Full Length Research Paper

Contribution of the melioration canal to the water regime of forest areas

Goran Gjetvaj[1], Dragutin Petošić[2] and Ivan Mustać[2]*

[1]Faculty of Civil Engineering, University of Zagreb, Kačićeva 26, 10 000 Zagreb, Croatia.
[2]Faculty of Agriculture, University of Zagreb, Svetošimunska 25, 10 000 Zagreb, Croatia.

The paper analyzes the intensity of draining and recharging action of the melioration canal foreseen for the Biđ-Bosut Field irrigation, with special reference to its potential impact on forest areas. The designed canal will enable a series of agro-amelioration interventions aimed at recharging or draining soils and thereby regulating their water regime. The paper describes the influence of infiltration and drainage through the hyporheic zone between the designed melioration canal and groundwater. The amount of water infiltrated from precipitation and from the designed canal are analyzed and compared. Research results indicate that, in dry periods of the year, canal water will infiltrate into the solum of canal-bank soils, while the draining impact of the canal will be noticed in forest areas in case of high groundwater levels. In the studied region, the canal will be dug into poorly permeable covering layers and, according to the designed numerical model, its impact on the groundwater level could be noticed at the distance of 1000 m, namely at 500 m on each side of the longitudinal canal axis. It is also expected that water infiltration from the canal will be considerably lower than the infiltration of precipitation.

Key words: Melioration canal, water regime, forest areas, water flow modelling.

INTRODUCTION

In alluvial regions such as the Eastern Slavonia (Croatia) there is constant and ubiquitous interaction between the surface and ground waters. In the present paper, the influence of the designed melioration canal on the oak woods areas through which it will be built has been investigated.

Eastern Slavonia is a region bounded with the Drava River on the north and the Sava River on the south (Figure 1). The area is plain lowland with developed agriculture and forestry. Forestry is the basis for a well-developed wood-processing industry. In order to improve the water regime a large hydro-melioration works are being planned the base of which is a melioration canal. It is planned that in the second phase the canal would be extended to multipurpose canal having the dimensions of

the waterway. Thus the shipping route from major industrial centers of the Northwest Croatia (Zagreb and Sisak) to Central Europe would be considerably shortened.

Open canals such as melioration canals influence groundwater regime through the processes of infiltration and drainage.

In the existing literature there are a lot of papers dealing with the exchange between surface and groundwater through the hyporheic zone. Approaches to determining the amounts of water to be exchanged vary from author to author, and are mostly based on statistical methods and hydraulic approach.

Some aspects of surface water - groundwater interaction in the North Bihar plains were investigated by Prasad (1990). He recommends that flood control, drainage improvement and irrigation development for the alluvial regions must be considered in an integrated manner and the methods for optimization should be

_____

*Corresponding author. E-mail: imustac88@gmail.com.

Figure 1. Investigated area – location of melioration canal.

evolved simultaneously. Seepage from irrigation canals can be an important source for recharging shallow groundwater aquifers (Arumí et al., 2009). It has been shown that recharge from irrigation canals causes groundwater to rise directly beneath the canals (Maurer, 2002).

Survival of pedunculate oak forests in Croatian lowlands as well as efficient forest management in these parts largely depend on constant maintenance of groundwater levels in the ecologically favourable soil profiles. Soil moisture dynamics depends on soil physical characteristics along with the influence of external factors. Changes in soil water regime are currently very frequent and often change the water-air relationships in soil, which leads to occurrence of surplus or deficit of available water and ultimately to drying up of forests (Gračan et al., 1999).

Changes in water regime of soil are mostly due to climatic impacts (precipitation surplus and/or deficit), but also to regulation of major watercourses and construction of hydrotechnical canals.

According to their function, hydrotechnical canals can be divided into two groups: draining and melioration canals. The main aim of constructing draining canals as well as of watercourse regulation is to reduce flooding of populated areas and thereby protect human lives and material goods. Other, adverse effects of such construction are often underestimated or even disregarded.

Construction of draining ditches may also cause decrease of the groundwater level in the canal-bank soils resulting in drying up of the forests.

The other type of canal used to regulate soil water regime are melioration canals. It is obvious that, throughout the history, the development of civilizations was often largely associated to the degree of development of melioration systems. It is well known that forests in lowland ecosystems generally depend on maintaining the optimum long-term groundwater dynamics in soil. Long-term groundwater dynamics involves annual cyclic exchange of high levels, very close to soil surface during the autumn-winter period, and lower levels in the growing period. Occurrence of extreme values, namely higher deviation from regular fluctuation within the growing period, can lead to forest stress (Pilaš and Vrbek, 2001).

The performed investigations point to a good stochastic relationship between forest stress, expressed by the amount of dried trees, and extremely low groundwater
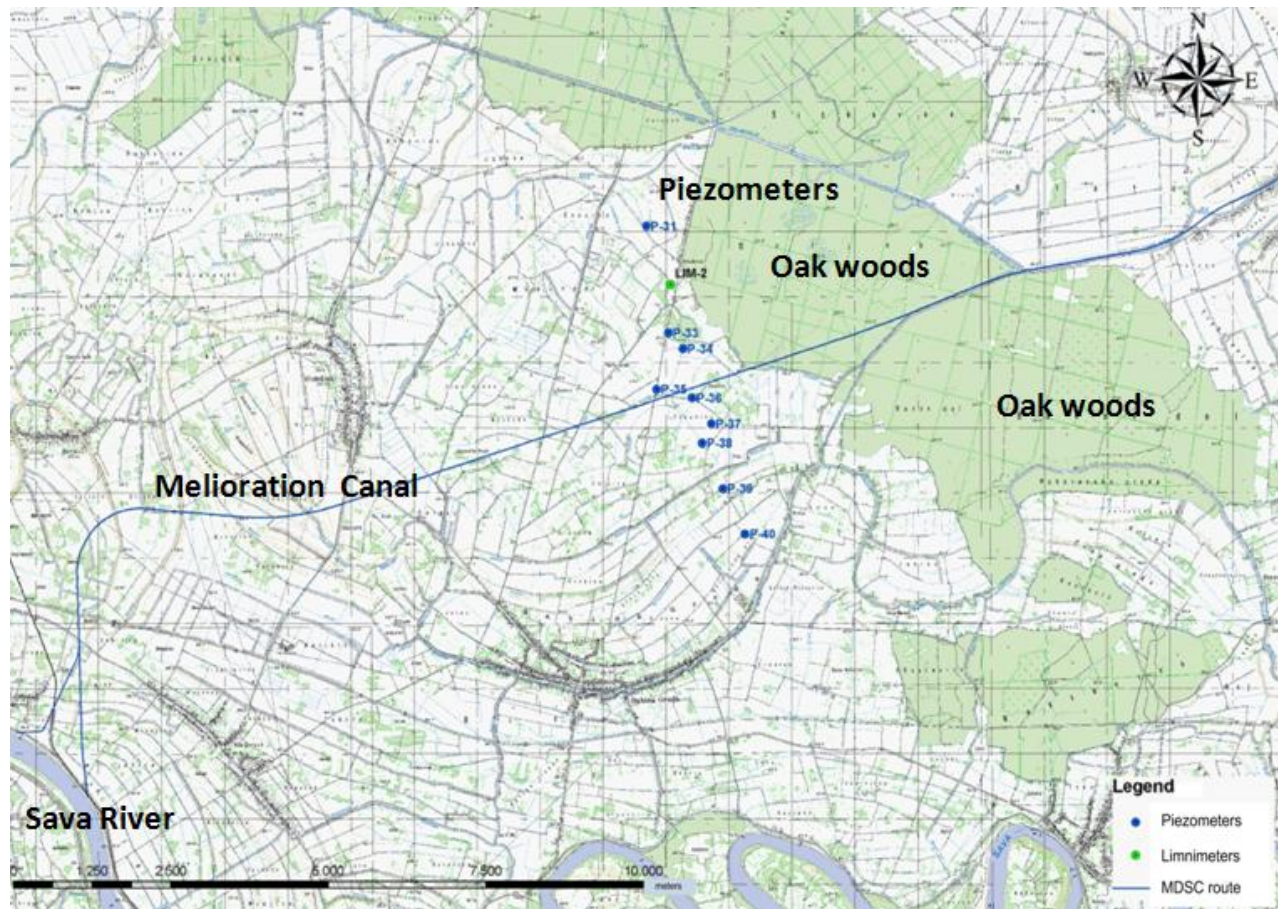
Figure 2. Melioration canal situation with plotted cross-section (profile) of monitoring.

levels in May, which occur every three to five years.

To avoid the consequences of long-term groundwater level decrease in a very sensitive lowland continental forest ecosystems, actions aimed at improvement of soil water regime in forest areas should be undertaken. Results of this study indicate that this can be achieved by constructing a melioration canal and the adequate accompanying infrastructure.

It should be emphasized that infiltration of water from draining canals or retentions into the aquifer can sometimes cause uncontrolled rising of groundwater level in soil; hence, it is also necessary to foresee the construction of appropriate systems that will contribute to reduction of surface water infiltration (Pelka and Horst, 1989).

MATERIALS AND METHODS

Surface and ground-waters are part of the hydrological cycle, and their interrelation is often investigated (Arumi et al., 2009). In hydrotechnical practice, the relationship between surface and groundwater is commonly investigated for the purpose of optimizing drainage and/or irrigation systems of agricultural areas; comprehensive analysis requires interrelation of canal flow models and groundwater flow models, taking into account also other relevant indicators, physical, chemical and biological processes going on in the hyporheic layer (Eglin et al., 1997; Kalbus et al., 2006; Schoups et al., 2005; Tsutsumi et al., 2004).

The assumption of this study was that an increase of water level in the melioration canal, compared to the groundwater level, will cause infiltration of surface water into the profile of soils in the immediate canal-bank area, which can be an essential factor for designing the canal (Pelka and Horst, 1989). Infiltration intensity can be determined by a number of methods, measurements of contact layer permeability as well as by using the continuity equation and analysis of input of chloride and hydrogen and oxygen isotopes (Trojan and Stockinger, 2004).

To investigate the impact of the designed canal on groundwater levels in the wider Biđ Field area, a series of piezometers were installed for permanent monitoring of groundwater levels and quality.

Monitoring the groundwater level by using observation wells is the major source of information about the effects of the melioration canal on the groundwater systems. Therefore, the knowledge and the insight in the groundwater system seem to be necessary for optimum water management. Because of the vicinity of forest areas (Orljak forest), the results of those investigations were also largely used in this study (Figure 2).

Some authors emphasize the use of geostatistics to analyze increase or decrease of groundwater near the melioration canal or river (Ahmadi and Sedghamiz, 2008) while other authors use numerical models, starting with simple one-dimensional model

based on the Darcy-s low till 3D numerical models with two-phase flow which include several processes such as rainfall, evapotranspiration, surface runoff, unsaturated flow and saturated subsurface water movement (Bereslavskii, 2006; Tsutsumi at al., 2004).

In the present paper, a simple but efficient model to calculate flow rate between melioration canal and groundwater is used. The VS2DTI (Hsieh et al., 2000) program has found application in a number of similar investigations such as: modelling of imidacloprid transport through soil (Burkingstock et al., 1997), modelling of the impact of soil slope and precipitation on lateral flow in soil (Crisfield and Radcliffe, 1999), estimation of characteristic soil moisture from aquifer data (Moench, 2003), role of subsurface water in river bed erosion (Fox et al., 2005), characterization of the variability of material transport from river beds into adjacent soil (Essaid et al., 2008), prediction of changes in soil water regime after construction of the Multifunctional Danube-Sava Canal (Mustać, 2009; Gjetvaj et al., 2008). However, regardless of whether transport of pollution through unsaturated media, lateral groundwater flow, or the influence of open watercourses on groundwater levels in adjacent soils are being modelled, the common characteristic of the mentioned models is that they all use functions that describe processes in the soil-water system in unsaturated media according to van Genuchten (1980).

Groundwater flow in characteristic hydrogeological cross-sections of the melioration canal was modelled. The used program is anticipated for modelling the two-dimensional unsteady flow and transport of pollution in saturated and/or unsaturated porous media.

The equation used to model groundwater flow through variably saturated porous media can be written as (Pelka, 1983):

$$\left(S \ \rho \ S_{op} + n \ \rho \ \frac{\partial S}{\partial p} \right) \frac{\partial p}{\partial t} - \nabla \cdot \left[\left(\frac{k \ k_r \ \rho}{\mu} \right) \cdot \left(\nabla p - \rho g \right) \right] = Q_p \qquad (1)$$

where:
S = degree of soil saturation; ρ = water density; S_{op} = storage coefficient; p = pressure; n = porosity; k = porous medium permeability coefficient; k_r = relative water permeability coefficient; μ = fluid viscosity coefficient and Q_p = fluid sink or source.

In modelling groundwater flow in variably saturated media, correct determination of the relative filtration coefficient (k_r), which increases non-linearly with the increase in soil saturation, is of great importance. Relative soil saturation (S) is defined as the ratio of water content in a soil sample (θ) to water content in a fully saturated soil sample (θ_s) reduced by the residual moisture content (θ_r):

$$S = \frac{\theta - \theta_r}{\theta_s - \theta_r} \qquad (2)$$

Soil saturation in aquifers depends on pore pressure and their interrelation is commonly defined by the van Genuchten expression (van Genutchen, 1980)

$$\theta = \left[\frac{1}{1 + \left(\alpha \ h \right)^n} \right]^m \qquad (3)$$

where h is pressure head and parameters n, m and α are called van Genuchten parameters.

Finally, the relative filtration coefficient equation can be written as:

$$k_r = \sqrt{S} \left[1 - \left(1 - S^{\frac{1}{m}} \right)^m \right]^2 \qquad (4)$$

The above expression was used to calculate the relative filtration coefficient for the case of flow in unsaturated medium along the melioration canal. Since van Genuchten's parameters have not been defined for soils into which the canal is dug the values from literature for similar materials were adopted (Hsieh et al., 2000; van Genutchen, 1980).

In all modelling variants, water level in the canal was adopted with the absolute elevation value of 80.00 m.a.s.l. The numerical model covered an area of the overall width of 3000 m and height of 15 m (Figures 6 and 7).

In the presented research water balance was done according to the Palmer's method (Palmer, 1965). Measurements of the soil vertical water permeability coefficient according to the Wray's method (Wray, 1986) were done in the surface solum to ca 1.5 m depth. Soil horizontal hydraulic conductivity was also determined in the solum to 4 m depth by the Auger Hole method (van Beers, 1962).

RESULTS

Water balance in soil

It is also assumed that groundwater levels in studied soils are, among others, affected by precipitation, evapotranspiration, surface runoff and water regimes of the rivers Sava and Biđ. Thus, after canal construction, draining of adjacent canal-bank soils can be expected in the wet periods of the year as well as its recharging from the canal in the dry periods.

It is also notable that a water bearing layer underlies the surface layer of approximately 15 m, in which sub-artesian and artesian flow often occurs (Figure 3). Sub-artesian water causes additional infiltration of the poorly permeable covering layer, contributing to an increase in surplus water in the wet periods of the year.

Precipitation

The studied region is situated in the transition zone from semiarid to semi-humid continental climate. Average amounts of annual precipitation (for the period from 1981 to 2009) in the wider investigation region are about 700 mm (Figure 4).

Measurements and literature data show that in the forest areas through which the future melioration canal will be built, the average precipitation is P = 700 mm, interception coefficient Int = 0.3 and infiltrated precipitation Inf =20% (Mustać, 2009). For the area along the canal of the width B = 3000 m (1500 m on each side of the canal), annual infiltration per kilometre (L=1000 m) can be calculated:

$W_{prec} = P * (1 - Int) * Inf * B * L$

Figure 3. Appearance of artesian water in the studied region (location Babina Greda).

$W_{prec}=0.7*0.7*0.2*3000* 1000 =2.94*10^5$ m^3/yr/km

Due to large amounts of precipitation water infiltrated into soil, water surplus can occur periodically. Water surplus is also caused by infiltration of sub-artesian water, which depends on the pressure in the deep water-bearing aquifer.

Water surplus and deficit in average soil in the studied region

Water balance, focused on estimating the occurrence of its surplus and/or deficit in average soil of the studied region over the period from 2001 to 2006, was done according to the Palmer's method (Palmer, 1965). The obtained values are given in Tables 1, 2 and Figure 5.

Analysis of the presented indicators shows that the values of annual water surplus in the average (hypogley) soil during the monitored period fluctuated in the range from minimum 19 mm (in 2002 to maximum 274 mm in 2004). Surplus water mostly appears in the winter-spring period (Nov., Dec., Jan., Feb., March and April). The highest water surplus generally occurs in January and amounts to approximately 33.5 mm. The average mean annual water surplus of 163 mm was recorded during the monitored period 2001 to 2006. However, maximum monthly and annual amounts of water surplus in average hypogley soil were much higher in humid years (for example, in 2004), notably in April with 75.0 mm, January with 64.0 mm and November with 600 mm.

Besides water surplus that occurs in wet periods of the year, water deficit also appears in dry periods. Water deficit values in average soil of the Biđ-Bosut region fluctuated in the range from minimum 67 mm (in 2005) to maximum 432 mm (in 2003) in the studied period (2001 - 2006). Occurrence of water deficit was mostly recorded in summer months (June, July, Aug. and Sep.). The highest water deficit generally occurs in August (41.8 mm) or July (39.0 mm). The mean annual water deficit in soils of the studied region during the investigation period (2001-2006) was about 178 mm. It is, however, noteworthy that occurrence of water deficit during dry years such as 2003 was much more expressed, with water deficit of 65.0 mm in June and 93.0 mm in August.

Model of groundwater flow in the immediate vicinity of the melioration canal

The basic assumption is that the impact of the melioration canal on groundwater dynamics in soil will primarily depend on the geological structure and permeability of strata into which the canal will be built, namely, on the

Table 1. The values of water surplus in the average soil (mm) according to the Palmer method (2001-2006).

Year	Months												Year Σ
	I	II	III	IV	V	VI	VII	VIII	IX	XI	XI	XII	
2001	64.0	0.0	11.0	0.0	0.0	61.0	0.0	0.0	48.0	0.0	60.0	20.0	264.0
2002	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	19.0
2003	37.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	44.0
2004	50.0	20.0	3.0	75.0	48.0	25.0	0.0	0.0	0.0	0.0	43.0	10.0	274.0
2005	21.0	45.0	13.0	11.0	0.0	0.0	31.0	48.0	0.0	0.0	0.0	27.0	196.0
2006	29.1	30.7	50.7	31.5	0.0	0.0	0.0	17.7	0.0	0.0	3.5	16.4	181.0
Max.	64.0	45.0	50.7	75.0	48.0	61.0	31.0	48.0	48.0	0.0	60.0	27.0	274.0
Sred.	33.5	18.8	13.0	19.6	8.0	14.3	5.2	11.0	8.0	0.0	17.8	13.7	163.0
Min.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.0

Table 2. The values of water deficit in the average soil (mm) according to the Palmer method (2001-2006).

Year	Months												Year Σ
	I	II	III	IV	V	VI	VII	VIII	IX	XI	XI	XII	
2001	0.0	0.0	0.0	0.0	27.0	0.0	32.0	86.0	0.0	10.0	0.0	0.0	155.0
2002	0.0	0.0	19.0	0.0	8.0	65.0	76.0	53.0	0.0	0.0	0.0	0.0	221.0
2003	0.0	0.0	27.0	34.0	44.0	65.0	79.0	93.0	50.0	11.0	16.0	13.0	432.0
2004	0.0	0.0	0.0	0.0	0.0	0.0	33.0	19.0	20.0	0.0	0.0	0.0	72.0
2005	0.0	0.0	0.0	0.0	0.0	16.0	0.0	0.0	20.0	31.0	0.0	0.0	67.0
2006	0.0	0.0	0.0	0.0	54.6	31.5	13.9	0.0	17.7	0.0	0.0	0.0	119.0
Max.	0.0	0.0	27.0	34.0	54.6	65.0	79.0	93.0	50.0	31.0	16.0	13.0	432.0
Sred.	0.0	0.0	7.7	5.7	22.3	29.6	39.0	41.8	18.0	8.7	2.7	2.2	177.7
Min.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	67.0

water level in the canal and groundwater level. The melioration canal has been designed as the first phase of the Multifunctional Danube-Sava Canal (MDSC). To estimate the amount of water infiltrated and/or drained from the canal, a model of groundwater flow in the 15 m thick covering layer was developed.

Geological structure of the covering layer of the studied profile

Measurements of the soil vertical water permeability coefficient were done in the surface solum to ca 1.5 m depth (Wray, 1986). Values of the vertical water permeability coefficient of the covering layer ranged from 3.4×10^{-8} to 1.27×10^{-5} m/s. Soil horizontal hydraulic conductivity was also determined in the solum to 4 m depth by the Auger Hole method (van Beers, 1962); its mean values per location fluctuated in the range from 4.75×10^{-6} to 1.4×10^{-3} m/s. When constructing the numerical model, the geological structure and major hydraulic characteristics of deeper strata (> 4 m depth) were adopted on the basis of indicators determined by geological investigations for the needs of canal design.

The adopted characteristic geological profile is represented in Figure 6.

The characteristic profile used to model groundwater flow in this study is located at MDSC chainage 47+750 (Figure 7). The main characteristic of this profile is that the strata into which the canal should be dug are made of poorly permeable materials.

At the lower boundary of the modelled region there is a water-bearing aquifer in which piezometer levels were measured by the installed piezometers. Long term monitoring (2001-2006) of groundwater levels revealed that fluctuation in the characteristic canal profile varies in the range of absolute values from 78.7 m.a.s.l. to 82.7 m.a.s.l. Groundwater level in the studied profile was lower than the standing water level in the canal (80 m.a.s.l.) in dry periods of the year, which points to the possibility of aquifer recharge with water from the canal.

Results of the numerical model show that in the case when the water level in the aquifer is 82.7 m.a.s.l., the canal will cause a decrease of groundwater level in soil by 1 cm (Δh = 1 cm) in the 970 m wide zone, i.e. 485 m to the left and to the right of the canal axis, with water inflow into the canal of 47.4 m^3/yr/km'. At the groundwater level in the covering layer of 81.7 m.a.s.l., the canal impact
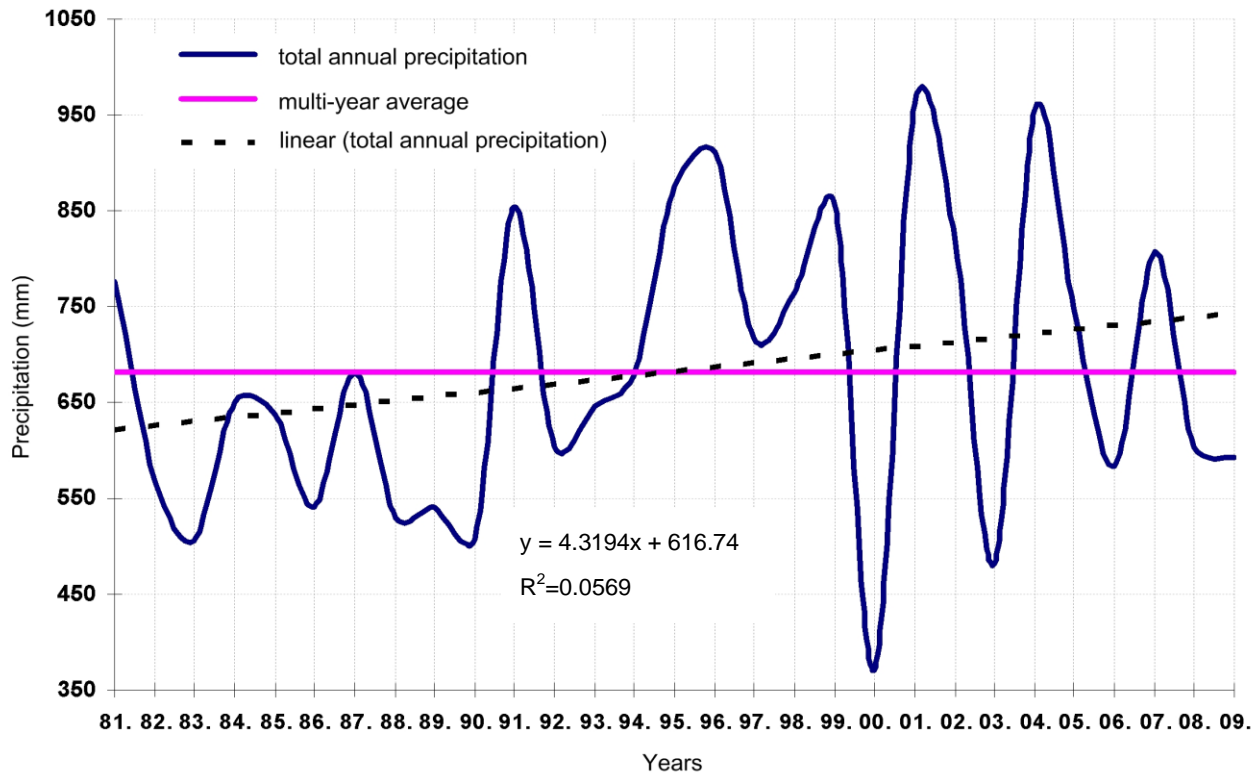
Figure 4. Annual fluctuation of average monthly precipitation in the Biđ-Bosut region, for the period from 1981 to 2009.

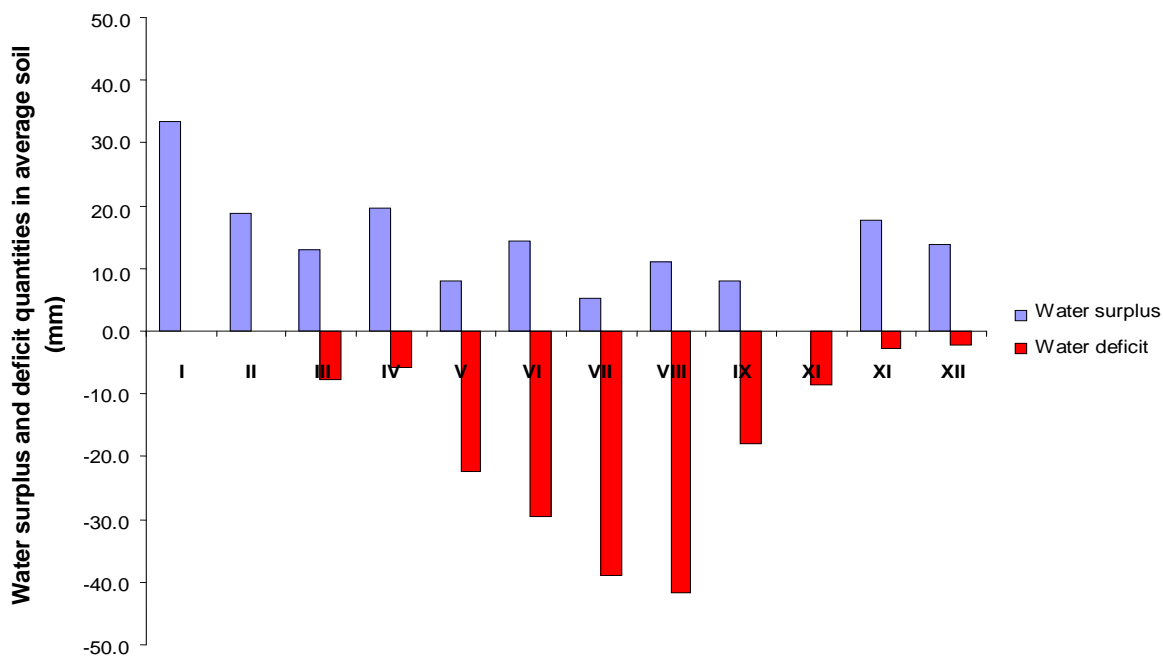$$y = 4.3194x + 616.74$$
$$R^2 = 0.0569$$

Figure 5. Mean values of water surplus and deficit quantities in average soil (mm), for the period from 2001 to 2006.

zone will be 410 m wide, and water inflow into the canal will amount to 32.8 m^3/yr/km'. In the conditions of groundwater level in soil of 80.7 m.a.s.l., the canal impact zone will be only 230 m wide (Figure 8).
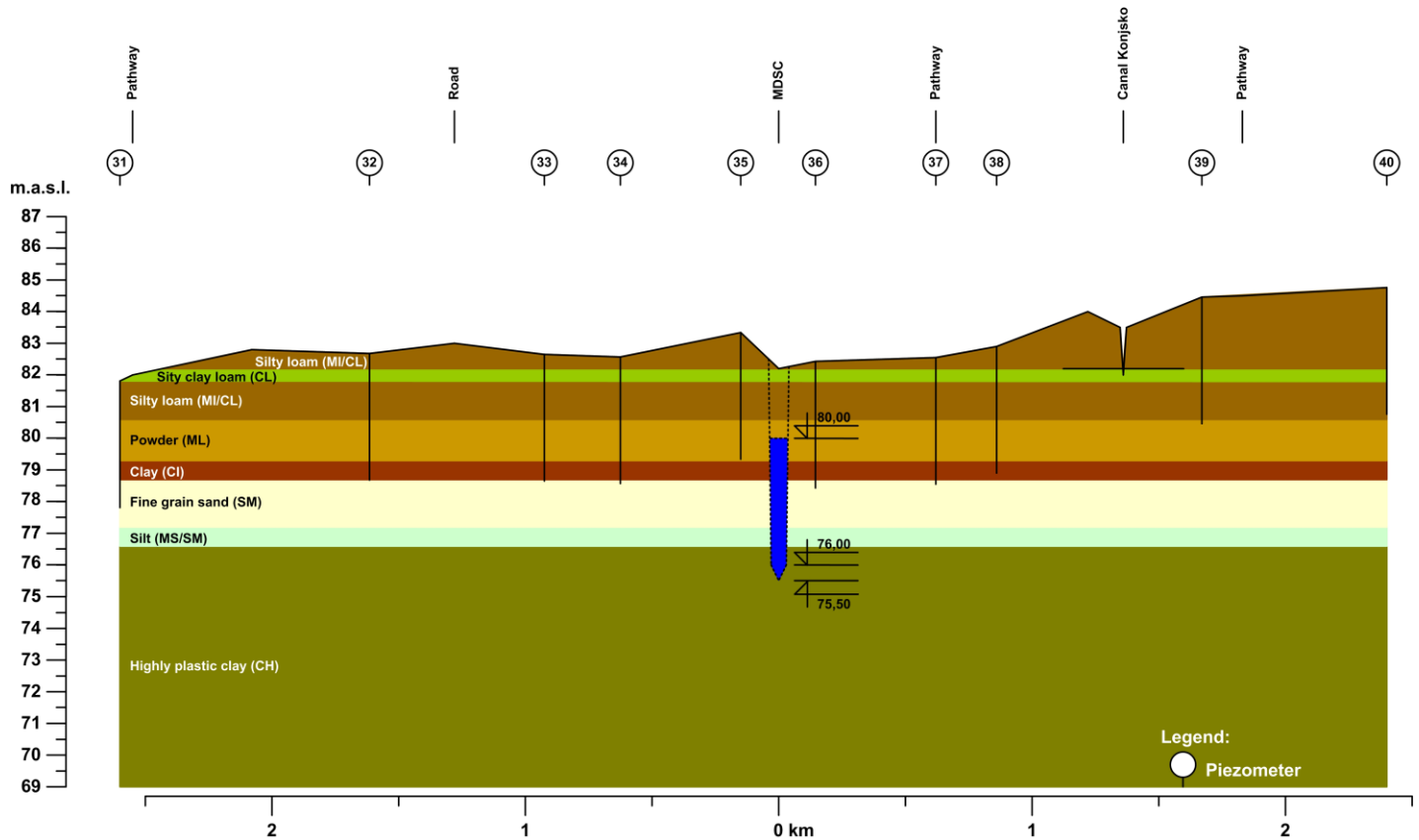
Figure 6. Relief and lithological structure of the Profile Babina Greda – Konjsko – Kladavac**.**
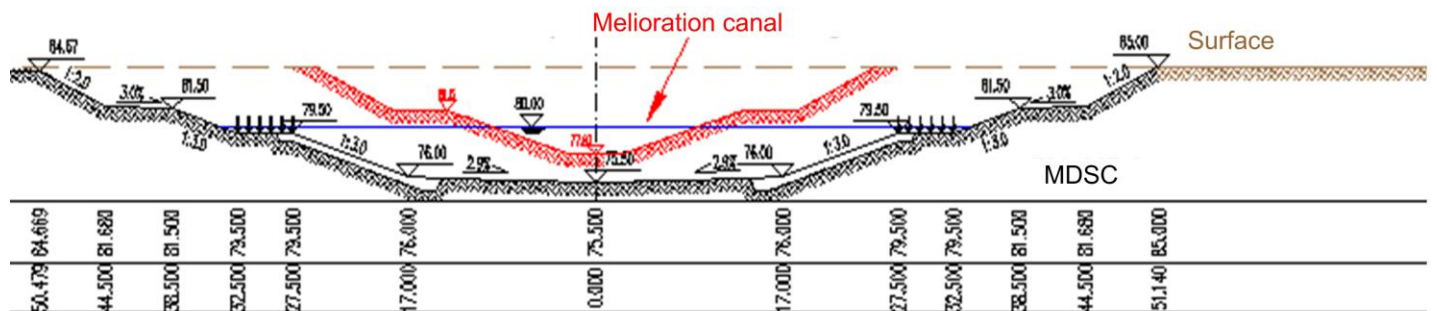

Figure 7. Characteristic cross-section of MDSC and Melioration Canal.

If the area in which the canal changes the natural water level by 10 cm is adopted as the zone of monitoring groundwater level changes, then it can be concluded that groundwater level changes will be observable in the width of 110 to 730 m, depending on the groundwater level in soil (Figure 8).

At the absolute groundwater level in soil below 80.0 m.a.s.l., occurrence of water infiltration from the canal into the aquifer and recharging of the canal bank area with water can be expected.

In the cases when the groundwater level in the aquifer (soil) is at the height of 79.7 m.a.s.l., aquifer recharge with canal water can be expected, as well as rise of water level by 1 cm in a 160 m wide zone.

Cases when the groundwater level in the aquifer (soil) is at the height of 78.7 m.a.s.l., recharging of canal-bank soils with water can be expected, and a rise of water level in soil by 1 cm due to canal construction will occur in a 250 m wide zone (125 m to the left and right of canal axis).
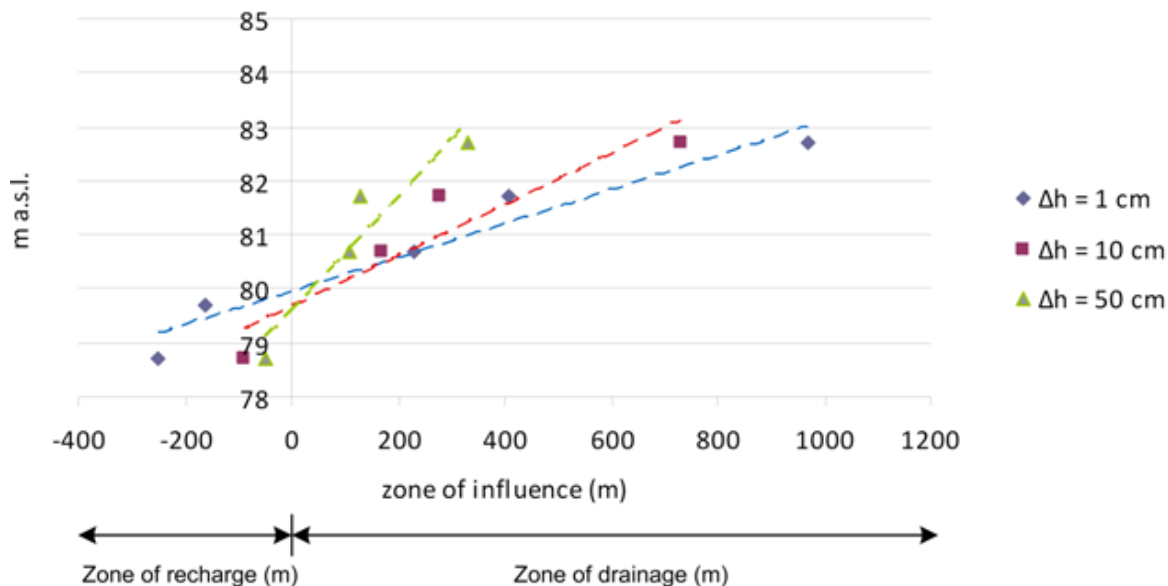
Figure 8. Zone of melioration canal impact on groundwater level in soil in the characteristic profile.

The amount of water infiltrated into the aquifer will be 77.0 m³/yr/km'. The increase of groundwater level in soil by 10 cm, at its absolute level of 78.7 m.a.s.l., should be expected in a 90 m wide zone.

Hydraulic calculations done in this study indicate that the impact of infiltration through the melioration canal bed will be noticed in an area less than 1000 m wide and that the amount of infiltrated water is much smaller compared to the water infiltrated by precipitation.

DISCUSSION

Canals are primarily constructed to reduce large water waves (i.e. hydrotechnical canals) or to improve water regime in agricultural areas and in forests (melioration canals). Some of current lowland forests are located in water-retention areas established to protect settlements against floods. The purpose of canals built in central Sava valley is to protect settlements against floods.

This system for flood protection uses some forest and swamp areas for water retention and accumulation (Vrbek at al., 2006). However, frequent incidence of floods in such areas, along with occurrence of anaerobic processes in soil, can also lead to drying up of forests (Gračan et al., 1999). It was established that this system increases excessive moisture in the area of the forests Turopoljski lug and Kalje, Žutica, Opeka, Zelenika and Međustrugovi (Vrbek at al., 2006). It is noteworthy that excessive soil moisture, as a consequence of the erected structures, can be reduced and/or fully eliminated by technical improvements, namely, additional hydrotechnical interventions. As a side effect in some

areas a decrease of water levels and drying of forests occur.

Data on groundwater dynamics collected throughout Croatia indicate that a trend of groundwater level decrease is generally present in the lowland forest zone (Vrbek at al., 2006). Occurrence of seasons with markedly low levels was especially noticed in 1993, 2000 and 2003. Available measurement results lead to the conclusion that the impact of groundwater level decrease on forest ecosystems is most critical in Eastern Slavonia. This is particularly obvious in the Spačva region, in pedunculate oak forests on hypogley and humogley soils with high groundwater level oscillations (Vrbek at al., 2006).

The results obtained in this study are in accordance with investigations done in the Netherlands (Mulder et al., 1994), which showed that the canal impact on the decrease of the groundwater level in soil by 50 cm should be expected about 500 m to the left and to the right from the longitudinal canal axis.

The studies of the impact of the Gabickovo hydroelectric power plant and its accompanying hydrotechnical structures upon the groundwater regime showed that hydrotechnical canals constructed in that region had a strong influence on groundwater regime stabilization (Bansky and Mazariova, 1995) and that the constructed canals had a positive effect on the development of agricultural production, because they enabled application of controlled drainage and irrigation (Šoltesz, 2001). Similar conclusions were also reached during the construction of the Marchfeld canal in Austria (Notz and Neudorfer, 2002).

It can be expected that the construction of large

hydrotechnical structures such as draining and melioration canals in a region, in dependence on their specific climatic, geomorphological, hydrological and hydropedological characteristics, will have different influence upon local ecosystems, notably on the water regime of soils.

The investigation results presented in this paper indicated that the main impact of the construction of the melioration canal on the stretch of settlements Babina Greda-Kladavac, namely, at the place where the canal directly borders the area of forest areas in the forest complex "Banov dol", would involve a certain lowering of the groundwater level in soil (drainage). However, in dry years such as 2000 and 2003 when groundwater levels in soil were lower than 2.5 and 3.0 m from ground surface, respectively, the primary role of the canal would be to enable the irrigation of canal-bank forest.

The amount of recharge/drainage through the canal bed is relatively small because of low permeable soil. On the other hand the construction of canals and related infrastructure for the regulation of ground-water level will enable the formation of an optimal water regime for forest growth.

Conclusion

The area of investigation is situated in the transition zone from semiarid to semi-humid continental climate with average amounts of annual precipitation of 700 mm. Annual water surplus in average (hypogley) soils in the period of investigation range from minimum 19 mm (in 2002) to maximum 274 mm (in 2004). Water deficit ranged from minimum 67 mm (in 2005) to maximum 432 mm (in 2003).

Values of the vertical water permeability coefficient of the surface layer ranged from 3.4×10^{-8} to 1.27×10^{-5} m/s. Mean values of soil horizontal hydraulic conductivity per location (up to 4 m depth) fluctuated in the range from 4.75×10^{-6} to 1.4×10^{-3} m/s. Multi-year monitoring (2001-2006) of groundwater dynamics revealed the fluctuation of it's level in the range of absolute values from 78.7 m.a.s.l. to 82.7 m.a.s.l.

Results of the numerical model show that in the case when the water level in the aquifer is 82.7, 81.7 and 80.7 m.a.s.l., the canal will cause a lowering of groundwater level in soil by 1 cm ($\Delta h = 1$ cm) in a 970, 410 and 230 m wide zone respectively. Decrease of groundwater level in soil by 10 cm ($\Delta h = 10$ cm) caused by canal can be observed in a zone of 110 to 730 m width depending on the groundwater level in soil.

At the absolute groundwater level in soil below 80.0 m.a.s.l., occurrence of water infiltration from the canal into the aquifer and feeding of the canal bank area with water can be expected. In the cases when the groundwater level in the aquifer (soil) is at a height of 79.7 and 78.7 m.a.s.l., aquifer recharge with canal water can be expected, as well as rise of water level by 1 cm in

a 160 and 250 m wide zone respectively.

REFERENCES

Ahmadi SH, Sedghamiz A (2008). Application and evaluation of kriging and cokriging methods on groundwater depth mapping. Environ. Monit. Assess., 138: 357-368.

Arumi JL, Rivera D, Holzapfel E, Boochs P, Billib M, Fernard A (2009). Effect of the Irrigation Canal Network on the Surface and Groundwater Interactions in the Lower Valley of the Cachapoal River. Chilean J. Agric. Res., 69(1): 12-20.

Bansky L, Mazariova K (1995). Ground Water Regime Changes in the Area Influenced by Construction of Gabickovo Hydropower Structures. Fround Water Consulting Ltd., Bratislava.

Van Beers WFJ (1962). Die Bohrlochmethode – Eine Feldvermessung der Wasserdurchlassigkeit unter dem Grundwasserspiegel. (Dt. R. Binsack) Bull. 1 D – Intern. Inst. f. Landgewinnung und Kulturtechnik. Wageningen/Niederlande: H. Veenman & Zn.

Bereslavskii EN (2006). Groundwater Flow to a System of Drainage Canals. Wat. Res., 33(4): 417-420.

Burkingstock KB, Bush PB, Berisford YC, Dowd JF, Feild JB, Johnson WW, Rasmussen TC, Taylor JW (1997). Predicting the Fate of Imidacloprid in a Coastal Plain Setting Using VS2DT: Proceedings of the 1997 Georgia Water Resources Conference held ate Athens, Georgia, pp. 508-511.

Crisfield E, Radcliffe DE (1999). Modeling the Effect of Slope and Precipitation on Lateral Flow in a Piedmont Soil: Proceedings of the 1999 Georgia Water Resources Conference held at Athens, Georgia, pp. 582-585.

Eglin I, Roeck U, Robach F (1997). Macrophyte Biological Methods used in the Study of the Exchange between the Rhine River and Groundwater. Wat. Res., 3: 503-514.

Essaid HI, Zamora CM, McCarthy KA, Vogel JR, Wilson JT (2008). Using Heat to Characterize Streambed Water Flux Variability in Four Stream Reaches. J. Environ. Qual., 37: 1010-1023.

Fox GA, Wilson GV, Priketi R, Cullum BF, Gordji L (2005). The Role of Subsurface Water in Contributing to Streambank Erosion: US-China Workshop on Advanced Computational Modelling in Hydroscience & Engineering held at Oxford, Mississippi, pp. 1-10.

Genutchen MT van (1980). A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J., 44: 892-898.

Gjetvaj G, Petošić D, Mustać I (2008). Prediction of Water Balance Change After Construction of the Danube-Sava Multipurpose Canal. Abstracts of the 24th Conference of the Danubian Countries on the Hydrological Forecasting and Hydrological Bases of Water Management held at Bled, Slovenia, pp 98.

Gračan J, Vrbek B, Pilaš I (1999). The Groundwater Monitoring in a Pedunculate oak Forrests in Croatia: Proceedings of the 3rd Workshop Javne gozdarske službe held at Murska Sobota, Slovenia, pp. 85.

Hsieh PA, Wingle W, Healy RW (2000). VS2DI - A Graphical Software Package for Simulating Fluid Flow and Solute or Energy Transport in Variably Saturated Porous Media: U.S. Geol. Surv. Water Resour. Investigat. Report, pp. 9-4130.

Kalbus E, Reinstorf F, Schirmer M (2006). Measuring methods for groundwater-surface water interaction. Hydrol. Earth Syst.Sci., 10: 873-887.

Maurer DK (2002). Ground-water flow and numerical simulation of recharge from streamflow infiltration near Pine Nut Creek, Douglas County, Nevada. US Geol. Surv., 4145: 48.

Moench AF (2003). Estimation of Hectare-Scale Soil-Moisture Characteristics From Aquifer-Test Data. J. Hydrol., 281: 82-95.

Mulder GJ, Luijten CJLM, Schouten CP (1994). Case study: modelling the impact of a drainage-system along a depressed roadbed and the resulting risks to agriculture: Proceedings of the Conference on the Future Groundwater Resources at Risk held at Helsinki, Netherlands. IAHS Publ., 222: 61-70.

Mustać I (2009). Modelling of Danube-Sava Multipurpose Canal Impacts on Ground Water Dynamics. PhD dissertation, University of Zagreb, Faculty of Agriculture, Zagreb, Croatia (in Croatian).

Notz M, Neudorfer W (2002). Development and operation of Marchfeldkanal system. 10 years of flooding Marchfeld channel beginning of Grundwasserbewirtschhaftung, pp. 25-40.

Palmer WC (1965): Meterological Drought. US Weather Bereau. Washington DC, P. 45.

Pelka W (1983). Heat and mass transport in saturated-unsaturated groundwater flow. Proceedings of the Hamburg Symposium held at Hamburg, Germany. IAHS Publ., 146: 159-166.

Pelka W, Horst R (1989). Finite element combined surface water/groundwater model for the River Rhine, Kehl/Strasbourg reservoir. Proceedings of the Benidorm Symposium held at Benidorm, Spain. IAHS Publ., 188: 523-532.

Pilaš I, Vrbek B (2001). An Examination of Groundwater Level Dynamics in Hydromorphic Lowland Forest Soils with the Aid of Spectral Analysis. Proceed. 9th Congres Croatian Soc. Soil Sci. held at Brijuni, Croatia, pp. 119-120.

Prasad T (1990). Role of surface water-groundwater interaction in water resource management and agricultural development in an alluvial region. The Hydrological Basis for Water Resour. Manage. IAHS Publ., 197: 79-88.

Schoups G, Addams CL, Gorelick SM (2005). Multi-objective calibration of a surface water-groundwater flow model in an irrigated agricultural region: Yaqui Valley, Sonara, Mexico. Hydrol. Earth Syst. Sci. Discuss., 2: 2061-2109.

Šoltesz A (2001). Water Management in Regions Affected by Water Structure Construction and Operation. Slovak University of Technology, Bratislava, Slovakia.

Trojan D, Stockinger M (2004). Estimated Surface Water Contribution to Ground Water Recharge in the Verdi Aquifer, Southwest Minnesota. MPCA's Environ. Bullet., 3: 2-8.

Tsutsumi A, Jinno K, Berndtsson R (2004). Surface and subsurface water balance estimation by the groundwater recharge model and a 3-D two-phase flow model. Hydrol. Sci. J., 49(2): 205-226.

Vrbek B, Pilaš I, Potočić N, Seletković I (2006). The Research of Groundwater Table Levels, Input of Heavy Metals and Crown Condition in Forest Ecosystems of Croatia. Croatian Forest Research Institute, Jastrebarsko, Croatia, pp. 159-180.

Wray W (1986). Measuring engineering properties of soil. Department of Civil Engineering Texas Tech. University, USA.