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IMPACT OF THE FUTURE MULTIPURPOSE DANUBE-SAVA CANAL ON GROUNDWATER DYNAMICS

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Original scientific paper

The main research goal was to assess the potential impact of the future Multipurpose Danube-Sava Canal (MDSC) on the groundwater level in agricultural soils spread in the immediate hinterland on both sides of the canal, in the lower part of its course. To observe the impact of the canal envisaged by the project on potential changes of the groundwater level, a series of piezometer boreholes were drilled along the canal course. Geological and hydropedological characteristics of the covering layer were determined in all boreholes and groundwater levels were continually monitored over a six-year period (2001 to 2006). The obtained indicators were used to design a numerical model of groundwater flow. The model indicated that MDSC would primarily have a draining role in the largest part of the studied area. Only in a smaller part of the studied area with the lowest terrain elevation will the MDSC feed adjacent agricultural soils with water.

Keywords: *groundwater, multipurpose Danube-Sava Canal, numerical model*

Utjecaj budućeg višenamjenskog kanala Dunav-Sava na dinamiku podzemnih voda

Izvorni znanstveni članak

Temeljni cilj istraživanja bila je procjena mogućeg utjecaja budućeg Višenamjenskog kanala Dunav-Sava (VKDS) na dinamiku podzemnih voda poljoprivrednih tala, koja se prostiru u neposrednom zaobalju s obje strane kanala, na donjem dijelu njegove trase. Za potrebe sagledavanja utjecaja projektom predviđenog kanala na moguće promjene razine podzemnih voda, duž trase kanala izrađen je niz pijezometarskih bušotina. Na svim bušotinama su određene geološke i hidropedološke značajke pokrova te je kontinuirano osmatrana razina podzemnih voda u razdoblju od 6 godina (2001. do 2006.). Dobiveni pokazatelji poslužili su za izradu numeričkog modela toka podzemnih voda. Modelom je utvrđeno da će VKDS na najvećem dijelu istraživanog područja prvenstveno imati drenirajuću ulogu. Na manjem dijelu istraživanog područja, s najnižim kotama terena, VKDS će prihranjivati vodom zaobalna poljoprivredna tla.

Ključne riječi: *matematički model**,** podzemna voda, višenamjenski kanal Dunav-Sava*

1 Introduction
Uvod

The first written documents about plans to build a canal that would connect the rivers Danube and Sava date from 1737. Since then, more than 14 variants of its construction have been considered. The idea of the canal was reactualized after Croatia gained independence and in 1991 the Government of the Republic of Croatia passed the *Decision on preparatory works for the Danube-Sava Canal construction*. There is no doubt that the future multipurpose Danube-Sava canal (MDSC) will have a strong impact on natural potentials and agricultural ecosystems, primarily on the water regime of soils along the whole canal course from Vukovar to Slavonski Šamac. Due to specific topographic, hydrological and hydropedological characteristics of the region, the strongest impact of the canal, particularly on groundwater dynamics, can be expected along its lower course (from 36 to 61,5 km).

In this study, the impact of the future MDSC upon groundwater dynamics was modelled in a part of the Biđ-field and covered solely agricultural soils between the settlements Velika Kopanica in the west and Babina Greda in the east, Sikirevci in the south and Kladavci in the north. Total area of the wider studied region is ca 9000 ha (Fig. 1).

From the hydrotechnical aspect, the region is protected from foreign waters, both flood and drainage water. However, surplus internal water (ground and/or surface water), which periodically appears due to specific characteristics of the climate, relief, soil stratigraphy and local hydrography, is still a problem.

It is notable that the most abundant reserves of best quality drinking water in Eastern Slavonia are found in such a narrow area [1]. 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 [2].

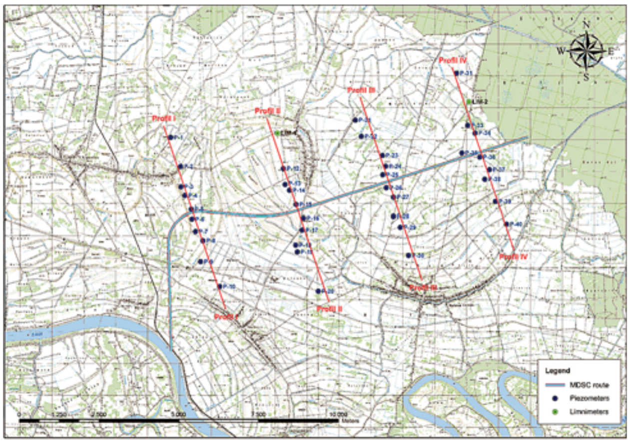

Figure 1 *Map of the studied area*
Slika 1. *Karta istraživanog područja*

The goal of the study was to apply a numerical model to precisely define the zones of impact of the future MDSC upon groundwater dynamics in soils in the immediate canal hinterland, which covers 6600 ha of agricultural areas.

2 Materials and methods
Materijali i metode rada

Detailed pedological investigations, including preparation of a 1:10000 scale soil map of the studied region in the immediate canal zone (8881 ha) were conducted in 2000. Hydropedological investigations encompassed field measurements of the soil horizontal hydraulic conductivity by the auger-hole method [3]. Vertical hydraulic conductivity was determined in the laboratory by standard methods after Darcy [4].

Groundwater dynamics was permanently monitored by means of hydropedological piezometers on 6600 ha in the period from 2001 to 2006, paying special attention to groundwater level fluctuation in the hydropedological profile to 4,0 m solum depth. For that purpose, 40 hydropedological piezometers were installed at a depth of 4,0 m (Fig. 1). It is worth mentioning that automatic Orphimedes limnimeters were mounted in two of the hydropedological piezometers for daily monitoring of groundwater level fluctuation.

Piezometers were laid out according to a defined scheme, in four lines – cross-sections (Profiles I, II, III and IV), perpendicular to the MDSC longitudinal axis (Fig. 1). Ten piezometers were installed on each line. The layout of piezometers (distance from the canal longitudinal axis) was the same on all lines (I, II, III and IV): 200, 500, 1000, 1500 and 2500 m to the left and right of the canal. Piezometer lines were positioned ca 3,5 km apart. Water levels in piezometers were measured by the traditional method each ten days (3 × a month) in the period 2001-2006. Daily groundwater levels were measured continually at two locations by means of automatic limnimeters (Orphimedes).

2.1 Numerical model

Matematički model

Groundwater flow in selected hydrogeological profiles of MDSC (I, II, III and IV) was modelled using the VS2DTI program (Version 1.2) produced by the *US Geological Survey* [5]. The program is foreseen for modelling the two-dimensional nonstationary flow and transport of matter in saturated and/or unsaturated porous media. The basic equation used to model groundwater flow can be written as:

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

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

As groundwater flow in saturated and unsaturated media is being modelled, correct determination of the relative permeability, which depends on the degree of soil saturation, is of great importance. The van Genuchten model was used to calculate the relative permeability:

$$S = \frac{V_V}{V_p} \Rightarrow S = \frac{\theta}{\theta_s}. \quad (2)$$

Van Genuchten [6] developed the empirical expression that defines increase in soil saturation in dependence on the pore pressure in soil. This model is represented by equations (3) where h_p is the piezometer water level in the studied soil pore.

$$\begin{aligned} \theta &= \theta_r + (\theta_s - \theta_r) \cdot \left[1 + \left(\alpha \cdot \left|h_p - h_{pa}\right|\right)^n\right]^m && \text{for } h_p < h_{pa} \\ \theta &= \theta_s && \text{for } h_p \geq h_{pa} \end{aligned} \quad (3)$$

The first equation contains unknown variables n, m and α. They are referred to as *van Genuchten's parameters*. As it is taken that the value of atmospheric pressure equals zero, the above equations can be written in the following way:

$$\begin{aligned} \theta &= \theta_r + (\theta_s - \theta_r) \cdot \left[1 + \left(\alpha \cdot \left|h_p\right|\right)^n\right]^m && \text{for } h_p < 0 \\ \theta &= \theta_s && \text{for } h_p \geq 0 \end{aligned} \quad (4)$$

Inserting the obtained expressions into the equation of the relative degree of saturation, the latter (S) is thus related to the pore water pressure in soil:

$$\begin{aligned} S &= \frac{\theta - \theta_r}{\theta_s - \theta_r} = \left[1 + \left(\alpha \cdot \left|h_p\right|\right)^n\right]^m && \text{for } h_p < 0 \\ S &= 1 && \text{for } h_p \geq 0 \end{aligned} \quad (5)$$

Maximum soil permeability is defined by the filtration coefficient of saturated media. The value of the filtration coefficient for unsaturated media was obtained by multiplying the filtration coefficient of saturated media by the *relative permeability* (k_r):

$$k_n = k_s \cdot k_r. \quad (6)$$

It is thus obvious that the value of the relative permeability must be a function of soil saturation, which in turn depends on pore pressure. Finally, the relative permeability, equation (7), can be written as:

$$k_r = \sqrt{S} \cdot \left[1 - \left(1 - S^{\frac{1}{m}}\right)^m\right]^2. \quad (7)$$

The above expression (7) was used to calculate the relative permeability for the case of flow in unsaturated media. In all modelling variants, the standing water level of MDSC implied the value of absolute elevation of 80,00 m.a.s.l. The numerical model covered an area of the overall width of 3000 m, or 1500 m to each side of the longitudinal canal axis and a solum depth (aquifer) of 15 m.

2.2 Model of the groundwater flow in the immediate zone of the future Multipurpose Danube-Sava Canal

Model toka podzemne vode u neposrednoj zoni budućeg višenamjenskog kanala Dunav – Sava

It was generally assumed in modelling that the impact of the future Danube-Sava canal on groundwater dynamics in soil would primarily depend on the geological structure of the strata into which the canal would be dug, water level in the canal, and the groundwater level in the said strata. It is noteworthy that according to the project [7], the MDSC in the studied region would be dug into a relatively shallow, poorly permeable covering stratum without intruding into deeper water-bearing strata. To determine the quantity of infiltrated and/or drained water in the immediate vicinity of the canal zone, groundwater flow in the covering stratum (to maximum thickness of 15 m) was modelled. Modelling was carried out in four characteristic hydrogeological Profiles (I, II, III and IV), for which appropriate hydropedological and hydrogeological investigations were performed.

3 Results
Rezultati istraživanja

3.1 Section Beravci-Gundinci-Sikirevci (Profile I)
Presjek Beravci-Gundinci-Sikirevci (Profil I)

For the needs of modelling groundwater flow in Profile I (which also applies to the other Profiles), canal geometry was adopted on the basis of design documentation [7]; it corresponds to the cross-section of the canal at the MDSC chainage 56+500 (Fig. 2). Full black line shows the cross-section of MDSC with the bottom elevation at 75,50 m a.s.l. Black line (and labeled "profile I. faze") represents a cross section of ameliorative canal which will be the first phase in construction of the MDSC. The profile of the excavation for the case of the formation of borrow pit for construction of Corridor Vc is marked with purple line. This also applies for Fig. 4, 6 and 8.

Tab. 1 presents the main characteristics of water-bearing strata adopted in modelling, while Tab. 2 and Fig. 3 give the values of the width of the zone of the MDSC impact on the groundwater level in Profile I. The zone of the canal impact on groundwater dynamics in soil (Fig. 3, 5, 7 and 9) is defined at three levels. Blue marks (◆) designate the value for water table lowering by 1 cm. Red marks (■) designate the expansion of the zone of MDSC impact on lowering and/or raising of water table by 10 cm compared to zero state, that is, state without canal influence. Water table lowering of 10 cm was analyzed because it was supposed that such groundwater level lowering could be observed in the studied region. Green marks (▲) designate the width of the zone of canal impact, in which groundwater level lowering of 50 cm is expected, which is highly significant from the aspect of agricultural production.

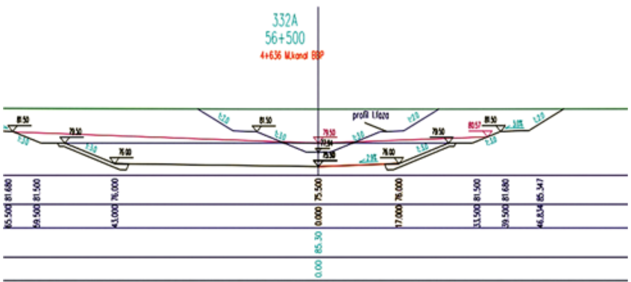

Figure 2 Characteristic cross-section of MDSC in Profile I
Slika 2. Karakteristični poprečni presjek VKDS-a na Profilu I

It is evident from the modelling results (Tab. 2 and Fig. 3) that the MDSC part located in Profile I would mainly have a draining role for the canal hinterland. In dependence on the absolute groundwater level in soil, the impact of the canal on its lowering would vary in the range of values from 1–50 cm depth (compared to ground surface), while the overall width of the impact zone would vary in the range of values from minimum 210 m to maximum 900 m, that is, from 105 m to 450 m to the left and right side from the longitudinal canal axis, respectively.

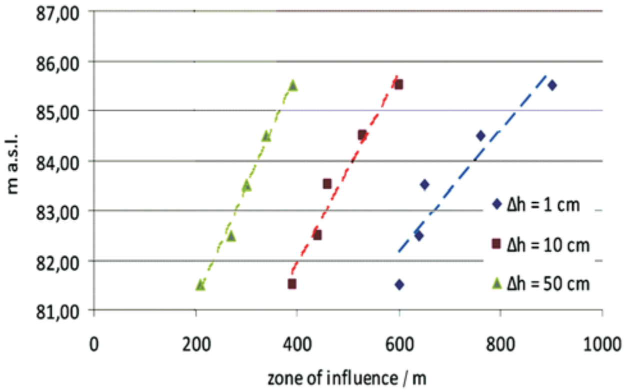

Figure 3 Zone of the MDSC impact on groundwater level in soil in Profile I
Slika 3. Zona utjecaja VKDS-a na razinu podzemne vode u tlu na Profilu I

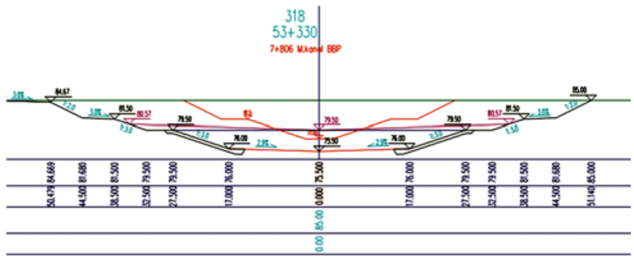

Figure 4 Characteristic cross-section of MDSC in Profile II
Slika 4. Karakteristični poprečni presjek VKDS-a na Profilu II

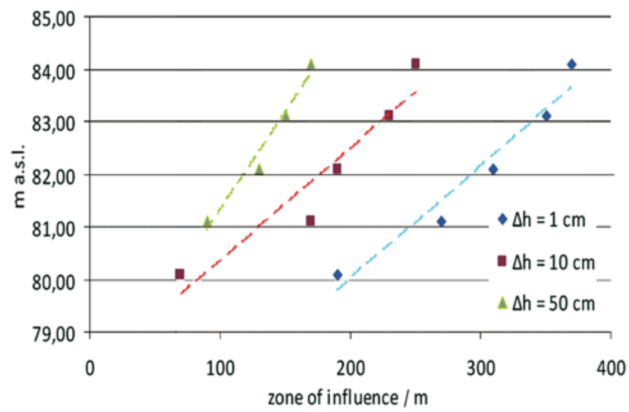

Figure 5 Zone of the MDSC impact on groundwater level in soil in Profile II
Slika 5. Zona utjecaja VKDS-a na razinu podzemne vode u tlu na Profilu II

3.2 Section Gundinci - Jasinje (Profile II)
Presjek Gundinci - Jasinje (Profil II)

A numerical model was also constructed for Profile II, located at the MDSC chainage 53+330. Compared to the flow model for Profile I, certain corrections were made in compliance with the canal geometry (Fig. 4) and

Table 1 *Major characteristics of water-bearing strata in Profile I*
Tablica 1. *Temeljne značajke vodonosnih slojeva na Profilu I*

Stratum	Depth m a.s.l.	Designation	Description	k_H / m/s	k_V / m/s	Anisotropy k_H/k_V
1	85,5-83,5	MI/CL	Silty loam	$4{,}30\times10^{-6}$	$1{,}85\times10^{-6}$	2,32
2	83,5-81,5	ML	Silt	$5{,}89\times10^{-6}$	$1{,}53\times10^{-6}$	3,84
3	81,5-79,7	SU	Sand of uniform particle size	$5{,}90\times10^{-5}$	$2{,}95\times10^{-5}$	2,00
4	79,7-78,7	CH	Highly plastic clay	$1{,}04\times10^{-7}$	$5{,}20\times10^{-8}$	2,00
5	78,7-76,5	CL	Silty clay loam	$2{,}89\times10^{-6}$	$1{,}52\times10^{-6}$	1,92
6	76,5-75,2	SM	Fine particle sand	$4{,}62\times10^{-5}$	$2{,}31\times10^{-5}$	2,00
7	75,2-73,6	GS	Gravel	$3{,}47\times10^{-3}$	$1{,}73\times10^{-3}$	2,00
8	73,6-72,3	SM	Fine particle sand	$4{,}62\times10^{-5}$	$2{,}31\times10^{-5}$	2,00
9	72,3-71,6	GW	Gravel	$3{,}47\times10^{-3}$	$1{,}73\times10^{-3}$	2,00
10	71,6-70,5	SM	Fine particle sand	$4{,}62\times10^{-5}$	$2{,}31\times10^{-5}$	2,00

Note: k_H – horizontal hydraulic conductivity; k_v – vertical hydraulic conductivity

Table 2 *Values of the width of the zone of the MDSC impact on groundwater level in soil in Profile I*
Tablica 2. *Vrijednosti širine zone utjecaja VKDS-a na razinu podzemne vode u tlu na Profilu I*

Groundwater level in the aquifer (m a.s.l.)	Effect of impact Δh = 1 cm (m)	Effect of impact Δh = 10 cm (m)	Effect of impact Δh = 50 cm (m)
85,5	900 (450)	600 (300)	390 (195)
84,5	760 (380)	530 (265)	340 (170)
83,5	650 (325)	460 (230)	300 (150)
82,5	640 (320)	440 (220)	270 (135)
81,5	600 (300)	390 (195)	210 (105)

Note: 85,5 m a.s.l. - fully saturated soil; 81,5 m a.s.l. - groundwater at 4 m below ground surface

Table 3 *Major characteristics of water-bearing strata in Profile II*
Tablica 3. *Temeljne značajke vodonosnih slojeva na Profilu II*

Stratum	Depth m a.s.l.	Designation	Description	k_H / m/s	k_V / m/s	Anisotropy k_H/k_V
1	84,1-82,6	MI/CL	Silty loam	$2{,}04\times10^{-5}$	$1{,}96\times10^{-6}$	10,40
2	82,6-80,1	ML	Silt	$5{,}88\times10^{-6}$	$1{,}50\times10^{-6}$	3,92
3	80,1-77,1	SU	Sand of uniform particle size	$5{,}90\times10^{-5}$	$2{,}95\times10^{-5}$	2,00
4	77,1-75,1	CL	Silty clay loam	$2{,}89\times10^{-6}$	$1{,}50\times10^{-6}$	1,92
5	75,1-69,1	SU	Sand of uniform particle size	$5{,}90\times10^{-5}$	$2{,}95\times10^{-5}$	2,00

Note: k_H – horizontal hydraulic conductivity; k_v – vertical hydraulic conductivity

Table 4 *Values of the width of the zone of the MDSC impact on groundwater level in soil in Profile II*
Tablica 4. *Vrijednosti širine zone utjecaja VKDS-a na razinu podzemne vode u tlu na Profilu II*

Groundwater level in the aquifer (m a.s.l.)	Effect of impact Δh = 1 cm (m)	Effect of impact Δh = 10 cm (m)	Effect of impact Δh = 50 cm (m)
84,1	370 (185)	250 (125)	170 (85)
83,1	350 (175)	230 (115)	150 (75)
82,1	310 (155)	190 (95)	130 (65)
81,1	270 (135)	170 (85)	90 (45)
80,1	190 (95)	70 (35)	not detected

Note: 84,1 m a.s.l. - fully saturated soil; 80,1 m a.s.l. - groundwater at 4 m below ground surface

characteristics of the permeable strata below the canal bottom. Major characteristics of water-permeable strata are given in Tab. 3.

It is evident from the modelling results (Tab. 4 and Fig. 5), that the MDSC part located in Profile II would also have a draining role for the canal hinterland. In dependence on the absolute groundwater level in soil, the impact of the canal on its lowering would vary in the range of values from theoretical 1 cm to maximum 50 cm depth, while the overall width of the impact zone would vary in the range of values from 90 m to 370 m, that is, from 45 m to 185 m to the left and right side from the longitudinal canal axis, respectively.

3.3 Section Babina Greda – Dobrovo (Profile III)
Presjek Babina Greda – Dobrovo (Profil III)

Profile III included in the model is located at the MDSC chainage 50+250. Canal cross-section in Profile III, adopted according to the engineering documents, is shown in Fig. 6.

Modelling results (Tab. 6 and Fig. 7) indicate that the MDSC part in Profile III would also have a draining role for the adjacent hinterland; It is expected that in dependence on the absolute groundwater level in soil, the canal impact on its lowering would vary in the range of values from 1–50 cm and over the overall width from minimum 80 m to maximum 460 m (40 m to 230 m laterally on both sides of the longitudinal canal axis).

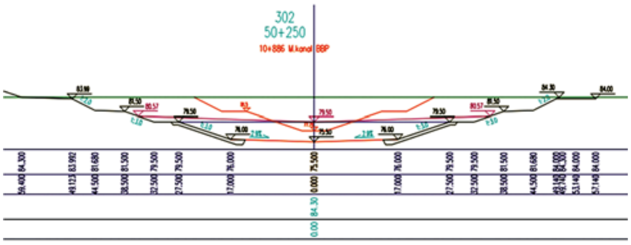

Figure 6 *Characteristic cross-section of MDSC in Profile III*
Slika 6. *Karakteristični poprečni presjek VKDS-a na Profilu III*

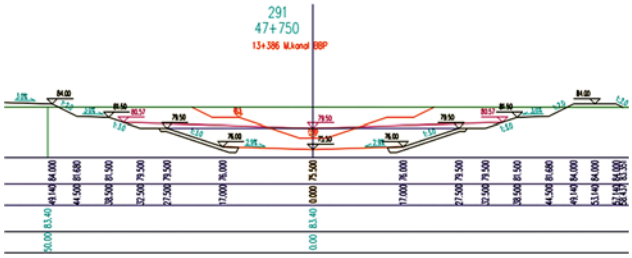

Figure 8 *Characteristic cross-section of MDSC in Profile IV*
Slika 8. *Karakteristični poprečni presjek VKDS-a na Profilu IV*

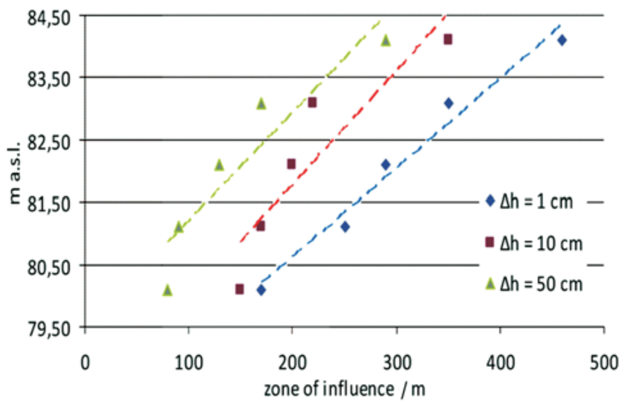

Figure 7 *Zone of the MDSC impact on groundwater level in soil in Profile III*
Slika 7. *Zona utjecaja VKDS-a na razinu podzemne vode u tlu na Profilu III*

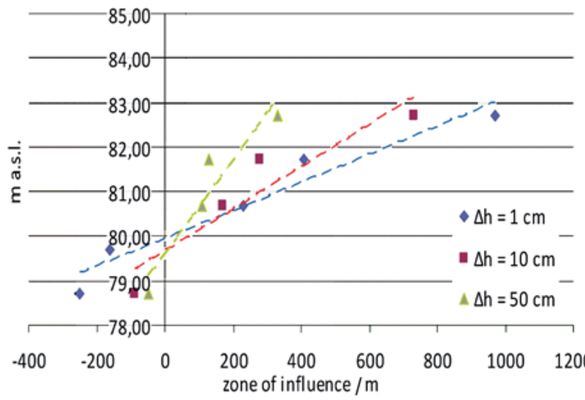

Figure 9 *Zone of the MDSC impact on groundwater level in soil in Profile IV*
Slika 9. *Zona utjecaja VKDS-a na razinu podzemne vode u tlu na Profilu IV*

3.4
Section B. Greda-Konjsko-Kladavac (Profile IV)
Presjek B. Greda-Konjsko-Kladavac (Profil IV)

Profile IV, in which groundwater flow was modelled, is located at the MDSC chainage 47+750 (Fig. 8). The main characteristic of this profile is that the strata into which the canal should be dug, are made up of poorly water-permeable materials (Tab. 7).

Multi-year monitoring (2001-2006) of groundwater dynamics revealed that fluctuation of its level in the MDSC Profile IV varies in the range of absolute values from 78,7 m a.s.l. to 82,7 m a.s.l. This profile is thus characteristic in that at this location groundwater level in the dry part of the year is expected to be lower than the projected standing water level values in the canal (80,0 m a.s.l.). For this reason, aquifer recharge through infiltration of canal water is likely to occur at this location - Profile (Fig. 9). Negative value of the canal impact, shown in Fig. 9, indicates the width of the zone in which MDSC would recharge (feed) the water-bearing strata of the surrounding soils.

Modelling Results (Tab. 8 and Fig. 9) point to the conclusion that the zone of canal impact on groundwater level in soil in Profile IV would be the largest as a consequence of poorly water-permeable clay found between the deep aquifer and the upper stratum into which the canal is dug.

Tab. 8 and Fig. 9 indicate that the MDSC impact on theoretical lowering of groundwater level in soil by 1 cm (Δh = 1 cm) at its level of 82,7 m a.s.l. would amount to a maximum of 970 m, or 485 m laterally on both sides of the longitudinal canal axis.

The overall width of the zone in which MDSC would influence groundwater level lowering in Profile IV soil by 50 cm (Δh = 50 cm), would be maximum 330 m at absolute groundwater level of 82,7 m a.s.l., and minimum 110 m at groundwater level of 80,7 m a.s.l.

It deserves special mention that at absolute groundwater level (height) in soil of 79,7 m a.s.l., water infiltration from the MDSC into the aquifer and feeding of the surrounding hinterland are to be expected. Rise of the theoretical groundwater level in soil by 1 cm should be expected in a 160 m wide zone. In cases of groundwater level in the aquifer at the absolute height of 78,7 m a.s.l., the aquifer recharge with canal water can be expected, as well as rise of its level by 1 cm in a 250 m wide zone. Rise 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.

Table 5 *Major characteristics of water-bearing strata in Profile III*
Tablica 5. *Temeljne značajke vodonosnih slojeva na Profilu III*

Stratum	Depth m a.s.l.	Designation	Description	k_H / m/s	k_V / m/s	Anisotropy k_H/k_V
1	84,1-82,1	MI/CL	Silty loam	$1{,}08\times10^{-5}$	$1{,}96\times10^{-6}$	5,49
2	82,1-80,3	ML	Silt	$5{,}88\times10^{-6}$	$1{,}50\times10^{-6}$	3,92
3	80,3-79,3	CH	Highly plastic clay	$1{,}04\times10^{-7}$	$5{,}20\times10^{-8}$	2,00
4	79,3-77,9	CL/CM	Silty clay	$5{,}00\times10^{-6}$	$2{,}50\times10^{-6}$	2,00
5	77,9-76,0	CH	Highly plastic clay	$1{,}04\times10^{-7}$	$5{,}20\times10^{-8}$	2,00
6	76,0-69,1	CL	Silty clay loam	$2{,}89\times10^{-6}$	$1{,}54\times10^{-6}$	1,92

Note: k_H – horizontal hydraulic conductivity; k_v – vertical hydraulic conductivity

Table 6 *Values of the width of the zone of the MDSC impact on groundwater level in soil in Profile III*
Tablica 6. *Vrijednosti širine zone utjecaja VKDS-a na razinu podzemne vode u tlu na Profilu III*

Groundwater level in the aquifer (m a.s.l.)	Effect of impact Δh = 1 cm (m)	Effect of impact Δh = 10 cm (m)	Effect of impact Δh = 50 cm (m)
84,1	460 (230)	350 (175)	290 (145)
83,1	350 (175)	220 (110)	170 (85)
82,1	290 (145)	200 (100)	130 (65)
81,1	250 (125)	170 (85)	90 (45)
80,1	230 (115)	150 (75)	80 (40)

Note: 84,1 m a.s.l. - fully saturated soil; 80,1 m a.s.l. - groundwater at 4 m below ground surface

Table *7 Major characteristics of water-bearing strata in Profile IV*
Tablica 7. *Temeljne značajke vodonosnih slojeva na Profilu IV*

Stratum	Depth m a.s.l.	Designation	Description	k_H / m/s	k_V / m/s	Anisotropy k_H/k_V
1	82,7-81,8	MI/CL	Silty loam	$2{,}89\times10^{-6}$	$1{,}97\times10^{-6}$	1,76
2	81,8-80,6	CL	Silty clay loam	$2{,}89\times10^{-6}$	$1{,}50\times10^{-6}$	1,92
3	80,6-79,3	MI/CL	Silty loam-more pervious	$2{,}16\times10^{-5}$	$1{,}86\times10^{-6}$	11,6
4	79,3-77,7	CI	Clay	$5{,}78\times10^{-7}$	$5{,}78\times10^{-7}$	1,00
5	77,7-78,7	MS/SM	Silt	$1{,}02\times10^{-6}$	$2{,}03\times10^{-7}$	2,00
6	78,7-67,7	CH	Highly plastic clay	$3{,}47\times10^{-3}$	$1{,}73\times10^{-3}$	2,00

Note: k_H – horizontal hydraulic conductivity; k_v – vertical hydraulic conductivity

Table 8 *Values of the width of the zone of the MDSC impact on groundwater level in soil in Profile IV*
Tablica 8. *Vrijednosti širine zone utjecaja VKDS-a na razinu podzemne vode u tlu na Profilu IV*

Groundwater level in the aquifer (m a.s.l.)	Effect of impact Δh = 1 cm (m)	Effect of impact Δh = 10 cm (m)	Effect of impact Δh = 50 cm (m)
82,7	970 (485)	730 (365)	330 (165)
81,7	410 (205)	280 (140)	130 (65)
80,7	230 (115)	170 (85)	110 (55)
79,7	+160 (+80)	not detected	not detected
78,7	+250 (+125)	+90 (+45)	+50 (+25)

Note: 82,7 m a.s.l. - fully saturated soil; 78,7 m a.s.l. - groundwater at 4 m below ground surface

4 Discussion
Diskusija

The studied region is situated within the wider Biđ-Bosut Field area, the so called Bosut Sava Valley [2]. The region extends along the route of the future Multipurpose Danube-Sava Canal (MDSC) and is 11,0 km long and 5,0 km wide, namely along its section from chainage 46+500 to 57+500 km.

Owing to the development of computer technology, conditions have been created for designing appropriate numerical models for precise prediction of the impact of future hydrotechnical structures such as MDSC upon groundwater dynamics, and thereby also on water regime of agricultural soils. The first quantitative analyses of groundwater flow in this respect were initiated by Darcy [4]. This author observed that in all studied samples in laminar flow regime, water flow was linearly proportional to the decrease in piezometer potential. To solve problems of this kind, numerical models are lately used in engineering practice for prediction of flow direction and transport of matter in one and/or two dimensions.

Along these lines, the VS2DTI program (also used in this work) found its application in similar investigations such as: modelling of imidacloprid transport in soil as porous medium [8], modelling of the impact of soil slope and precipitation on lateral flow in soil [9], estimation of characteristic soil moisture from aquifer data [10], role of subsurface water in river bed erosion [11], characterization of the variability of material transport from river beds into adjacent soil [12], prediction of changes in soil water regime after construction of the multipurpose Danube-Sava canal [13]. It should be pointed out that, regardless of whether transport of material through unsaturated media, that is, 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 [6].

Based on the modelling of the impact of the future Danube-Sava canal on groundwater dynamics in soil, carried out within four characteristic profiles (cross-sections), it was established that the primary role of MDSC in the first, second and third profiles would be that of draining the surrounding hinterland area and lowering the soil groundwater level. Width of the zone in which significant lowering of groundwater level in soil is expected in Profiles II and III does not surpass the value of 460 m from the longitudinal canal axis. In his modelling of the watercourse-aquifer interaction by means of linear functions, [14] reports a similar impact of watercourses on groundwater dynamics.

In our investigations (first of the kind in this country), very interesting modelling results were obtained for Profile IV. In this Profile, the groundwater level in the studied period oscillated in the range of values from 78,7 m a.s.l. (bottom of installed piezometers) to 82,7 m a.s.l. and was thus below the projected standing water level in MDSC (80,00 m.a.s.l.); it is hence to be expected that in this part the future canal would, along with draining, also feed the adjacent hinterland with water. Thus, at the absolute groundwater level in soil of 79,7 m a.s.l., the MDSC would feed the surrounding area with water. Maximum width of zone would be 250 m, or 125 m laterally on both sides of the longitudinal canal axis. Similar results were also obtained by [8] in their modelling of imidacloprid transport through sandy and clayey soils, in the territory of the American federal state of Georgia.

Results obtained in this study by a numerical model, which confirmed the impact of MDSC on groundwater dynamics in soil, are "logical" in that they prove the initial hypothesis, set on the basis of previous comparable results obtained by Petošić et al. [15] by using the empirical formula of I. I. Agroskin [16].

Mention should be also made of other researchers, notably Mulder et al. [17], who achieved results similar to ours in modelling the impact of two drainage canals in the south of the Netherlands.

According to the investigators of Ground Water Consulting Ltd. [18], who studied the impact of the Gabickovo hydroelectric power plant and its accompanying hydrotechnical structures upon the groundwater regime, the amelioration canals constructed simultaneously in that region had a strong influence on the groundwater regime. Investigating the impact of hydrotechnical structures on groundwater regime in the same region, Šoltesz [19] found that the constructed canals had a strong influence on the development of agricultural production because they enabled application of controlled drainage and irrigation. Similar results were also obtained in the construction of the Marchfeld canal in Austria [20].

Our results indicate that the same effects of MDSC construction can be expected also in the narrower investigation area. Namely, in Profiles I, II and III, the canal would mainly have a draining influence on high groundwater levels during the winter months, especially in the area dominated by hypogley-humogley soils, which cover 4950 ha. During the summer months, MDSC in Profile IV (lowest parts of the region) would have the role of discharging deep groundwater in soil [21]. In both cases, MDSC would indirectly improve the water-air regime in the upper soil solum.

5 Conclusions
Zaključci

Based on numerical modelling of groundwater flow in the investigation region it was found that a decrease in hydrostatic pressure in lower gravelly horizons of the subsurface soil layer, from which also the covering soil solum is fed to 4,0 m depth, decreases also the zone of the future multipurpose canal impact on groundwater level changes in the hydropedological profile of agricultural soils in the immediate vicinity of the canal.

Modelling has confirmed that the future MDSC at the locations of the observed cross-sections-profiles (I, II and III), in years with average climatic conditions, would primarily drain the surrounding hinterland area. In Profile IV, the canal would, along with its draining role, also feed agricultural soils through infiltration of water from its bed.

Width of the draining zone of the MDSC impact, in which groundwater level lowering should be expected in the range of values from 1 to 50 cm and at its depth from 0 to 4 m from ground surface, would vary from minimum 170 m to maximum 970 m (from 85 m to 485 m laterally on both sides of the longitudinal canal axis).

The model has also shown the in the case of a very deep groundwater level in soil (> 3 m from ground surface), in Profile IV (Babina Greda – Konjsko – Kladavac), MDSC would feed water to the solum of agricultural soils through water infiltration from its bed. Pursuant to calculations, the width of the impact zone, in which MDSC would feed water to the surrounding area, would range from 90 m to 250 m from the longitudinal canal axis.

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