumović and Sokač, 1994). Layers of coarse clastic material (gravel and sand) get thinner with their distance from the source of distribution in northern direction. This hydropedologically very heterogeneous region is dominated by hydromorphic soils with specific moistening regimes, of diverse stratigraphic and textural profiles and of ununiform vertical and horizontal hydraulic conductivity (Škorić et al., 1989). The region is transversed by the route of the future multifunctional Danube–Sava Canal. The surface part of the solum comprising the covering layer of 0-3 m depth is mainly built of heavier clay sediments. These are, however, often intersected by interlayers of considerably lighter materials made of sandy silty particles. Different interlayers extend between the covering layer and the gravely subsurface layer, commonly at depths of 1.5 m to 15 m below the ground surface. These interlayers are in the largest part of the studied region dominated by clayey silt sediments with lime concretions –the Kladavac-Cerna stretch, or different sand and silt fractions – the Kladavac-Sikirevci stretch (Civil Engineering Institute of Croatia, Zagreb 1997).

In the topographic sense (Figure 1), the studied region lies in the zone of typical lowland relief, between absolute elevation points from 81.81 m a.s.l. to 85.77 m a.s.l.. The general ground slope is west-east oriented. The studied region covers a total net area of 5838 ha.

Materials and methods

This study is mainly based on long-term groundwater monitoring (Mustać, 2004). Preliminary detailed hydropedological investigations were carried out in the studied region (2000). The available data, which was elaborated by various methods or extended for the needs of this study, was used.

Water balance in the system soil–plant–atmosphere was made according to Palmer's (1965) method, modified after Vidaček (1981). In the analysis and interpretation of hydrological characteristics of the region during the investigation period, the water level data of the river Sava at Šamac and Županja and of the river Biđ at Vrpolje and Cerna was used.

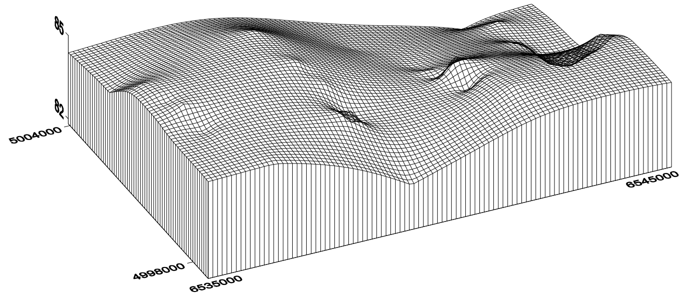


Figure 1. Digital model of the relief of the studied region

For the analyses and interpretation of pedological characteristics, detailed pedological investigations of the entire region were conducted at the end of 2000. Investigations were done on a 1:10000 scale map. Detailed pedological investigations covered a total area of 8722 ha. Forty soil profiles and about 190 probing hydropedological auger holes were opened in the area. In addition, another 40 soil profiles covering the areas of hydroameliorated-drained soils were analyzed.

Groundwater monitoring in the covering (soil) layer to 1.0 m and 4.0 m profile depths was done using 80 hydropedological piezometers, installed on 40 locations. Piezometers were installed in four lines, vertically to the direction of the future multifunctional Danube-Sava Canal. Ten pairs of piezometers were set up in each line. Groundwater levels in hydropedological piezometers were measured every 10 days in the period from 01.06.2001 to 31.12.2003.

The study included the analysis of data on groundwater levels, measured in five hydrogeological piezometers at 9.5-m depth. These piezometers penetrate into the more pervious sandy-silty materials overlying the gravely aquifer. Groundwater level fluctuations in these piezometers were measured every three (3) days throughout 2001.

Besides by hydropedological and hydrogeological piezometers, groundwater levels were measured on two locations by means of automatic limnimeters of the Orphimedes type. Measurements were taken continually each day in the period from 01.01.2002 to 31.12.2003.

Decade series of hydrological values of groundwater level in the studied period (01.06.2001 to 31.12.2003) were submitted to mathematical-statistical processing using the computer statistical program SPSS for Windows. Stochastic relation between the Sava and Biđ water levels and the groundwater of the studied region was determined by cross-correlation with one decade shifts (k=1), by the expression (Srebrenović, 1986):

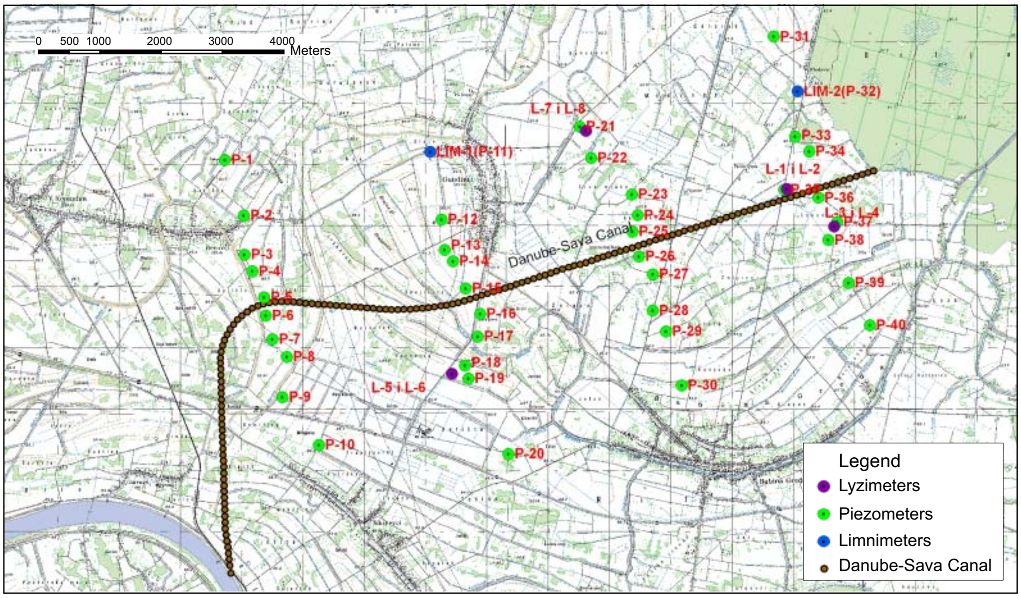


Figure 2.
Lay-out of piezometers, limnimeters and lysimeters in the studied region

$$rk\,(xy) = \frac{cov\,(x_i, y_{i+k})}{(var\ x_i\ \ var\ y_i)^{0,5}}$$

The computer program Surfer 7.0 was used to determine the direction of groundwater movement in the water-bearing aquifer to 4.00 m depth.

The soil map of the studied region (scale 1:10000), layer plans and the 3D terrain presentation were made using the computer programs ArcMap 9.0. and Surfer 7.0. Distribution of lysimeters, piezometers and limnimeters was primarily conditioned by the route of the future multifunctional Danube-Sava Canal (Figure 2).

Results and discussion

Based on the detailed field and laboratory soil investigations (Petošić et al., 2002) and the available soil classification (Škorić et al., 1985), five pedosystematic units were identified in the studied region (Table 1 and Figure 3).

Water balance was taken in the soils of the studied region to determine their water deficit or water surplus. Annual water deficit and water surplus values are presented in Tables 2 and 3 according to soil types and crops grown. The listed parameters show that the soils of the studied region require hydrotechnical interventions of irrigation or drainage.

Based on detailed hydropedological investigations conducted in 2000 (Petošić et al., 2002), five major moistening regimes were separated in the studied region: semigley-pseudogleyed, hypogley, humogley, amphigley and hydroameliorated. Major characteristics of the separated moistening regimes are given in Table 4.

Table 1. Distribution of pedosystematic units in the studied region

Pedosystematic unit	Area	
	ha	%
Semigley, non-calcareous, pseudogleyed, clayey loamy soil	740	12.7
Eugley, hypogley, mineral, calcareous soil	3329	57.0
Humogley, calcareous, clayey loamy soil	227	3.9
Eugley, amphigley, mineral, vertic, calcareous soil	137	2.3
Hydroameliorated (drained) soil	1405	24.1
Total	5838	100.0

Fluctuation of mean monthly groundwater levels in hydropedological piezometers to 4.0 m depth throughout the three-year period (2001-2003) is presented in Graph 1.

The mean groundwater level in the studied period (2001-2003) in semigley pseudogleyed soil was 1.54 m from the ground surface. Fluctuation of the mean monthly level with respect to the ground surface in the studied period was within the range of 0.80 m (February 2002) to >4.0 m (August, September and October 2003).

The mean groundwater level in hypogley soil, in the three-year monitoring period, was 1.44 m with respect to the ground surface, with the mean monthly values of groundwater levels varying within the range from 0.45 m (February 2002) to >4 m (September 2003).

Very similar values were obtained for humogley. Thus, its mean groundwater level in the three-year period was 1.41 m. The mean monthly groundwater level values ranged from 0.55 m (February 2002) to >4.0 m (September, October and November 2003).

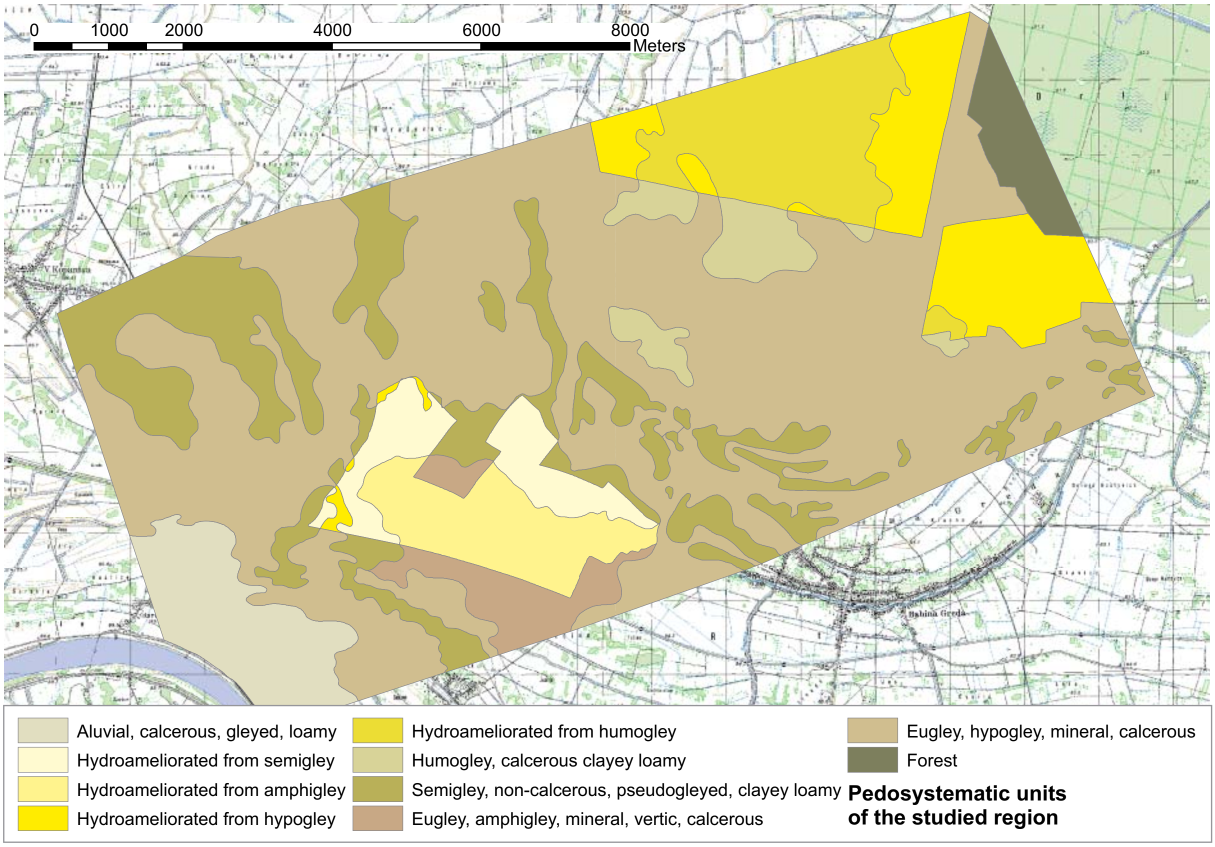


Figure 3. Soil map of the studied region

Table 2. Annual water deficit in soils of the studied region (mm) – 2001-2003

Soil type	Year	Spring barley	Winter wheat	Maize	Sugar beet	Alfalfa
Semigley, non-calcareous, pseudogleyed, clayey loamy	2001	117.4	150.2	129.6	131.2	199.7
	2002	190.0	223.1	186.2	294.5	299.7
	2003	410.4	505.8	388.6	369.3	499.5
	2001-2003	717.8	879.1	704.4	795.0	998.9
Eugley. hypogley, mineral. calcareous	2001	111.8	150.2	124.0	125.7	199.1
	2002	187.3	253.8	185.7	292.4	298.5
	2003	407.7	503.4	386.9	367.6	494.8
	2001-2003	706.8	907.4	696.6	785.7	992.4
Humogley calcareous. loamy clayey	2001	173.9	217.1	125.3	180.9	270.0
	2002	237.6	303.6	183.7	354.1	344.1
	2003	455.1	551.8	421.4	414.0	508.7
	2001-2003	866.6	1072.5	730.4	949.0	1122.8
Eugley. amphigley, mineral, vertic. calcareous	2001	114.3	152.1	125.4	128.3	201.7
	2002	197.2	253.1	187.4	290.4	295.6
	2003	401.8	495.4	381.7	367.3	485.0
	2001-2003	713.3	900.6	694.5	786.0	982.3

The mean groundwater level in amphigley soil during the monitoring period was 1.56 m, while the mean monthly groundwater level values were in the range from 0.70 m (February 2002) to >4.0 m (September 2003).

The mean groundwater level in hydroameliorated soil was 1.72 m during the monitoring period, with the mean monthly values of groundwater levels varying within the range from 0.65 m (February 2002) to >4.0 m (September 2003).

The above data show that the three-year (2001-2003) monitoring of the groundwater level dynamics in the studied soils confirmed the principal soil moistening re-

Table 3. Annual water surplus in soils of the studied region (mm) – 2001-2003

Soil type	Year	Spring barley	Winter wheat	Maize	Sugar beet	Alfalfa
Semigley, non-calcareous, pseudogleyed, clayey loamy	2001	301.2	271.9	333.9	283.0	327.6
	2002	66.1	76.1	84.5	37.7	55.6
	2003	54.7	58.3	54.7	54.7	0.0
	2001-2003	422	406.3	473.1	375.4	383.2
Eugley. hypogley, mineral. calcareous	2001	299.7	261.9	332.4	281.2	327.6
	2002	66.3	51.4	84.0	35.6	54.8
	2003	54.7	58.0	54.7	54.7	0.0
	2001-2003	420.7	371.3	471.1	371.5	382.4
Humogley calcareous. loamy clayey	2001	357.7	329.0	329.6	332.3	358.6
	2002	113.7	100.4	82.0	97.3	94.0
	2003	88.1	104.3	81.1	94.8	0.0
	2001-2003	559.5	533.7	492.7	524.4	452.6
Eugley. amphigley, mineral, vertic. calcareous	2001	298.1	264.2	329.7	279.7	327.6
	2002	63.3	50.7	85.7	33.6	71.6
	2003	54.7	58.0	54.7	54.7	0.0
	2001-2003	416.1	372.9	470.1	368.0	399.2

Table 4. Major moistening regimes of the studied soils

Prevailing soil moistening regime within 2 m depth			Abbreviated name of the pedosystematic unit
Type	Subtype	Moistening regime	
Semigley/ pseudogleyed	Moderately pseudogleyed and medium deep gley	Slow moistening by percolating surface water to ca 1 m; deeper by medium deep groundwater	Semigley, pseudogleyed
Gley	Hypogley	Excessive moistening by very shallow to shallow groundwater	Hypogley
Humogley	Shallow gleyic	Slow moistening by percolating and stagnating and flood surface waters; deeper by shallow, intensively fluctuating groundwater	Humogley
Gley	Amphigley	Slow moistening by percolating and stagnating surface water to 1 m; deeper by medium deep groundwater	Amphigley
Hydroameliorated	Detailed (open canals + pipe drainage)	Satisfactory regulation of excess surface and ground water	Hydroameliorated

gimes that were diagnosed by hydropedological investigations in 2000.

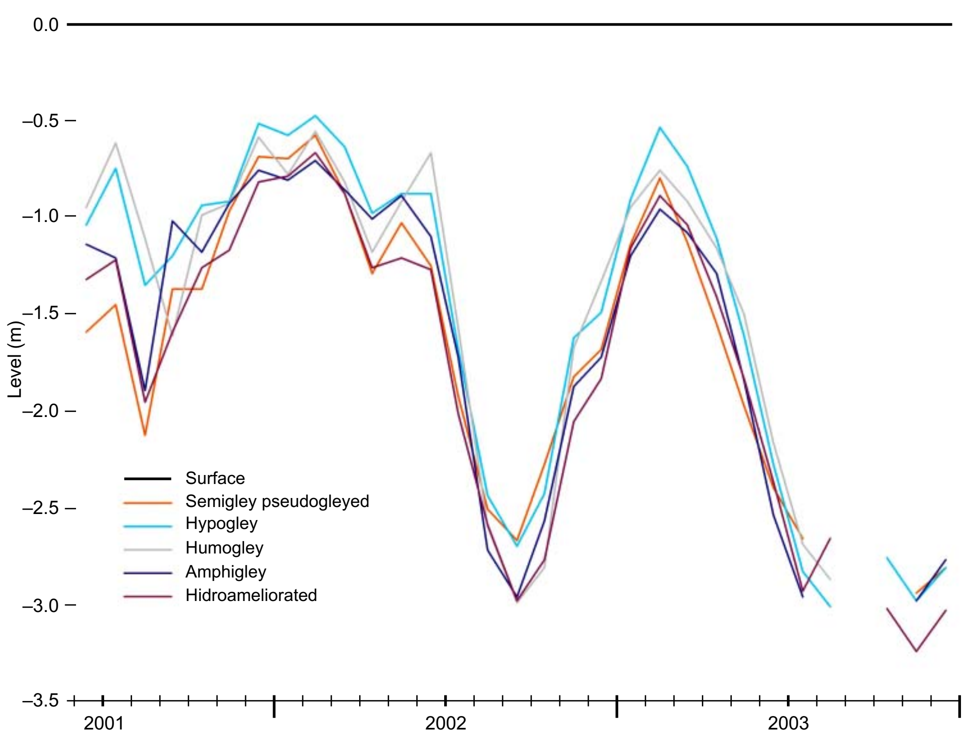
The stochastic relation between the Sava and Biđ water levels and groundwater in the deep gravely-sandy aquifer of the studied region (Table 5 and Figure 4) points to the conclusion that the river Sava feeds deep groundwater of the gravely-sandy aquifer all the way to the watershed Babina Greda-Gundinci-Beravci, as well as Biđ waters from its source to the water measurement station Vrpolje. Downstream of the water measurement station Vrpolje, the river Biđ also affects the feeding of deep groundwater in the gravely-sandy aquifer. This influence goes as far as the watershed Babina Greda-Gundinci-Beravci, where the influence of the Sava starts to get stronger. Influence of the river Sava on the dynamics of very deep groundwater in the monitored region (hydrogeological piezometers) is notable in the time period from 2.68 to 10.66 days, and that of the River Biđ from 1.40 to 8.89 days.

In the analysis of the influence of the Sava and Biđ rivers on groundwater in the covering layer of the region, i.e., in the soil profile to 4.0 m depth, all the correlation coefficients obtained were statistically significant at significance levels LSD = 0.01 and LSD = 0.05. However, weak to medium correlation was determined: r = 0.23-0.69. In 0 to 1 decade shifts the correlation was somewhat stronger between the Biđ water level at the water measurement station Vrpolje and groundwater levels in piezometers P-1, P-3, P-15, P-17, P-28, P-34, P-35 and P-40, in the range r = 0.65-0.69 at the significance level LSD = 0.01. The cross-correlation analysis indicates that the groundwater in hypogley soils, which cover 57% of the studied region, communicate less intensively with the river Sava and more intensively with the river Biđ. The established correlation occurs with a time delay from 0 to 10 days. Similar results were obtained in the central Sava valley by Dolanjski et al., 1999 and Milović, 1986.

Table 5. Interdependence of the Sava and Biđ water levels and groundwater as expressed by the cross-correlation coefficient r for 2001

Pairs of time series X	Y	Cross-correlation coefficient r	Shift (step) k = 10 days	Parabola equation	Maximum value of the correlation coefficient	Change in level after k (days)
Sava – Slavonski Šamac	Biđ Vrpolje	0.767**	0	$r = -0.226\,k^2 + 0.027\,k + 0.767$	0.768	0.588
	ATP-6	0.712**	0	$r = -0.039\,k^2 + 0.212\,k + 0.712$	0.748	3.428
	ATP-7	0.711**	+1	$r = -0.131\,k^2 + 0.136\,k + 0.706$	0.741	5.192
	ATP-8	0.758**	+1	$r = -0.201\,k^2 + 0.480\,k + 0.479$	0.766	11.958
	BTP-8	0.781**	+1	$r = -0.206\,k^2 + 0.364\,k + 0.623$	0.784	8.835
	BTP-10	0.783**	+1	$r = -0.206\,k^2 + 0.272\,k + 0.717$	0.807	6.606
Sava - Županja	Biđ Cerna	0.602**	0	$r = -0.120\,k^2 + 0.028\,k + 0.602$	0.603	0.689
	ATP-6	0.760**	0	$r = -0.308\,k^2 + 0.165\,k + 0.760$	0.782	2.675
	ATP-7	0.767**	0	$r = -0.284\,k^2 + 0.241\,k + 0.767$	0.818	4.242
	ATP-8	0.797**	+1	$r = -0.209\,k^2 + 0.445\,k + 0.561$	0.798	10.660
	BTP-8	0.808**	+1	$r = -0.213\,k^2 + 0.317\,k + 0.704$	0.822	7.447
	BTP-10	0.796**	+1	$r = -0.209\,k^2 + 0.217\,k + 0.788$	0.844	5.192
Biđ - Vrpolje	ATP-6	0.831**	0	$r = -0.303\,k^2 + 0.085\,k + 0.831$	0.837	1.403
	ATP-7	0.831**	0	$r = -0.300\,k^2 + 0.184\,k + 0.831$	0.859	3.063
	ATP-8	0.807**	+1	$r = -0.210\,k^2 + 0.373\,k + 0.644$	0.810	8.890
	BTP-8	0.823**	+1	$r= -0.217\,k^2 + 0.239\,k + 0.801$	0.867	5.507
	BTP-10	0.860**	0	$r = -0.317\,k^2 + 0.262\,k + 0.860$	0.914	4.133
Biđ - Cerna	ATP-6	0.750**	0	$r = -0.237\,k^2 + 0.052\,k + 0.750$	0.753	1.089
	ATP-7	0.748**	0	$r = -0.220\,k^2 + 0.137\,k + 0.748$	0.769	3.109
	ATP-8	0.752**	+1	$r = -0.199\,k^2 + 0.324\,k + 0.627$	0.759	8.149
	BTP-8	0.791**	+1	$r = -0.231\,k^2 + 0.268\,k + 0.754$	0.832	5.803
	BTP-10	0.819**	0	$r = -0.238\,k^2 + 0.208\,k + 0.819$	0.864	4.368

Note: (+)=X⟶Y; (–) = X⟵Y; LSD = 0.01 **



Graph 1.
Mean monthly groundwater levels in the studied soils

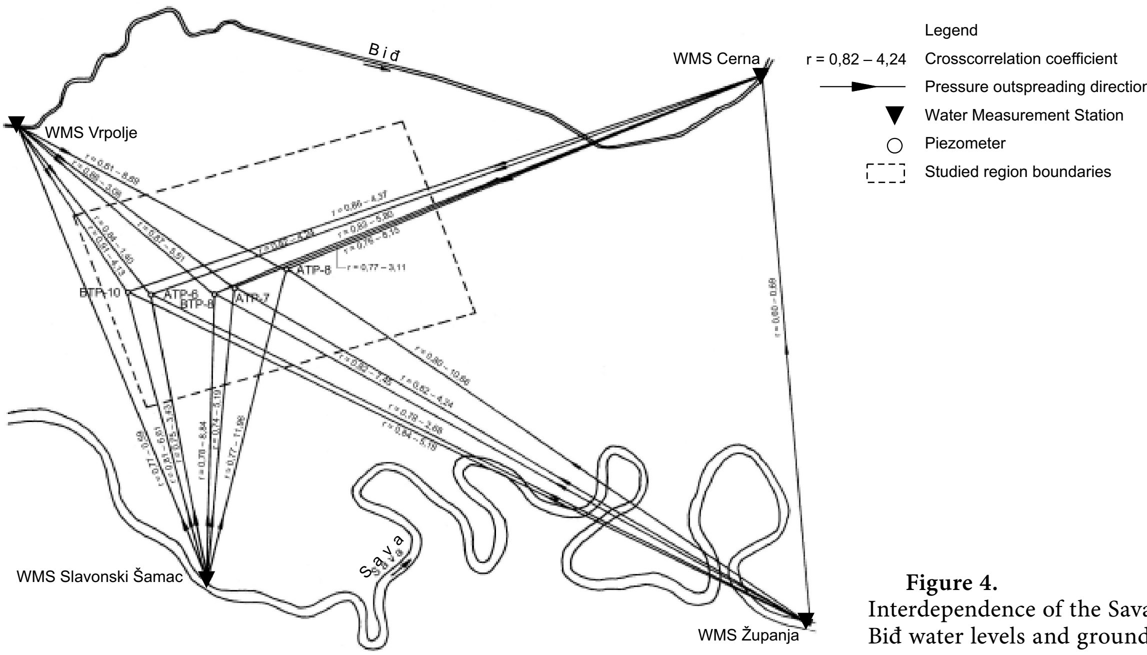


Figure 4.
Interdependence of the Sava and Biđ water levels and groundwater

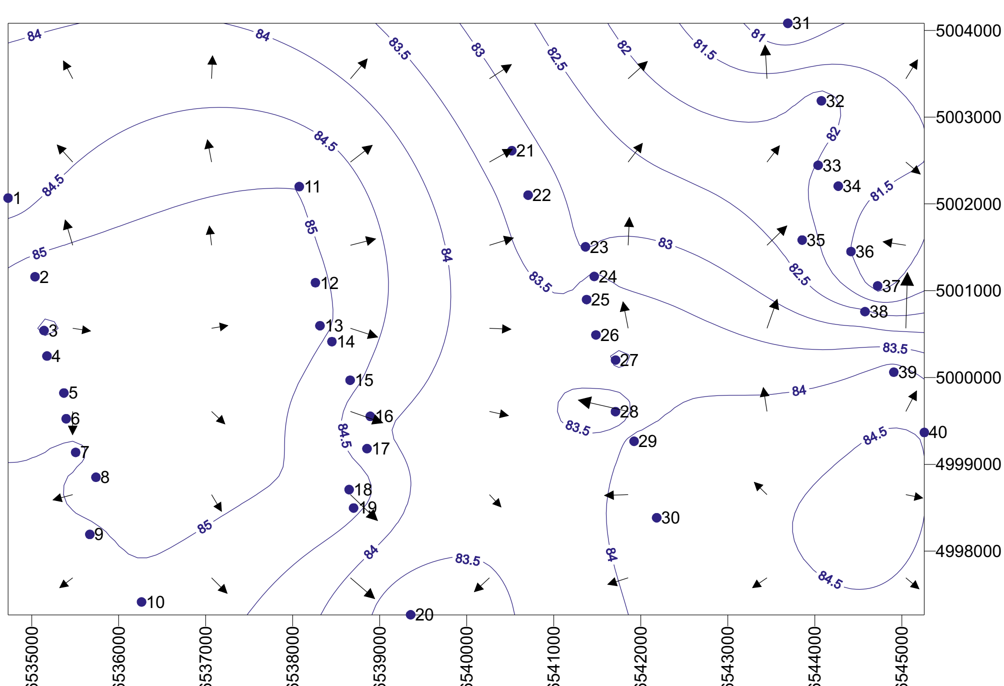


Figure 5.
Groundwater level contour map with the direction of groundwater movement at its maximum level

Figure 5 shows the groundwater level contour map of the studied region for the event of maximum groundwater levels as well as the direction of groundwater movement during the three-year investigation period. As can be seen, groundwater movement proceeds in two main directions – towards the Sava and towards Biđ and Bitulja.

Figure 6 displays the map of groundwater depth with respect to the ground surface in the conditions of its maximum levels (third decade in November 2001). Spatial distribution of groundwater level in the studied region with respect to the ground surface is presented in the range from 0.00 to 4.00 m of the soil profile depth, with the groundwater contour line equidistance of 0.10 m.

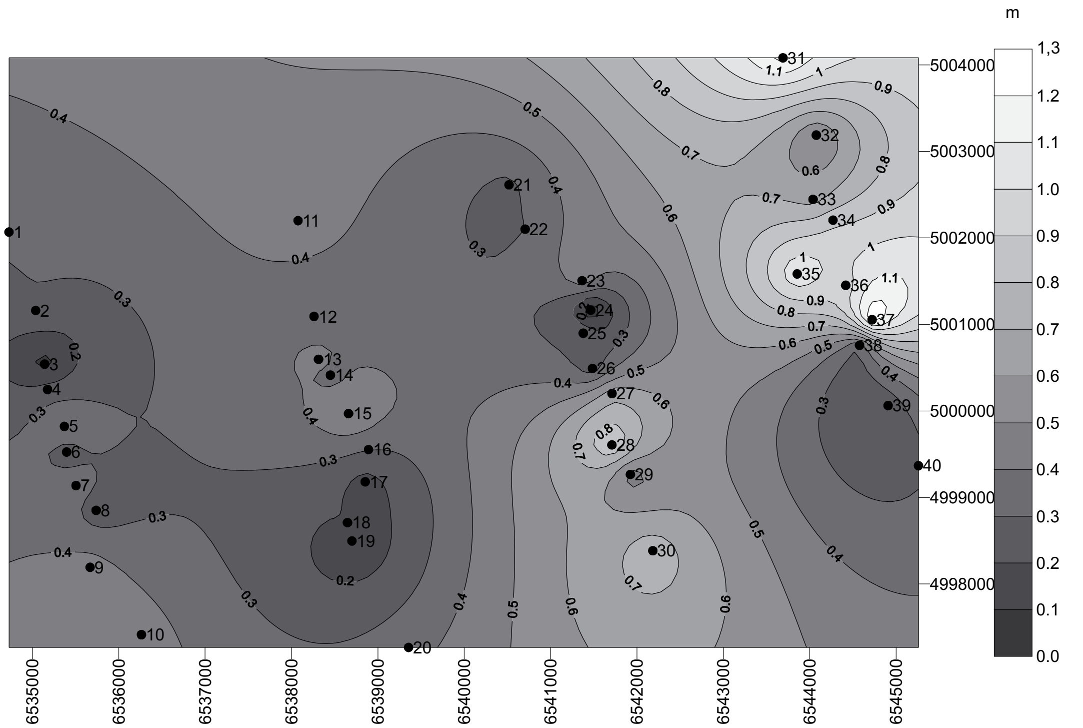


Figure 6. Groundwater depth map (November 2001)

Conclusions

In the wider physiographic sense, the studied region is situated in the central part of Biđ-field. From the climatic aspect, the region is in the transition zone from semiarid to semihumid climate. Annual precipitation of 952 mm was recorded in 2001, 642 mm in 2002, and only 483 mm in the dry 2003.

Annual soil water deficit in the period 2001-2003 ranged from 694.5 mm to 1122.8 mm in dependence on the crop and soil type, while water surplus ranged from 368.0 mm to 559.5 mm.

The following five pedosystematic units were identified in the studied region (net area 5838 ha): semigley pseudogleyed (740 ha or 12.7%), eugley hypogley (3329 ha or 57.0%), humogley (227 ha or 3.9%), eugley amphigley (137 ha or 2.3%) and hydroameliorated soil (1405 ha or 24.1%).

Monitoring of groundwater dynamics in the period from 2001 to 2003 confirmed the principal soil moistening regimes that were separated on the basis of morphological signs of gleyization in soil investigations done in 2000.

Strong correlation was determined between the Sava and Biđ water levels and the groundwater level in hydrogeological piezometers at 9.5 m depth (r = 0.74-0.91), indicating a strong influence of these rivers on groundwater dynamics in the deep aquifer of the region.

Correlation between the Sava and Biđ water levels and the groundwater level in hydropedological piezometers at 4.0 m depth was weak, ranging from r = 0.23-0.69. The performed cross-correlation analysis points to the conclusion that groundwater in hypogley soil, which covers 57% of the studied areas, communicates more intensively with the river Biđ water level. This correlation sets up with a certain time delay, ranging from 0-10 days.

In the three-year investigation period, a strong correlation (r = 0.75-0.94) between water levels in hydrogeological and hydropedological piezometers was determined on 87.5% of analyzed locations. This indicates good vertical communication of very deep groundwater of the gravely aquifer with groundwater of the covering (soil) layer. Vertical groundwater communication was especially good in eugley hypogley soils. Somewhat weaker communication was recorded in humogley and semigley pseudogleyed, and the weakest in amphigley soil.

Groundwater level fluctuations in hydropedological piezometers to 4.0 m depth were analyzed to determine its horizontal communication in the covering layer of investigated soils. The determined correlation is strong and in the range of r = 0.79-0.99.

The produced groundwater level contour map of the region with the direction of groundwater movement at maximum levels confirmed the direction of its movement in two main directions, towards the river Sava and the rivers Biđ and Bitulja. It should be emphasized that the same regularity of groundwater movement was also recorded at the time of its medium and minimum levels.

This points to the conclusion that the shallow soil aquifer to 4.00 m profile depth is mainly fed by precipitation percolation waters from the wide riverside area and to a lesser extent indirectly by infiltration waters from the rivers Sava and Biđ.

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