GEOFIZIKA VOL. 34 2017

DOI: 10.15233/gfz.2017.34.9
Original scientific paper
UDC 556.142

Fluvisol permeability estimation using soil water content variability

Stanko Ružičić [1], *Zoran Kovač* [2], *Zoran Nakić* [2] *and Daria Kireta* [3]

[1] Department of Mineralogy, Petrology and Mineral Resources, Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, Zagreb, Croatia

[2] Department of Geology and Geological Engineering, Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, Zagreb

[3] Craft College - Institution for Adult Education, Zagreb, Croatia

Received 10 March 2017, in final form 4 May 2017

The use of unsaturated hydraulic conductivity can help to define soil permeability, *i.e.* can contribute to the estimation of water percolation through unsaturated zone. The goal of this paper was the estimation of soil permeability at the location of case study profile *Kosnica*, situated in the alluvial plain of the Zagreb aquifer, Croatia, based on the variation in soil water content. Zagreb aquifer represents the only source of potable water for inhabitants of the City of Zagreb and Zagreb County. The thickness of unsaturated zone of the Zagreb aquifer varies from 8 meters in NW part to 2 meters in SE part. The unsaturated hydraulic conductivity values were calculated according to the granulometric composition of soil horizons and with optimized soil parameters. Variation in unsaturated hydraulic conductivity showed that the upper part of the soil profile was generally permeable throughout the 2011/2012 hydrologic year. The unsaturated hydraulic conductivity calculated with optimized soil parameters gave the highest values, always greater than 1E-9 m/s. Even though the estimation of soil profile permeability would be more precise with measurements of water content and pressure head in each soil horizon, calculation performed in this manner can give the first insight in general estimation of the unsaturated hydraulic conductivity variability and related soil permeability.

Keywords: soil permeability, unsaturated hydraulic conductivity, water content, well field Kosnica

1. Introduction

The soil permeability may change spatially due to horizontal and vertical changes in many factors, especially due to variation of unsaturated hydraulic conductivity. There is no engineering soil property that can vary more widely than soil permeability (Fredlund et al., 1994). For saturated soils, the hydraulic conductivity can vary by more than 10 orders of magnitude when considering soils that range from sand to clay. Soils that become unsaturated are even more difficult to analyse. In addition, it is possible for a single soil to have a value of hydraulic conductivity that ranges over 10 orders of magnitude. However, experience has shown that many important questions can be addressed using seepage analyses of unsaturated soils. Analyses have shown that water flow through soil is directly proportional to the hydraulic conductivity (Fredlund et al., 1994). Knowledge of pore water pressures or pressure heads is of primary interest. These values are relatively insensitive to saturated hydraulic conductivity and permeability. Soil water retention curve (*SWRC*) is defined as the relationship between soil suction and water content. Through the history, numerous equations were suggested for the construction of soil water retention curve. Buckingham (1907) calculated the first equations and created *SWRC*. Among the most used equations are those of Brooks and Corey (1964), van Genuchten (1980) and Fredlund and Xing (1994). Several parameters, such as water content, pressure head, soil structure (or aggregation), compaction energy, mineralogy, texture, organic content and hysteresis, influence the *SWRC* behaviour (Vanapalli et al., 1999; Ng and Pang, 2000). All of the parameters that influence soil-water behaviour also influence hydraulic conductivity of unsaturated soils. Even though there are different laboratory techniques (Klute and Dirksen, 1986) and field methods (Green at al., 1986), they are generally time consuming and have many different practical limitations (van Genuchten et al., 1988). Fredlund et al. (1994) predicted coefficient of permeability and permeability function using empirical methods. Lobbezoo and Vanapalli (2002) proposed a simple technique for the estimation of unsaturated soil hydraulic conductivity based on conventional soil properties; namely, saturated hydraulic conductivity, degree of saturation (or water content) in soil.

Due to its applicability to almost all types of soils, van Genuch ten equation (1980) was used to estimate Fluvisol permeability based on the variation of soil water content and associated unsaturated hydraulic conductivity, which was the main objective of this paper.

2. Area description

2.1. Location

Case study profile (Fig. 1) is located in the eastern part of the Zagreb aquifer, which represents the only source of potable water for inhabitants of the City of Zagreb and Zagreb County. Highly variable lithology, pedological features and land use characterize the broader region. The study area consists of a large alluvial plain that has two marked geomorphological features: the raised sealed

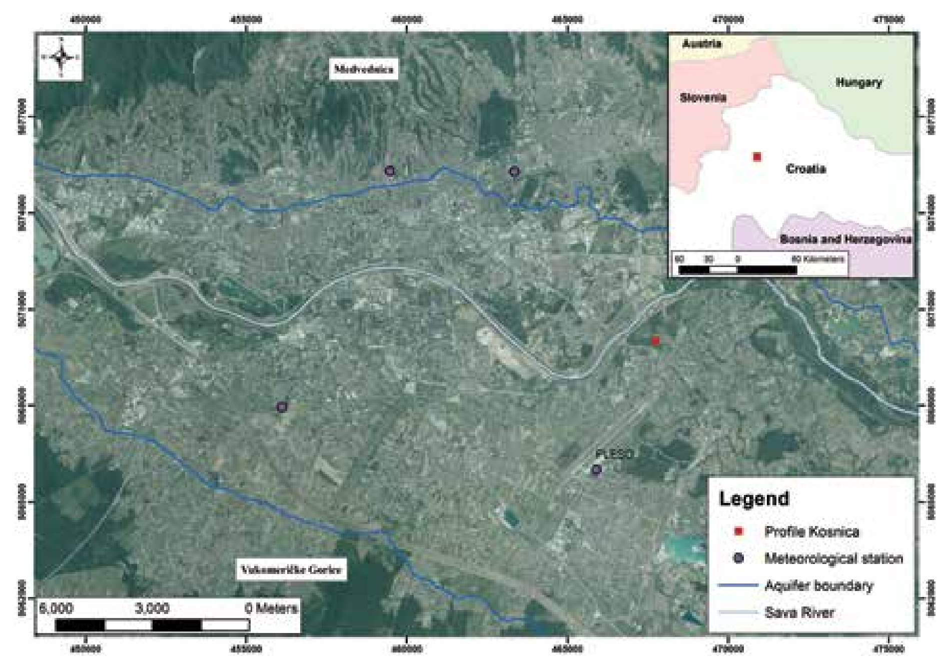

Figure 1. Location of the study area and profile Kosnica.

terrace of the Sava River (varying in width down the rivers length), and a Holocene terrace (Nakić et al., 2013). Numerous meanders of the Sava River inundated fluvial cones and numerous bowl-shaped depressions abound in the alluvial plain. Case study profile is located about eight hundred meters from the right bank of the Sava River.

2.2. Geology and hydrogeology

Mostly unconsolidated Quaternary sediments constitute the shallow unconfined Zagreb aquifer and its unsaturated zone. Lower Pleistocene deposits are predominantly composed of clayey silts/silty clays with sporadic lenses and interbeds of gravelly-sands, up to a few decimeters in thickness (Velić and Durn, 1993). While the lower and the middle part of Middle Pleistocene unit is predominantly composed of sands, the upper part comprises silt and clay sized material (Velić and Durn, 1993; Velić and Saftić, 1996). The Upper Pleistocene unit is characterized by frequent lateral changes of gravels, sands, silts and clays. The Holocene deposits are composed of gravels and sands with high permeability, in which limestone cobbles prevail.

Consequently, Zagreb aquifer is made of two main layers, deep and shallow. The deep layer contains Pleistocene lacustrine-marshy deposits, while the shallow layer contains Holocene alluvial deposits (Velić and Durn, 1993; Velić et al., 1999). Even though they present one hydrogeological unit, geochemical stratification along the depth is recognized (Marković et al., 2013). Zagreb aquifer is the only source of potable water for the inhabitants of the City of Zagreb and a part of Zagreb County and it is designated as part of strategic water reserves protected by the Republic of Croatia.

2.3. Unsaturated zone

The thickness of unsaturated zone of the Zagreb aquifer varies from 8 meters in NW part to 2 meters in SE part, depending mostly on the Sava River water levels. The upper part of this zone is composed mainly of silty to sandy material, while the lower part consists of gravels (Ružičić et al., 2012). In some parts, this material was intersected by clay layers. Three pedological units have predominantly developed on these sediments: Fluvisols, Stagnic Podzoluvisols (Pseudogley) and Eutric Cambisols (Sollitto et al., 2010).

At the Kosnica case study site, the lower part of the unsaturated zone profile consists of gravels with sand component, while gravels with silty to sandy material dominate in the upper part. Pebbles are mainly rounded and oval in shape (Ružičić et al., 2012). Sands reveal different granulation, from gravely to silty sands. In some places, these sediments are red to black in colour. According to *FAO* classification (FAO, 2006) Fluvisols are developed on top of the unsaturated zone profile.

The following soil horizons were recognized: A-AC-C-2C/Cl-3Cl-4Cl/Cr-5Cr (Figs. 2 and 3b). Soil profile is mainly silt loam in texture; in some parts sandy loam prevails (Ružičić et al., 2016). The structure of this type of soils is mainly granular.

3. Materials and methods

Theoretical soil water retention curves and unsaturated hydraulic conductivities (van Genuchten, 1980; eqs. (1) to (4)) were constructed and calculated based on the data from grain size analysis for every pedological horizon (Tab. 1) and based on optimized soil hydraulic parameters (Ružičić et al., 2016; Tab. 2).

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

$$n = \frac{1}{1-m} \tag{2}$$

$$\alpha = \frac{1}{h_b}\left(2^{1/m} - 1\right)^{1-m} \tag{3}$$

Table 1. Physical properties and grain size analysis for soil horizons (modified according to Ružičić et al., 2016).

Soil horizon	Depth (m)	Water content (% vol.)	Bulk density (kg/m^3)	Porosity (%)	Sand (%)	Silt (%)	Clay (%)
A	0–0.19	44.56	1040	59.26	24.56	65.27	10.17
AC-C	0.19–0.68	41.57	1360	48.38	13.79	76.69	9.52
2C/Cl	0.68–1.1	39.89	1390	47.39	56.33	38.23	5.44
3Cl	1.1–1.4	38.53	1370	48.96	43.29	47.43	9.28
4Cl/Cr	1.4–1.9	42.06	1410	46.17	37.21	50.50	12.29
5Cr	1.9–2.1	41.27	1430	46.74	55.62	38.45	5.93

Table 2. Soil hydraulic parameters.

Soil horizon	Depth (m)	Soil hydraulic parameters	With bulk density	Without bulk density	Optimized parameters (Ružičić et al., 2016)
A	0–0.19	θ_r	0.0518	0.0609	0.06
		θ_s	0.4343	0.4716	0.4
		α (1/cm)	0.0043	0.0036	0.0077
		n	1.7130	1.7723	1.5769
		m	0.4162	0.4358	0.3658
		$1/m$	2.4025	2.2948	2.7334
		K_s (cm/day)	36.70	154.81	44
AC-C	0.19–0.68	θ_r	0.0558	0.0572	0.06
		θ_s	0.4641	0.4201	0.4
		α (1/cm)	0.0052	0.0050	0.1
		n	1.6943	1.6931	2.5
		m	0.4098	0.4094	0.6
		$1/m$	2.4403	2.4428	1.667
		K_s (cm/day)	34.26	43.54	45
2C/Cl	0.68–1.1	θ_r	0.0328	0.0337	0.03
		θ_s	0.3984	0.3718	0.38
		α (1/cm)	0.0199	0.0208	0.1
		n	1.4340	1.4453	1.9839
		m	0.3026	0.3081	0.4959
		$1/m$	3.3041	3.2457	2.0164
		K_s (cm/day)	48.94	57.78	160

Table 2. Continued.

Soil horizon	Depth (m)	Soil hydraulic parameters	With bulk density	Without bulk density	Optimized parameters (Ružičić et al., 2016)
3Cl	1.1–1.4	θ_r	0.0425	0.0419	0.04
		θ_s	0.4017	0.3732	0.37
		α (1/cm)	0.0080	0.0092	0.0096
		n	1.5536	1.5464	1.5396
		m	0.3563	0.3533	0.3505
		$1/m$	2.8064	2.8302	2.8532
		K_s (cm/day)	30.33	33.88	35
4Cl/Cr	1.4–1.9	θ_r	0.0500	0.0480	0.05
		θ_s	0.4052	0.3732	0.37
		α (1/cm)	0.0060	0.0074	0.0077
		n	1.6051	1.5849	1.5784
		m	0.3770	0.3690	0.3664
		$1/m$	2.6526	2.7097	2.7289
		K_s (cm/day)	28.90	23.63	24
5Cr	1.9–2.1	θ_r	0.0338	0.0338	0.03
		θ_s	0.3974	0.3644	0.36
		α (1/cm)	0.0189	0.0212	0.0223
		n	1.4375	1.4407	1.4364
		m	0.3043	0.3059	0.3038
		$1/m$	3.2857	3.2691	3.2915
		K_s (cm/day)	45.70	47.87	51

$$K(\theta) = K_s S_e^{1/2}\left[1-\left(1-S_e^{1/m}\right)^m\right]^2 \tag{4}$$

where ψ is matric potential (m), θ_s saturated water content (m^3/m^3), θ_r residual water content (m^3/m^3), h_b bubbling pressure (m), K(θ) unsaturated hydraulic conductivity (m/s), K_s saturated hydraulic conductivity (m/s), S_e effective saturation (%), while α (1/m), n and m are parameters which depend on the slope of the curve (van Genuchten 1980; Fetter 1999).

Soil hydraulic parameters were estimated using Rosetta Lite software (Schaap et al., 2001), with and without taking into account soil bulk density (Tab. 2). Rosetta Lite software uses granulometric composition and soil bulk density to estimate soil hydraulic parameters. Soil hydraulic parameters are shown in units directly projected from the Rosetta Lite software and transformed into International system of Units for further calculation. Water content and soil tension variation in hydrologic year 2011/2012 was measured in two soil horizons on

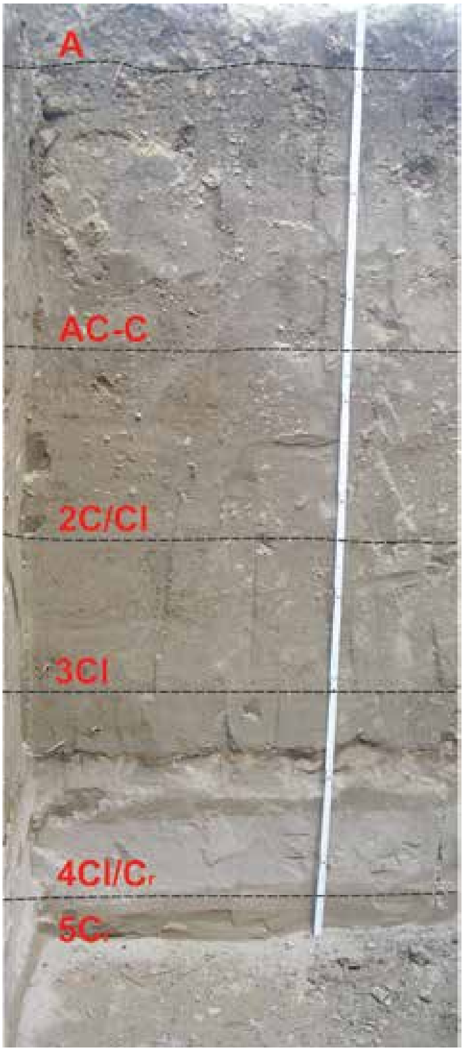

Figure 2. Soil horizons at the study profile Kosnica.

daily basis, at 0.4 and 1.1 m depth. Water content was measured using *Time domain reflectrometry* (*TDR*) probes, (Fig. 3a), while soil water tension was measured using tensiometers (Fig. 3b).

Unsaturated hydraulic conductivities (K_{unsat}) were calculated for each percentage of water content, ranging from θ_r to θ_s, for two observed soil horizons. Then K_{unsat} values were placed in function of water content variation in two soil horizons where water content was measured during observed hydrologic year. The variation of K_{unsat} was calculated for three different scenarios. The first two scenarios were developed according to soil hydraulic parameters (Tab. 2) projected from Rosetta Lite software based on grain size analyses and bulk density (Tab. 1), while the third scenario was developed according to optimized parameters (Tab. 2) calculated using inverse modelling in *HYDRUS 1D* software (Ružičić et al., 2016). Consequently, in this way the assessment of K_{unsat} variation was made for one hydrologic year and was used for soil permeability prediction at the study area. Terzaghi and Peck (1967) suggested that hydraulic conductivity value of 1E-9 m/s represents a boundary between permeable and impermeable soils.

Finally, all values were compared with daily precipitation data from the nearest meteorological station Pleso to see the association between precipitation and water content. In order to obtain the estimate of maximal precipitation available for infiltration, average yearly evapotranspiration was calculated according to Turc (1953).

4. Results and discussion

Theoretical soil water retention curves (Figures 4 to 6) for each pedological horizon were constructed using soil hydraulic parameters shown in Tab. 2. Figures 4 and 5 show measured values of water content and pressure head compared with theoretical soil water retention curves with and without taking into account bulk density for horizons at 0.4 and 1.1 m depth, while Fig. 6 shows the comparison according to optimized soil hydraulic parameters, where bulk density was also used.

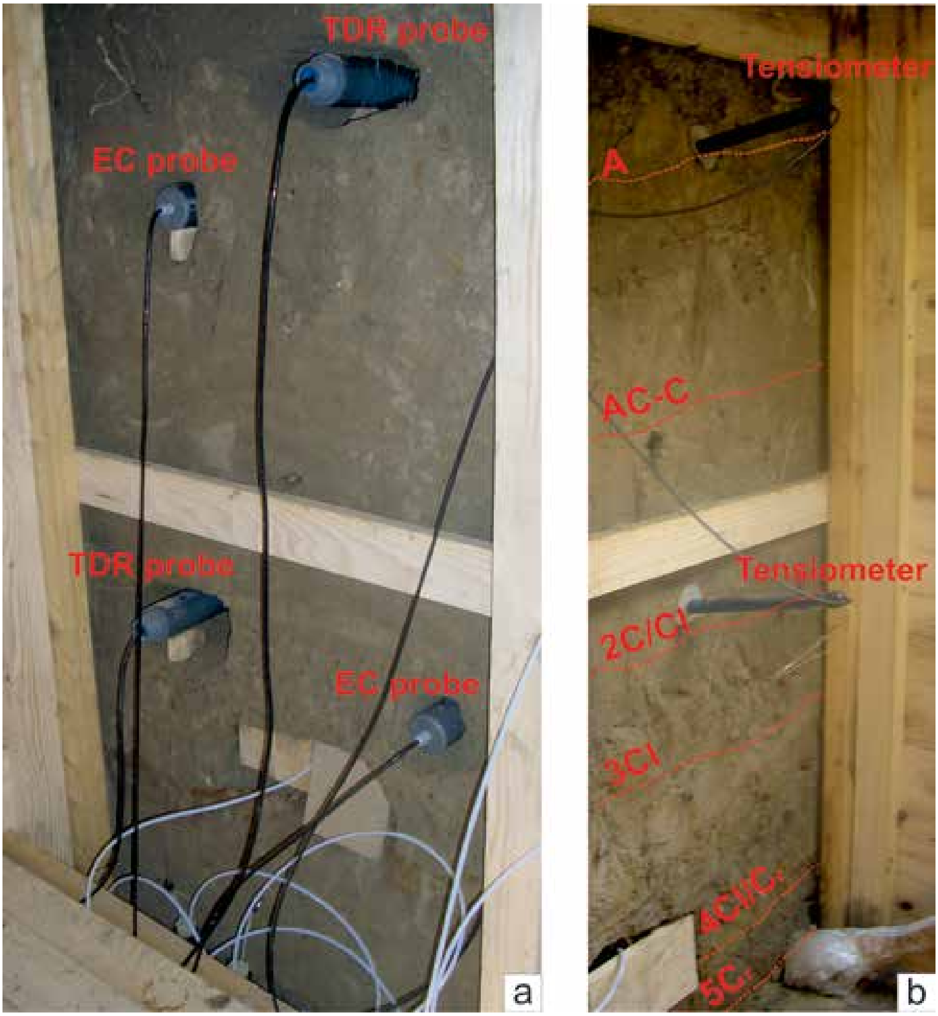

Figure 3. *a*) Research pedological burrow with TDR probes and EC-probes; *b*) tensiometers (modificated according to Ružičić et al., 2012).

Matric potential at 1.1 m depth ranges from –0.0186 to 8.2622 m, while at 0.4 m depth it varies from –0.0314 to 7.0209 m. Figs. 4 to 6 show that data overlapping between theoretical *SWRC* curves and measured values does not match, although overlapping is the best with optimized hydraulic parameters. The main reason is probably associated with problems in the tensiometers measurements. Measurements of water content present more quality data (Fig. 7) which was the main reason it was used in K_{unsat} variability assessment. It can be seen that the observed values of water content generally range from 0.13 to 0.31 at 1.1 m depth, and from 0.17 to 0.37 on 0.4 m depth.

Theoretical variation of unsaturated hydraulic conductivity in two pedological horizons (Fig. 8) suggests that the soil becomes impermeable in those layers only when water content drops below 0.2, *i.e.* between 0.09 and 0.19. Unsaturated hydraulic conductivity varies from 4.26E–11 to 3.2E–6 m/s at 1.1 m depth and from 7.21E–10 to 2.88E–6 m/s at 0.4 m depth.

Variation of unsaturated hydraulic conductivity based on the measured variation of soil water content in two pedological horizons, and compared to daily precipitation, is shown in Fig. 9. Values at 1.1 m depth, except those calculated with optimized hydraulic parameters, suggest that soil permeability was on the impermeable boundary in the autumn of 2011 and impermeable in the summer of 2012. In the meantime, the soil was permeable. Values at 0.4 m depth suggest that in the upper part, the soil profile was permeable throughout the 2011/2012 hydrologic year. Values of K_{unsat} are the highest when optimized hydraulic parameters are considered. The K_{unsat} values are higher on both depths throughout the 2011/2012 hydrologic year than the critical value of 1E–9 m/s which suggests constantly permeable soil. Precipitation values in Fig. 9 show that only a long term and intense rainfall has influence on water content variation at 1.1 m depth. Very small amount of precipitation, which was 717.1 mm for 2011/2012 hydrologic year, reached the lower part of soil horizon which coincides with evapotranspiration of 502.7 mm and only 214.4 mm of precipitation available for infiltration. Ružičić e al. (2016) built a prognostic transport model, which suggests that only 5% of potentially toxic elements, in case of an accident, would be transported from soil surface to the aquifer. Although K_{unsat} values suggest that the upper part of soil profile is generally permeable, but varies in permeability, the main problem arises from the lack of measurements in the lower part. Considering the available data, it can be assumed that the water content in the lower part of soil profile is smaller than those measured at 0.4 and 1.1 m depth. In this regard, it can be expected that K_{unsat} values would also be smaller. Considering grain size analysis, it can be seen that in the lower part of the profile there is generally more sand, which can indicate faster infiltration and generally higher K_{unsat} values. On the other hand, bulk density increases with depth, which generally causes lower K_{unsat} values. For a better estimation, it is necessary to perform measurements in each soil horizon.

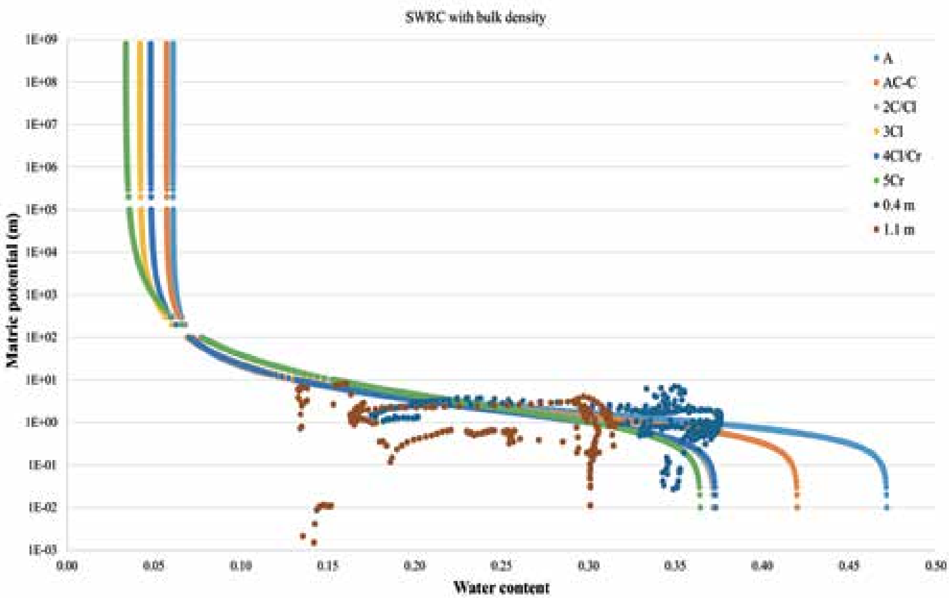

Figure 4. Theoretical SWRC (with bulk density) for all pedological horizons compared with measured data of water content and matric potential.

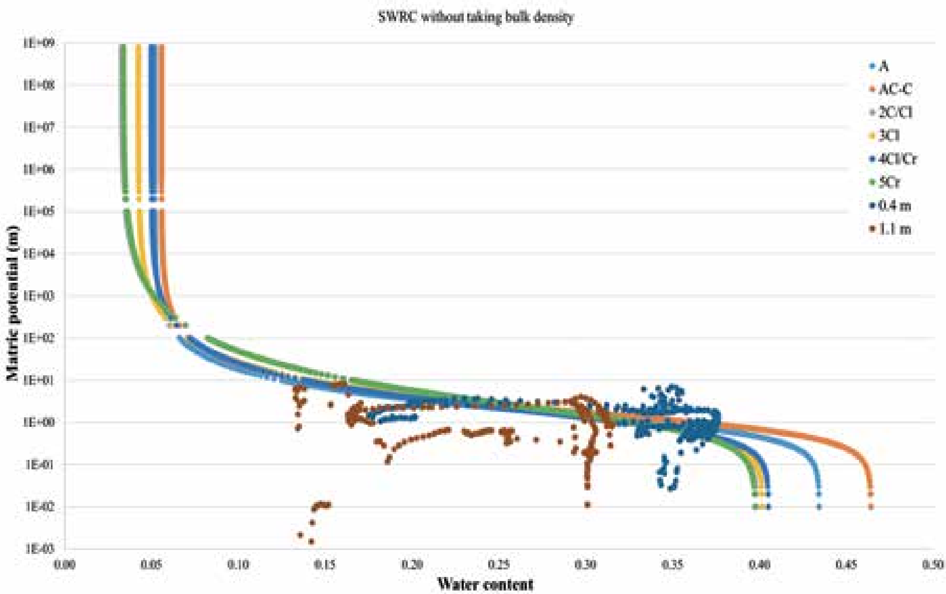

Figure 5. Theoretical SWRC (without bulk density) for all pedological horizons compared with measured data of water content and matric potential.

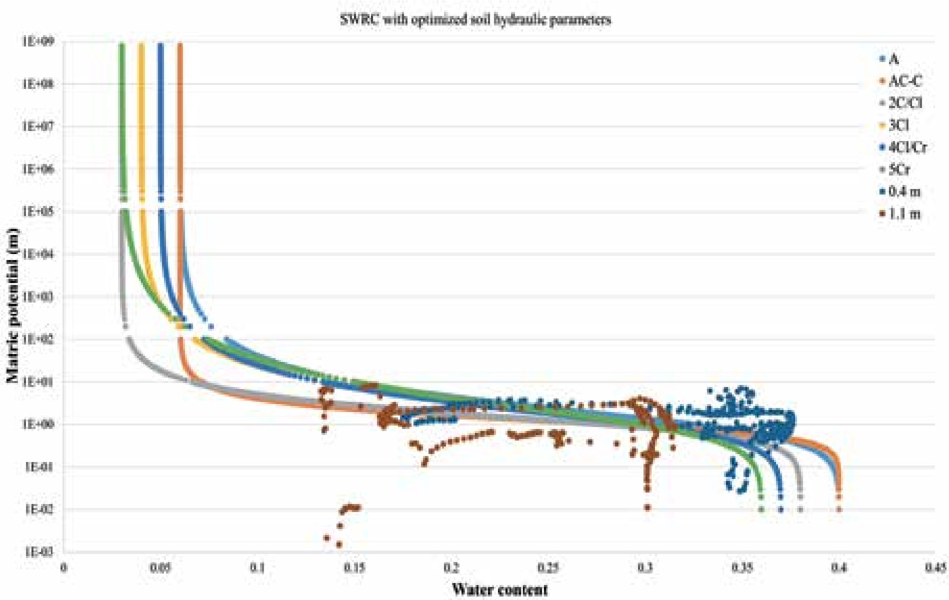

Figure 6. Theoretical SWRC constructed with optimized hydraulic parameters for all pedological horizons compared with measured data of water content and matric potential.

5. Conclusion

Permeability of soil profile at Kosnica site was estimated based on the variability of water content and associated variability of unsaturated hydraulic conductivity. Six soil horizons were determined. *TDR* probes were used to measure water content, while tensiometers were used to measure soil pressure in two pedological horizons, at 0.4 and 1.1 m depth. *SWRC* were constructed and compared with measured data. Given the data quality, only water content data throughout the 2011/2012 hydrologic year was used to estimate the variation of K_{unsat} using van Genuchten equations (1980). Three scenarios of different soil hydraulic parameters were used for calculation: those estimated with Rosetta Lite software (based on grain size analysis) with and without taking into account bulk density, and those optimized as shown in Ružičić et al. (2016).

Comparison between calculated *SWRC* and measured values showed that data generally does not match, probably due to problems in soil pressure measurements and natural factors such as the hysteresis. Variation of K_{unsat} showed that the upper part of soil profile was generally permeable throughout the observed hydrologic year. Unsaturated hydraulic conductivities calculated with optimized parameters gave the highest values, always greater than the impermeable boundary, while values without taking into account bulk density gave the smallest values. Even though the estimation of soil profile permeability would be

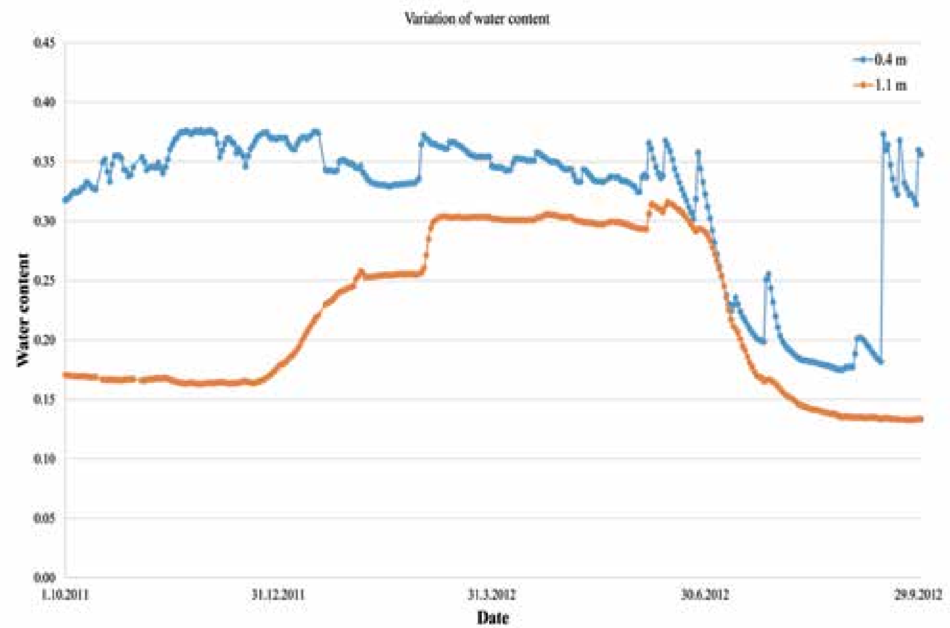

Figure 7. Variation of water content at 0.4 and 1.1 m depth.

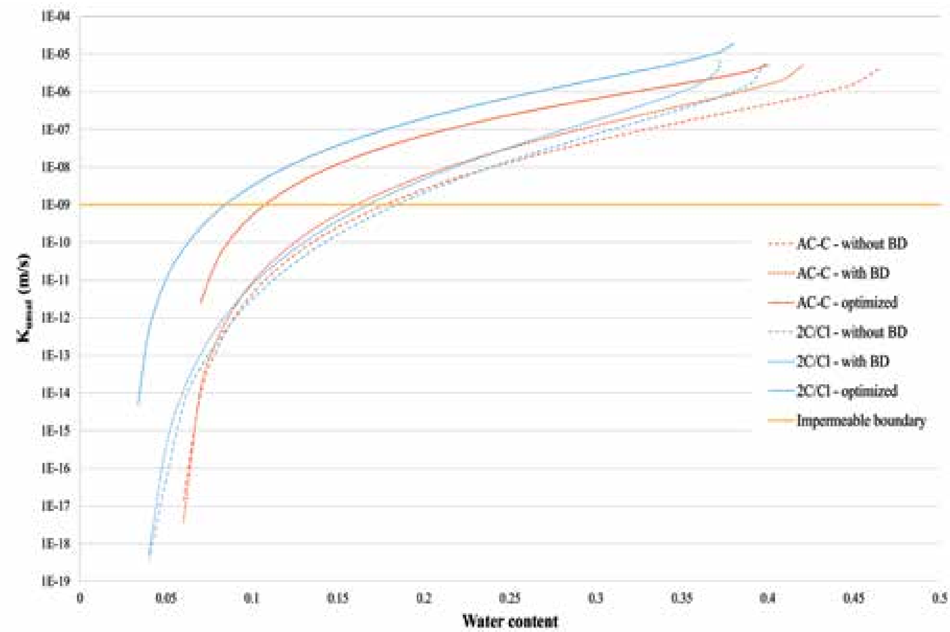

Figure 8. Variation of unsaturated hydraulic conductivity at 0.4 and 1.1 m depth.

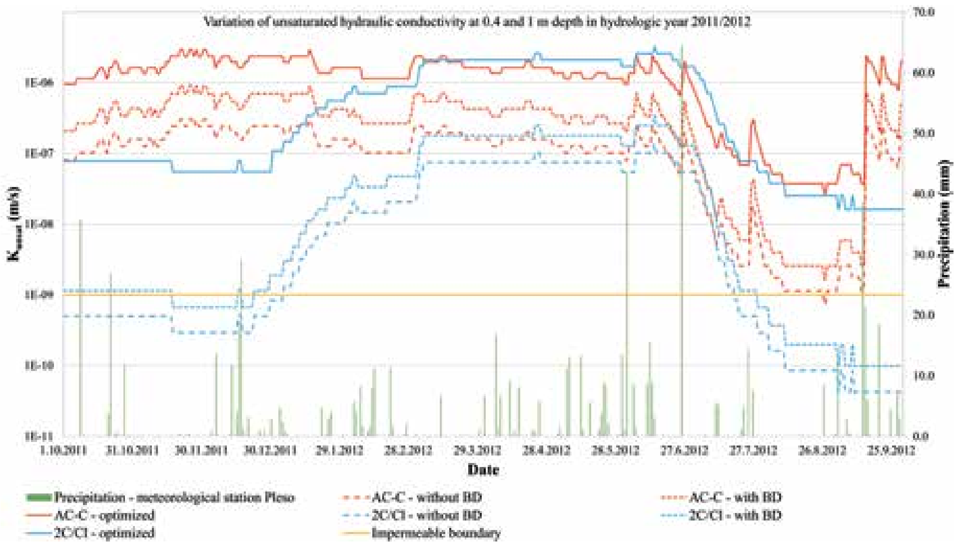

Figure 9. Variation of unsaturated hydraulic conductivity at 0.4 and 1.1 m depth compared to daily precipitation.

much more precise with quality measurements in each soil horizon, it can be concluded that this method of calculation can give the first insight in general estimation of K_{unsat} variability and related soil permeability. Also, it can provide approximate threshold values of water content under which all of the measured horizons become impermeable. To conclude, this way of soil permeability estimation indicates that the upper part of soil profile at Kosnica site is generally permeable, with the exception of very dry periods. Given the lack of data in the lower part, soil permeability can only be assumed. In that sense, the expected decrease in water content and increase of bulk density with depth suggest lower permeability than in the upper part of the soil profile. On the other side, higher sand content in the lower soil horizons of observed soil profile suggests higher soil permeability.

References

Brooks, R. H. and Corey, A. T. (1964): *Hydraulic Properties of Porous Media*. Hydrology Paper No. 3, Civil Engineering Department, Colorado State University, Fort Collins, CO.

Buckingham, E. (1907): *Studies on the Movement of Soil Moisture*. Bulletin 38, United States Department of the Agriculture, Bureau of Soils, Washington, DC.

FAO (2006): *A Framework for International Classification, Correlation and Communication World Soil Resources*. Reports No. 103, FAO, Rome.

Fetter, C. W. (1999): *Contaminant Hydrogeology*. Prentice Hall, Upper Saddle River, New Jersey, Additional Class Material, 500 pp.

Fredlund, D. G., Xing, A. and Huang, S. (1994): Predicting the permeability function for unsaturated soils using the soil-water characteristic curve, *Can. Geotech. J.*, **31**, 533–546.

Green, R. E., Ahuja, L. R. and Chong, K. S. (1986): Hydraulic conductivity, diffusivity, and sorptivity of unsaturated soils: Field methods, in: *Methods of Soil Analysis, 1. Physical and Mineralogical Methods*, edited by Klute, A. American Society of Agronomy, Madison, WI, 771–798.

Klute, A. and Dirksen, C. (1986): Hydraulic conductivity and diffusivity: Laboratory methods, in: *Methods of Soil Analysis, 1. Physical and Mineralogical Methods*, edited by Klute, A. American Society of Agronomy, Madison, WI, 687–734.

Lobbezoo, J. P. and Vanapalli, S. K. (2002): A simple technique for estimating the coefficient of permeability of unsaturated soils, in: *Proceedings of the 55th Canadian Geotechnical Conference*, edited by Stolle, D., Piggott, A. R. and Crowder, J. J. Niagara Falls, 1277–1284.

Marković, T., Brkić, Ž. and Larva, O. (2013): Using hydrochemical data and modelling to enhance the knowledge of groundwater flow and quality in an alluvial aquifer of Zagreb, Croatia. *Sci. Total Environ.,* **458–460**, 508–516, DOI: 10.1016/j.scitotenv.2013.04.013.

Nakić, Z., Ružičić, S., Posavec, K., Mileusnić, M., Parlov, J., Bačani, A. and Durn, G. (2013): Conceptual model for groundwater status and risk assessment - Case study of the Zagreb aquifer system, *Geol. Croatica*, **66**, 55–77, DOI: 10.4154/GC.2013.05.

Ng, C. W. W. and Pang, Y. W. (2000): Influence of stress state on soil-water characteristics and slope stability, *J. Geotech. Geoenviron. Eng.*, **126**, 157–166, DOI: 10.1061/(ASCE)1090-0241(2000)126:2(157).

Ružičić, S., Mileusnić, M. and Posavec, K. (2012): Building Conceptual and Mathematical Model for Water Flow and Solute Transport in the Unsaturated zone at Kosnica Site, *Mining-Geol.-Petrol. Engin. Bull.*, **25**, 21–31.

Ružičić, S., Mileusnić, M., Posavec, K., Nakić, Z., Durn, G. and Filipović, V. (2016): Water flow and solute transport model of potentially toxic elements through unsaturated zone at regional wellfield Kosnica, *Hydrol. Process.*, **30**, 4113–4124, DOI: 10.1002/hyp.10914.

Schaap, M. G., Leij, F. J. and van Genuchten, M. Th. (2001): ROSETTA: A computer model for estimating soil hydraulic parameters with hierarchical pedotransfer functions, *J. Hydrol.*, **251**, 163–176, DOI: 10.1016/S0022-1694(01)00466-8.

Sollitto, D., Romić, M., Castrignano, A., Romić, D. and Bakić, H. (2010): Assessing heavy metal contamination in soils of the Zagreb region (Northwest Croatia) using multivariate geostatistics, *Catena*, **80**, 182–194, DOI: 10.1016/j.catena.2009.11.005.

Terzaghi, K. and Peck, R. B. (1967): *Soil Mechanics in Engineering Practice*. J. Wiley and Sons, New York, 529 pp.

Vanapalli, S. K., Fredlund, D. G. and Pufahl, D. E. (1999): The influence of soil structure and stress history on the soil-water characteristics of a compacted till, *Geotechnique,* **49**, 143–159, DOI: 10.1680/geot.1999.49.2.143.

Van Genuchten, M. T. (1980): A closed form equation for predicting the hydraulic conductivity of unsaturated soils, *Soil Sci. Soc. Am. J.*, **44**, 892–898, DOI: 10.2136/sssaj1980.03615995004400050002x.

Van Genuchten, M. Th, Kaveh, F., Russell, W. B. and Yates, S. R. (1988): Direct and indirect methods of estimating the hydraulic properties of unsaturated soils, in: *Land Qualities in Space and Time*, edited by Bouma, J. and Bregt, A. K. International Society of Soil Science, Wageningen, 61–72.

Velić, J. and Saftić, B. (1991): Subsurface spreading and facies characteristics of middle pleistocene deposits between Zaprešić and Samobor, *Geol. Bull.*, **44**, 69–82.

Velić, J. and Durn, G. (1993): Alternating lacustrine-marsh sedimentation and subaerial exposure phases during quaternary: Prečko, Zagreb, Croatia, *Geol. Croatica*, **46**, 71–90.

Velić, J., Saftić, B. and Malvić, T. (1999): Lithologic composition and stratigraphy of quaternary sediments in the area of the "Jakuševec" waste depository (Zagreb, Northern Croatia), *Geol. Croatica,* **52**, 119–130, DOI: 10.4154/GC.1999.10.

SAŽETAK

Procjena propusnosti aluvijalnog tla korištenjem varijacije sadržaja vlage

Stanko Ružičić, Zoran Kovač, Zoran Nakić i Daria Kireta

Korištenje nesaturirane hidrauličke vodljivosti može pomoći u definiranju propusnosti tla, odnosno procjeđivanju vode kroz nesaturiranu zonu. Cilj ovog rada je procjena propusnosti tla na lokaciji profila Kosnica, koji se nalazi u aluvijalnoj ravnici zagrebačkoga vodonosnika, Republika Hrvatska, na temelju varijacije sadržaja vlage u tlu. Zagrebački vodonosnik predstavlja jedini izvor pitke vode za stanovnike Grada Zagreba i dijela Zagrebačke županije. Debljina nesaturirane zone zagrebačkoga vodonosnika varira od 8 m u sjeverozapadnom dijelu, do 2 m u jugoistočnom dijelu. Vrijednosti nesaturirane hidrauličke vodljivosti izračunate su na temelju granulometrijskog sastava horizonata tla i na temelju optimiziranih parametara tla. Varijacija nesaturirane hidrauličke vodljivosti pokazala je da je gornji dio profila općenito propustan tijekom 2011./2012. hidrološke godine. Nesaturirane hidrauličke vodljivosti proračunate na temelju optimiziranih parametara tla generirale su najviše vrijednosti, uvijek veće od 1E–9 m/s. Iako bi procjena propusnosti profila tla bila preciznija kada bi postojala mjerenja sadržaja vlage i tlaka u svakom horizontu, ovakav način proračuna može dati prvi uvid u okvirne vrijednosti varijacije nesaturirane hidrauličke vodljivosti i povezane propusnosti.

Ključne riječi: propusnost tla, nesaturirana hidraulička vodljivost, sadržaj vlage, vodocrpilište Kosnica

Corresponding author's address: Zoran Kovač, Department of Geology and Geological Engineering, Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, Pierottijeva 6, HR-10 000 Zagreb, Croatia; tel: +385 1 5535 789, fax: +3851 4836 064, e-mail: zoran.kovac@rgn.hr