Using of pedotransfer functions for assessment of hydrolimits

V. Štekauerová[1], J. Skalová[2], J. Šútor[1]

[1]Institute of Hydrology, Slovak Academy of Sciences, Bratislava, Slovak Republic
[2]Faculty of Civil Engineering, Slovak University of Technology in Bratislava, Slovak Republic

ABSTRACT

Soil hydrologic coefficients, also called hydrolimits, are soil water contents defined for certain values of water potentials. Closer attention is paid to three hydrolimits: field capacity, point of decreased availability, and wilting point. The hydrolimits can be found by various ways. Their assessment under natural conditions should be seen as laboratory assessment of hydrolimit values or use of soil water retention curves for reading of hydrolimits. Therefore, some methods for indirect assessment of the water retention curve from actually mapped soil characteristics such as soil texture, bulk density and calcium content were devised. They are generally called pedotransfer functions (PTFs). Aim of the study is to calculate values of some important hydrolimits using PTFs. The hydrolimits calculated by this way are compared to hydrolimits determined from another measured water retention curves. The presented study documents an efficiency and promptness of PTFs use for a region of interest for dynamics evaluation of water storage in the soil aeration zone considering the water supply of plants.

Keywords: water storage; hydrolimit; water retention curve; pedotransfer function

Soil aeration zone is one of the most important parts of the hydrologic cycle and for water movement evaluation, it is also one of the most complicated. Soil water regime, which determines its production ability, depends on inflow into or outflow from the area. Considering the fact that plants are supplied by water from the soil aeration zone, it is necessary to know the water amount that the soil can provide to the plants. The water amount (or water storage) in the soil aeration zone reacts to weather changes and to technical impacts realised within the area from the long-term point of view. The hydrolimits can be used for estimation of water storage in the soil aeration zone in relation to plants.

Hydrolimits are soil water contents defined for certain values of water potentials. Closer attention is paid to three hydrolimits: field capacity Θ_{FC}, soil water content defining point of decreased availability Θ_{PDA} and wilting point Θ_{WP}.

The hydrolimits can be found by various ways. Their assessment under natural conditions should be seen as a laboratory assessment of hydrolimit values of the individual soil samples. The assessment is a lengthy and it has only one-sided use. Use of soil water retention curves for reading of hydrolimit values for respective water potentials is another possibility. And then the problem of hydrolimit assessment is concentrated on assessment of dependence of a soil water potential on volume soil water content (moisture) $h_w(\Theta)$ in balanced state, that is the water retention curve.

Measuring of the dependence $h_w(\Theta)$ is expensive and time consuming. An obvious relationship between $h_w(\Theta)$ and soil texture has led to formulation of models that are trying to put into relation e.g. sand, clay and dry bulk density with $h_w(\Theta)$, etc. and they are generally called pedotransfer functions (PTFs) (Gupta and Larson 1979, Rawls et al. 1982, Saxton et al. 1986, Šútor and Štekauerová 1999, Šútor et al. 2001).

Aim of the study is to calculate values of some important hydrolimits using pedotransfer functions that were devised from a smaller file of water retention curves, with calcium content was determined in soil samples too. The hydrolimits calculated this way are compared to hydrolimit values determined from another measured retention curves. Suitability of the method for its use in practice is verified.

MATERIAL AND METHODS

A data file consisting of 57 drying branches of water retention curves (WRC) that were measured on soil samples under laboratory conditions by overpressure apparatus Soil Moisture Equipment, Santa Barbara, California was used to devise pedotransfer functions. Water contents (moistures) were determined at water potentials of –3, –30, –300, –800, –1300 cm. The soil samples originated from regions of The Rye Island and Záhorie namely from localities of Kráľovská lúka, Baka, Horný Bar, Šamorín, Gabčíkovo, Čilistov, Čiližská Radvaň, Šintava, Gáň, Sereď, Trakovice, Bučany, Šulekovo, Lošonec, Sekule. Content of $CaCO_3$ was determined for each sample as well as bulk density ρ_d. Particle size distribution was determined by Cassagrande's method.

Pedotransfer functions (PTFs) were obtained by sextuple linear regression for soil volume water contents Θ_{hw} at water potentials $h_w = -3, -30, -300, -800, -1300$ cm depending on percentage content of I., II., III. and IV. grain category according to Kopecký, on percentage content of $CaCO_3$ and on dry bulk density ρ_d (g.cm^{-3}).

Table 1. Coefficients A, B, C, D, E, F, G of regression relations and correlation coefficient R for pedotransfer functions that can be used for water retention curves points calculation, i.e. volume water contents at respective water potentials h_w

h_w (cm)	Coefficients of regression relations							Correlation coefficient R
	A	B	C	D	E	F	G	
–3	0.309	0.222	0.232	0.164	–0.038	–28.953	67.504	0.9032
–30	0.212	0.135	0.032	–0.049	0.032	–17.464	58.398	0.8309
–300	0.267	0.081	–0.512	–0.054	–0.137	–7.159	48.034	0.8188
–800	0.270	0.049	–0.610	–0.023	–0.126	–5.487	42.921	0.8095
–1300	0.261	0.033	–0.562	–0.037	–0.118	–6.303	42.287	0.8002

Table 2. The hydrophysical characteristics of soil samples A1–A9 (I. cat., II. cat., III. cat., IV. cat. – grain categories, ρ_d – dry bulk density) and $CaCO_3$ content

WRC	I. cat. %	II. cat. %	III. cat. %	IV. cat. %	ρ_d g.cm^{-3}	$CaCO_3$ %
A1	6.30	55.79	4.84	33.07	1.624	7.84
A2	16.68	77.98	1.72	3.62	1.319	27.37
A3	5.67	56.33	4.65	33.35	1.619	6.85
A4	7.60	61.46	6.59	24.35	1.503	0.23
A5	6.70	56.91	4.57	31.82	1.576	7.94
A6	17.30	48.93	5.33	28.44	1.479	5.60
A7	9.36	56.17	4.63	29.83	1.400	6.82
A8	6.20	60.49	6.51	26.80	1.469	0.43
A9	19.33	64.26	4.07	12.34	1.416	19.45

Resultant PTFs have the general form:

$$\Theta_{hw} = A.(\text{I. cat}) + B.(\text{II. cat}) + C.(\text{III. cat}) + D.(\text{IV. cat}) + E.(CaCO_3) + F\rho_d + G \qquad (1)$$

where: A, B, C, D, E, F, G are regression coefficients, I., II., III. and IV. grain categories are presented in %, ρ_d in g.cm^{-3} and $CaCO_3$ in mass %.

Regression coefficients A, B, C, D, E, F, G are presented in Table 1 for all water potentials together with a correlation coefficient R.

A new data file of drying branches of WRC measured in 9 soil samples was obtained from congenerous localities from which the data file of 57 drying branches of WRC appointed for PTF quantification was obtained. The WRC of the 9 samples were measured using the same above-mentioned method for water potentials of –3, –30, –300, –800, –1300 cm (Table 3). They were approximated using a relation by Genuchten (1980) and thereby the values of coefficients α_m and n_m, where m stands for coefficients obtained for measured drying branches of WRC, were obtained. A value of residual moisture Θ_r was calculated for the soil samples using the relation (Šútor and Majerčák 1988): $\Theta_r = 0.20058.(\%\ \text{I. cat}) + 1.03747$.

The data file of the approximated WRC was labelled as S_m. Point values of WRC at water potentials of –3, –30, –300, –800, –1300 cm were calculated from the grain cat-

Table 3. Measured values of water retention curves for soil samples A1–A9; Θ is volume water content and h_w is water potential

WRC	Θ (m^3.m^{-3})				
	Θ (h_w = –3 cm)	Θ (h_w = –30 cm)	Θ (h_w = –300 cm)	Θ (h_w = –800 cm)	Θ (h_w = –1300 cm)
A1	0.4357	0.3622	0.3295	0.2944	0.2714
A2	0.5275	0.4717	0.4407	0.4114	0.3877
A3	0.4493	0.3862	0.3518	0.3105	0.2890
A4	0.5199	0.4426	0.4012	0.3573	0.3280
A5	0.4771	0.4205	0.3810	0.3358	0.3071
A6	0.4482	0.3876	0.3491	0.3229	0.3005
A7	0.4838	0.3988	0.3496	0.3079	0.2841
A8	0.5418	0.4541	0.4132	0.3766	0.3448
A9	0.4821	0.4159	0.3702	0.3338	0.3150

Table 4. Basic parameters of the water retention curve (WRC) obtained by approximation using Genuchten (1980) relation (α, n), where S_m stands for measured WRC, S_{PTF} stands for WRC calculated using PTFs, Θ_S stands for the full water capacity and Θ_r stands for residual volume water content equal for both files

WRC		S_m			S_{PTF}		
	α_m	n_m	Θ_S	α_{PTF}	n_{PTF}	Θ_S	Θ_r
A1	0.00308	1.43009	0.4357	0.00087	1.77630	0.4105	0.0230
A2	0.00125	1.59781	0.5275	0.00131	1.61913	0.5175	0.0438
A3	0.00238	1.47283	0.4493	0.00087	1.77924	0.4117	0.0217
A4	0.00262	1.45777	0.5199	0.00190	1.65047	0.4549	0.0256
A5	0.00211	1.50287	0.4771	0.00096	1.72924	0.4258	0.0238
A6	0.00243	1.45779	0.4482	0.00106	1.67931	0.4657	0.0451
A7	0.00476	1.38122	0.4838	0.00145	1.57888	0.4805	0.0292
A8	0.00261	1.45047	0.5418	0.00135	1.60629	0.4619	0.0228
A9	0.00300	1.43083	0.4821	0.00118	1.65143	0.4898	0.0492

egories of the soil samples, $CaCO_3$ content and from values of dry bulk densities ρ_d (Table 2) using the PTFs (eq. 1, Table 1). The above-mentioned point values were also approximated according to Genuchten (1980) and thereby the coefficient values α_{PTF} and n_{PTF} were obtained. The PTF index means that the coefficients obtained for WRC were calculated using PTFs. The file of approximated WRC was labelled as S_{PTF}.

The hydrolimits field capacity Θ_{FC}, the soil water content defining point of decreased availability Θ_{PDA} and the wilting point Θ_{WP} were determined from the WRC approximated according to Genuchten (1980) for both files S_m and S_{PTF}.

RESULTS AND DISCUSSION

Main parameters obtained by approximation of WRC using the Genuchten (1980) relation for both files S_m and S_{PTF} are presented for 9 soil samples A1–A9 (Table 4).

Θ_{FC}, Θ_{PDA} and Θ_{WP} for mean values of water potentials namely for $\mathrm{pF}_{\mathrm{FC}} = 2.5$, $\mathrm{pF}_{\mathrm{PDA}} = 3.3$ and $\mathrm{pF}_{\mathrm{WP}} = 4.18$ were obtained from water retention curves from the file S_{PTF} and from measured WRC (the file S_m). The results are presented in Table 5.

Figure 1 shows the water retention curves of soil samples A1 to A9 from the both files and the values of three presented hydrolimits are displayed too. It is also possible to determine a value of another hydrolimit Θ_S from representation of WRC. The hydrolimit is characterised by the soil water content at complete soil pore saturation by water and it expresses the maximum water amount that can be found in soil. It is defined for the water potential that equals 0 cm. Figure 1 represents its measured or using PTFs calculated soil water value for the water potential of –3 cm.

A close agreement is evident when comparing WRC measured and calculated using PTFs as it is displayed in Figure 1. Accuracy of the calculated WRC is quantified with the mean difference (MD) and with the root of mean squared difference (RMSD). MD and RMSD are calculated using the method of numerical quadrature within an interval of water potentials $\langle a; b \rangle \equiv \langle -74130\ \mathrm{cm}; 0\ \mathrm{cm} \rangle$ using integrals, where Θ_m stands for a measured water content, Θ_p stands for an equivalent water content calculated from PTFs and $d\psi$ is a water potential increment:

Table 5. Hydrolimits calculated from water retention curves approximated using Genuchten (1980) relation for both files S_m and S_{PTF}; Θ_{FC}, Θ_{PDA}, Θ_{WP} are marked hydrolimit values in order of the field capacity, the soil water content defining point of decreased availability and the wilting point; Δ is difference between hydrolimit values from the files S_m and S_{PTF}

WRC		S_m			S_{PTF}			$\Delta = f(S_{\mathrm{PTF}} - S_m)$	
	Θ_{FC} pF = 2.5	Θ_{PDA} pF = 3.3	Θ_{WP} pF = 4.18	Θ_{FC} pF = 2.5	Θ_{PDA} pF = 3.3	Θ_{WP} pF = 4.18	Θ_{FC} pF = 2.5	Θ_{PDA} pF = 3.3	Θ_{WP} pF = 4.18
A1	0.3500	0.2080	0.1020	0.3946	0.2427	0.0752	0.0446	0.0347	–0.0268
A2	0.4919	0.3029	0.1269	0.4801	0.2067	0.1081	–0.0118	–0.0162	–0.0088
A3	0.3852	0.2199	0.0998	0.3957	0.2425	0.0738	0.0105	0.0226	–0.0260
A4	0.4395	0.2513	0.1172	0.3984	0.1987	0.0738	–0.0411	–0.0526	–0.0434
A5	0.4158	0.2359	0.1031	0.4060	0.2461	0.0807	–0.0098	0.0102	–0.0224
A6	0.3876	0.2350	0.1224	0.4413	0.2736	0.1087	0.0537	0.0386	–0.0137
A7	0.3728	0.2196	0.1182	0.4401	0.2584	0.1045	0.0673	0.0388	–0.0137
A8	0.4585	0.2630	0.1217	0.4259	0.2473	0.0931	–0.0326	–0.0157	–0.0286
A9	0.4045	0.2450	0.1327	0.4598	0.2807	0.1164	0.0553	0.0357	–0.0163

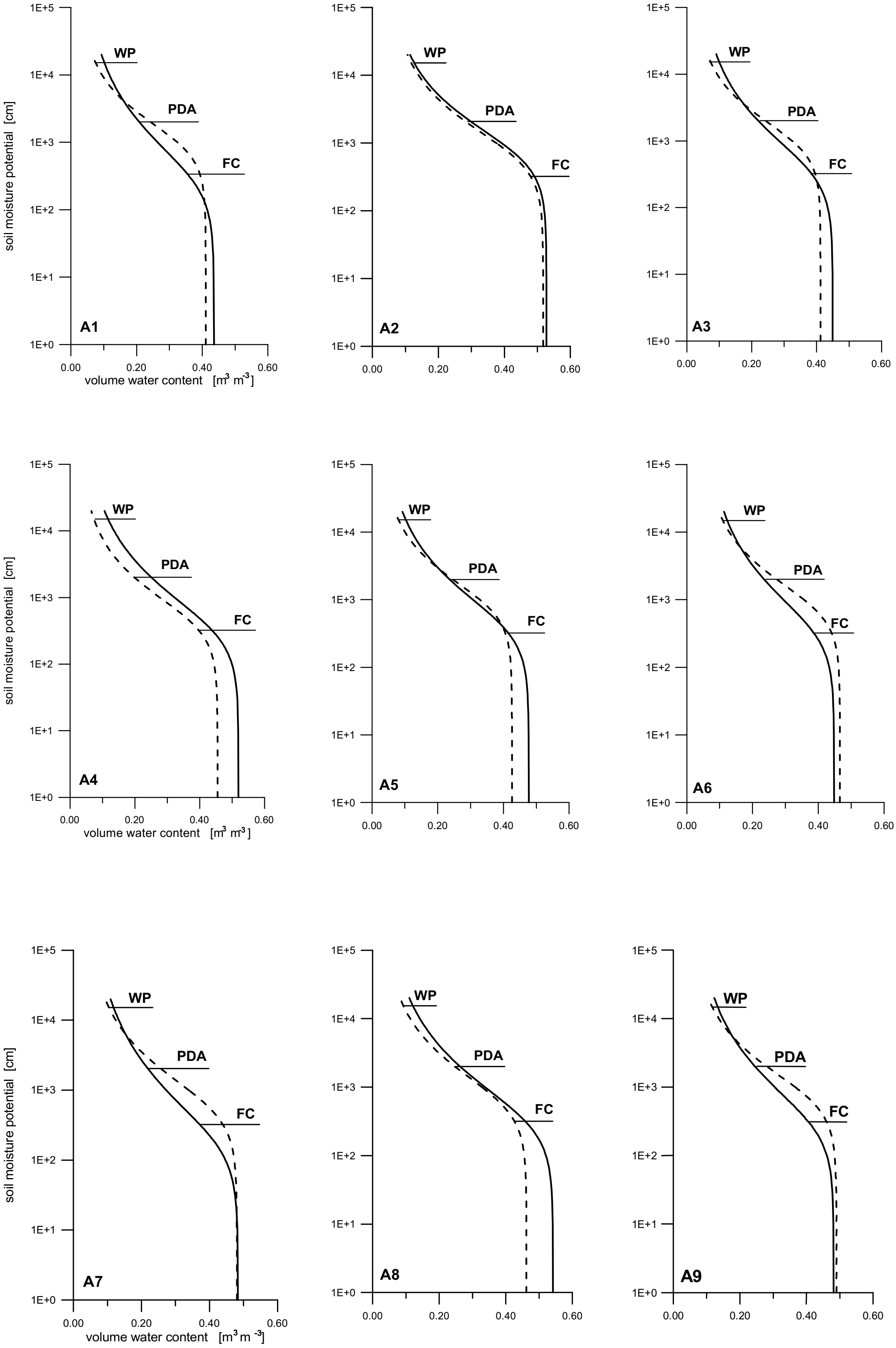

Figure 1. Water retention curves (—— measured, - - - calculated by PTFs) approximated using Genuchten (1980) relation (FC, PDA and WP are marked hydrolimit values in order of the field capacity, the soil water content defining point of decreased availability and the wilting point)

$$\mathrm{MD} = \frac{1}{b-a}\int_a^b (\theta p - \theta m)\,d\psi \qquad (2)$$

$$\mathrm{RMSD} = \left[\frac{1}{b-a}\int_a^b (\theta p - \theta m)^2\,d\psi\right]^{1/2} \qquad (3)$$

RSMD values determine the closeness between measured values of a water retention curve and its values obtained using PTF. Tietje and Tapkenhinrichs (1993) present results of PTF evaluation by 13 authors and 100% applicability is evident with five authors, RMSD values occur between 1.29 and 6.11% of the volume water content. The results of MD and RMDS values for soil samples A1–A9 are given in the (Table 6), and occur between 0.76 and 3.7% of the volume water content.

Another close agreement is obvious between hydrolimit values of the field capacity, the soil water content defining point of decreased availability for plants and the wilting point determined from measured WRC and from WRC calculated using PTFs (Table 5).

The hydrolimit values are dependent on time variability throughout a year that is related to soil bulk changes. Therefore, the hydrolimit values are always within certain intervals of soil water content. They are not specific values. The soil water content defining point of decreased availability and the wilting point are dependent on a type of growth.

Difference between values of the hydrolimit Θ_{FC} from data files S_m and S_{PTF} ranges from 0.98 to 6.73% of the volume water content. Difference between values of the hydrolimit Θ_{PDA} from data files S_m and S_{PTF} ranges from 1.02 to 5.26% of the volume water content. Difference between values of the hydrolimit Θ_{WP} from data files S_m and S_{PTF} ranges from 0.88 to 4.34% for all the cases.

Assessment of WRC or the hydrolimits by this simplified way is advantageous for a water regime management of areas and for soil water regime interpretation using mathematical models.

Table 6. Mean difference (MD) and root of mean squared difference (RMSD) for comparison of the measured values with the calculated values of water retention curves for soil samples A1–A9

WRC	MD ($m^3.m^{-3}$)	RMSD ($m^3.m^{-3}$)
A1	−0.0226	0.0266
A2	−0.0071	0.0076
A3	−0.0218	0.0241
A4	−0.0362	0.0370
A5	−0.0188	0.0199
A6	−0.0118	0.0177
A7	−0.0130	0.0195
A8	−0.0249	0.0252
A9	−0.0144	0.0197

CONCLUSION

Pedotransfer functions (PTFs) were obtained from 57 drying branches of water retention curves (WRC). The PTFs were used for a calculation of 9 water retention curves that were measured (data file S_m) and were not included in the foregoing data file. The WRC were approximated using Genuchten (1980) relation in the both cases. Figure 1 and Table 6 clearly demonstrate a close agreement for all 9 WRC. Measured and calculated WRC were used for hydrolimit values assessment of the field capacity Θ_{FC}, the soil water content defining point of decreased availability Θ_{PDA}, and the wilting point Θ_{WP}. It was found, that differences between hydrolimit values Θ_{FC} and Θ_{PDA} determined from approximated WRC measured and calculated from PTFs did not exceed 6.38% of volume water content and a difference Θ_{WP} did not exceed 2.57% for all the cases.

The presented study documents an efficiency and promptness of PTFs use for a region of interest for dynamics evaluation of water storage in the soil aeration zone considering the water supply of plants.

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REFERENCES

Genuchten M.Th. van (1980): A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil.Sci. Soc. Amer. J., *44*: 892–898.

Gupta S.C., Larson W.E. (1979): Estimating soil water retention characteristics from particle size distribution, organic matter percent, and bulk density. Wat. Res. Res., *15*: 1633–1635.

Rawls W.J., Brakensiek D.L., Saxton K.E. (1982): Estimation of soil water properties. Trans. ASAE, *25*: 1316–1320.

Saxton K.E., Rawls W.J., Romberger J.S., Pependick R.I. (1986): Estimating generalized soil-water characteristics from texture. Soil Sci. Soc. Amer. J., *50*: 1031–1036.

Šútor J., Majerčák J. (1988): Extrapolation of measured values of soil hydrophysical characteristic for given soil type. J. Hydrol. Hydromech., *36*: 639–654. (In Slovak)

Šútor J., Skalová J., Štekauerová V. (2001): Pedotransfer functions for estimation the soil water retention curves of region Záhorská nížina. Acta Hydrol. Slovac., *2*: 156–160. (In Slovak)

Šútor J., Štekauerová V. (1999): Pedotransfer functions of soils of the Rye Island environment. J. Hydrol. Hydromech., *47*: 443–458. (In Slovak)

Tietje O., Tapkenhinrichs M. (1993): Evaluation of pedotransfer functions. Soil Sci. Soc. Amer. J., *57*: 1088–1095.

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ABSTRAKT

Využití pedotransferních funkcí pro určení hydrolimitů

Hydrolimity jsou hodnoty vlhkosti půdy, které byly dosaženy za určitých podmínek a jsou definovány pro určité vlhkostní potenciály. Bližší pozornost je věnována třem hydrolimitům: polní vodní kapacita, bod snížené dostupnosti a bod vadnutí. Hydrolimity je možné stanovit více způsoby. Jejich stanovení v přírodních podmínkách je zapotřebí chápat jako laboratorní stanovení hodnot hydrolimitů jednotlivých půdních vzorků nebo odečtením hydrolimitů z vlhkostních retenčních čar. Proto byly navrženy metody pro určení vlhkostních retenčních čar nepřímo, z reálně vhodných půdních zmapovaných dat, jako je zrnitostní složení půd, objemová hmotnost půdy a obsah $CaCO_3$ v půdě. Takto navržené modely se nazývají pedotransferní funkce (PTF). Cílem práce je vypočítat hodnoty některých důležitých hydrolimitů za pomoci PTF. Takto vypočítané hydrolimity jsou porovnávány s hodnotami hydrolimitů určenými z jiných naměřených retenčních čar. Práce dokumentuje efektivnost a rychlost využití PTF v regionu pro vyhodnocení dynamiky vodních zásob v půdě s ohledem na zabezpečenost porostu vodou.

Klíčová slova: zásoba půdní vody; hydrolimity; vlhkostní retenční čára; pedotransferní funkce

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Corresponding author:

RNDr. Vlasta Štekauerová, CSc., Ústav hydrológie SAV, Račianska 75, 838 11 Bratislava, Slovenská republika,
tel.: + 421 2 49 26 83 02, fax: + 421 2 44 25 94 04, e-mail: stekauer@uh.savba.sk