HYPRESCZ – Database of Soil Hydrophysical Properties in the Czech Republic

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Abstract

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The database of soil hydrophysical properties in the Czech Republic called HYPRESCZ was created. It is based on the European database HYPRES, HYdraulic PRoperties of European Soils, and follows its structure with few modifications. It collects the available data from the Czech Republic from which pedotransfer functions (PTFs) for the estimation of soil hydrophysical properties from easily available soil properties can be derived and 2101 database entries were collected. The entries have different quality of data, out of the total number of entries 707 entries were applicable to PTFs derivation for the estimation of soil water retention curves (SWRCs). After elimination of replicates, finally 159 unique soil horizons (arable land only) were used for PTFs derivation. The parametric continuous pedotransfer functions for estimation of SWRCs in the Czech Republic were derived within this study and are based on Wösten's model. The retention curves were estimated using both these newly derived PTFs and Wösten's original model, which was derived for European soils in general. The uncertainty of estimation was evaluated, employing the root mean squared error (RMSE) and the coefficient of determination (R^2) comparing the PTF-estimated and the directly fitted retention curves. The reliability of the newly derived PTFs for Czech soils was higher (RMSE = 0.059 cm^3/cm^3 and R^2 = 71%) compared to Wösten's general PTFs (RMSE = 0.11 cm^3/cm^3 and R^2 = 36%).

Keywords: HYPRES; pedotransfer functions; soil water retention curve

While environmental modelling and prediction of future situations with relevance to sustainable development of agriculture, climate changes and the increasing population dynamics are widely used, the problem of input data to the models is still crucial in many regions. Hydraulic conductivity and soil water retention curve (SWRC) are the most important soil hydrophysical characteristics for sustainable use of water as a natural resource. However, in contrast to the ever-improving methods of measurement (Scanlon *et al.* 2002; Anderson & Stormont 2003; Cancela *et al.* 2006; Schindler & Müller 2006; Bakker *et al.* 2007), the process of obtaining these characteristics for many areas of practical interest is still time and labour consuming, and thus costly.

Pedotransfer functions (PTFs) for the estimation of these important characteristics from more easily or routinely measured soil properties can serve (if their uncertainty is known) as a valuable alternative to direct measurements, especially in regional environmental studies (Wösten *et al.*

2001; Nemes *et al.* 2006). Pedotransfer functions are empirical relations between the known soil properties, called predictors, and the unknown but required soil properties (Bouma 1989). The definition given by Minasny *et al.* (1999) "Translating data we have into what we need" is very much fitting in this respect. The development of different PTFs has become very popular, as illustrated by McBratney *et al.* (2011).

Various combinations of particle size distribution, dry bulk density and organic matter content are the most widely used predictors in pedotransfer functions for the estimation of soil hydraulic properties (Nemes *et al.* 2003).

However, the pedotransfer functions are not recommended for use outside the area for which they were derived (e.g. Wösten *et al.* 1999; Nemes *et al.* 2003). Thus, a source database containing locally measured data is always necessary (Nemes *et al.* 2003). Several large databases for the PTFs development have been built and are being updated on a national as well as international level. For example, one can cite the works by Nemes *et al.* (2001), Nemes (2002), Minasny *et al.* (2004), and Schindler and Müller (2010). The most important database for Europe is HYPRES, HYdraulic PRoperties of European Soils (Wösten *et al.* 1999). It was built in cooperation of 21 European institutions. Pedotransfer functions derived from this database belong to the most widely used worldwide (McBratney *et al.* 2011).

The present study follows the recommendation by Wösten *et al.* (1999), who suggested that further data from Central and Eastern Europe be added to the HYPRES project database. The main objective of this study was to create a database of soil hydrophysical properties for the Czech Republic, while maintaining compatibility with the European database. The newly created database can be used in many applications. Similarly to the European project, the parametric continuous pedotransfer functions were derived for arable land in the Czech Republic.

MATERIAL AND METHODS

The main purpose of this paper is to present HYPRESCZ, the database of soil hydrophysical properties for the Czech Republic related to the original database of the HYPRES project (Wösten *et al.* 1999). HYPRES has a flexible relational structure for inventorial storage of different soil hydrophysical data and soil survey data within a wide range of quality and completeness. It is created in the Oracle Relational Database Management System™ and was described in detail by Wösten *et al.* (1999).

The HYPRESCZ database is created by means of the commonly used Microsoft Access 2003 database code. Its structure follows the original HYPRES structure (Figure 1), with few differences explained below.

The primary key used in the original HYPRES is the European standard system of geo-referencing (the field called gridref) combined with a horizon notation (the field called horizon) as a secondary key. On the contrary, HYPRESCZ uses only a numerical identification code as a primary key, similar to UNSODA 2.0 encoding (Nemes *et al.* 2001). The field name is thus modified to ID. The reason for this modification is the impossibility of a sufficiently accurate conversion from the Czech S-JTSK cartographic system, to which many older data refer, to new global positioning systems.

Six data tables have the same contents and field names as the original HYPRES tables. The seventh table called CZ_SPEC was created to collect additional data, specific for the Central-European soil survey and classification methodologies.

The table BASICDATA contains basic data on locality, soil type, date of sampling (sometimes only the year of sampling is available) and a contact to the person responsible for the data. The table structure is designed for storing a wide range of information, but many of its fields remain poorly filled. For example, the data on groundwater table or weather conditions are usually missing; sometimes even no information is available about the soil type or soil horizon. For these cases, the abbreviations NA or ND (not available or not determined, respectively) are used.

The table SOIL_PROPS contains the basic pedological and hydrophysical information, such as the texture in FAO/USDA categories (content of clay below 0.002 mm, silt between 0.002 and 0.05 mm and sand between 0.05 and 2 mm), dry bulk density, organic matter content, saturated hydraulic conductivity, saturated water content etc. Some comments on the methodologies used for determination of these characteristics are also stored. This table contains the fitted Mualem-van Genuchten parameters for the stored soil water retention and hydraulic conductivity data. A cer-

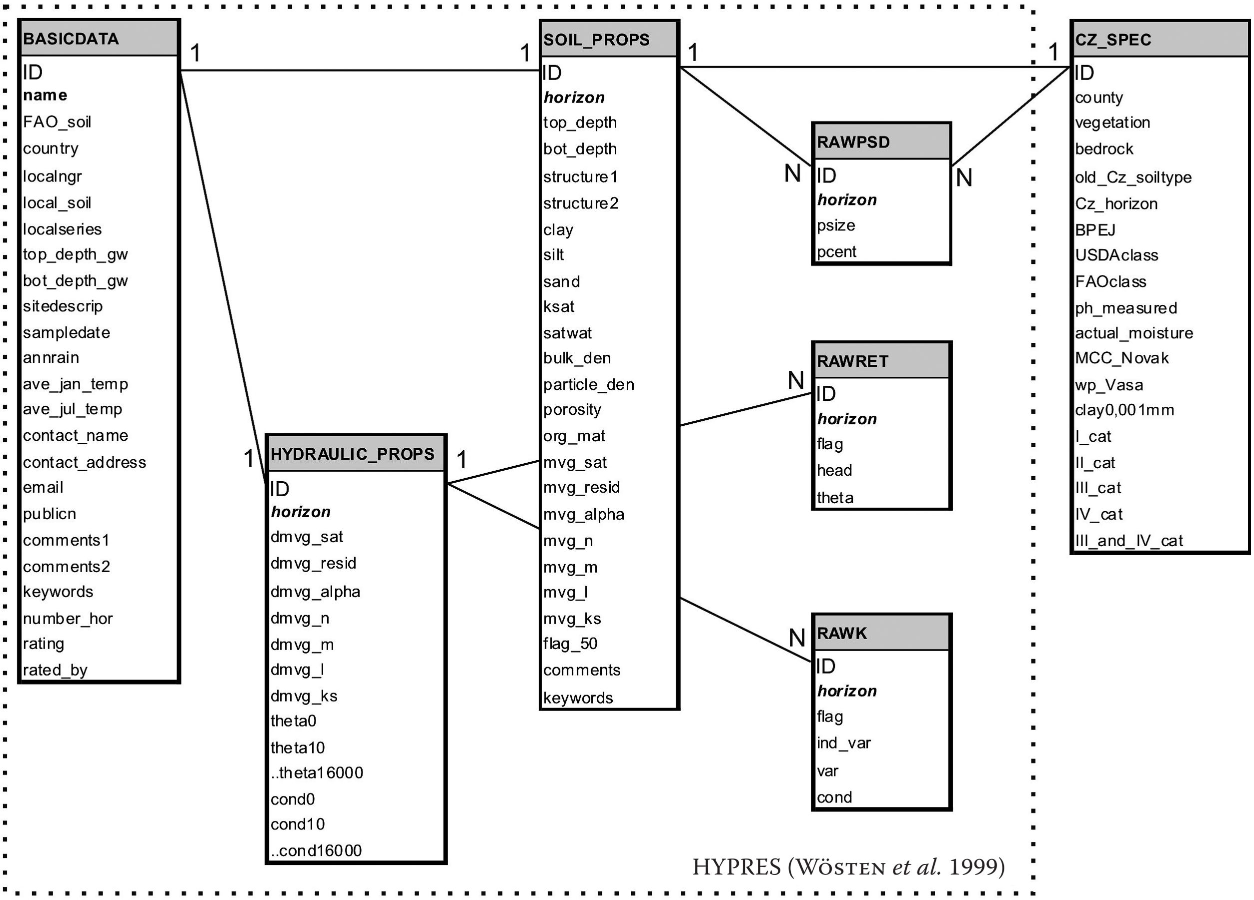

Figure 1. Relational structure of HYPRESCZ database following the HYPRES structure

tain sort of standardization of raw data points was necessary. It was carried out by fitting the data with the Mualem-van Genuchten model parameters (Mualem 1976; van Genuchten 1980) for each individual retention or hydraulic conductivity curve ($\theta(h)$ or $K(h)$, respectively). The following retention curve equation (van Genuchten 1980) was used:

$$\theta = \theta_r + \frac{(\theta_s - \theta_r)}{\left(1 + \left(\alpha|h|\right)^n\right)^{1-1/n}} \quad (1)$$

where:

$|h|$ – absolute value of the actual pressure head (cm)

θ – actual soil water content (cm^3/cm^3)

θ_r – model parameter expressing the residual soil water content (cm^3/cm^3)

θ_s – model parameter expressing the saturated soil water content (cm^3/cm^3)

a, n – shape factors

The fitted parameters of Eq. (1), namely θ_r, θ_s, α and n, were obtained by employing the RETC code (van Genuchten *et al.* 1991). Figure 2 shows the correlation between the measured saturated water content and the model parameter θ_s. An effort was made during the fitting procedure to use the measured value of the saturated water content as a model parameter θ_s to maintain a relation to the physical reality. When this was not possible, the model parameter θ_s was found by optimization.

The table HYDRAULIC_PROPS contains van Genuchten's parameters (1980) of the retention curves, estimated by employing the continuous parametric pedotransfer functions (as described below) and the calculated volumetric water contents at characteristic pressure heads down to $h = -16\,000$ cm. The hydraulic conductivities were not estimated in this way because of data scarcity.

The table RAWPSD contains raw particle size distribution curves as much detailed as provided by data suppliers. The data pairs stored contain the particular particle size fraction and its content in per cent of dry mass.

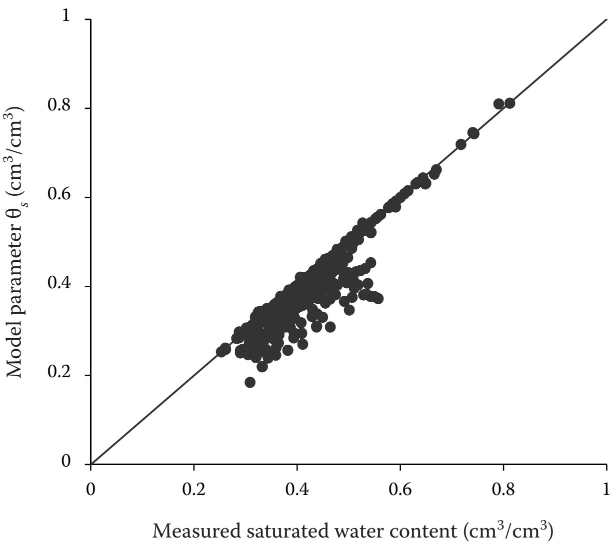

Figure 2. A 1:1 correlation of the saturated water content θ_s (model parameter) and the measured saturated water content (arable lands, 709 samples)

The table RAWRET contains the measured retention curves, recorded as pairs of pressure head vs. volumetric water content. An indication of the way of measurement (laboratory or field) is also recorded.

The table RAWK contains the measured unsaturated hydraulic conductivity curves, recorded as pairs of K value vs. either the corresponding pressure head or the corresponding soil water content. An indication of the type of data ($K(h)$ or $K(\theta)$) is also recorded.

The table CZ_SPEC contains additional information that cannot be accommodated within the other tables, like county, type of vegetation, bedrock, the old Czechoslovak soil classification (if available for the older data), maximum capillary capacity according to Novák (an empirical value approximating the field capacity), permanent wilting point determined by Váša's technical method, particle size distribution categories according to Kopecký etc. It also contains the highest (in the absolute value) pressure head for which the retention curve data are available, because the majority of the collected retention curves was measured at pressure heads considerably smaller than $|h|$ = 15 000 cm. This information is important because it indicates the interval within which the curve fitted with van Genuchten's parameters can be used. The fitted curve should not be extrapolated outside the measured pressure head range (cf. the discussion by Kosugi *et al.* 2002).

The HYPRESCZ database was established and filled with available data from about 70 locations on arable lands and 25 locations of forest soils all over the Czech Republic. The age of the data varies from very recent back to the early 1970's. An overview of the collected retention curve data, indicating also their applicability, is presented in Table 1. Dry bulk densities of soils are overviewed in Table 2. The organic matter content is frequently below 1% for arable soils but it can be as high as 7% for forest soils. A relationship between the saturated water content and the soil porosity was derived from 799 samples of arable soils. On average the saturated water content makes 89% of the total porosity (R^2 = 77%). Table 3 shows a differentiation of this relationship among five textural groups of soils as defined by Němeček *et al.* (2011).

Table 1. The number of entries of different quality in HYPRESCZ database

No. of entries	Quality of data
2191	the total No. of entries
1970	entries containing a measured retention curve
1237	entries containing a retention curve measured at least to h = –5000 cm
908	entries containing a retention curve measured at least to h = –15 000 cm
707	entries suitable to PTFs derivation (containing retention curve over –15 000 cm and essential predictors)

Table 2. Dry bulk density (g/cm^3) of the samples stored in HYPRESCZ

Land use	No. of samples	Arithmetic mean	Mode	Median
Arable	1 730	1.46	1.56	1.50
Forest	246	1.29	1.32	1.37

Table 3. Relationship between the measured saturated water content and the porosity of the soil for textural groups according to Němeček *et al.* (2011)

Soil textural groups	Saturated water content in percent of total porosity (%)	No. of samples	R^2(%)
Coarse (1)	86	38	70
Medium coarse (2)	79	177	68
Medium (3)	88	225	85
Medium fine (4)	74	152	77
Very fine (5)	99*	93	97

*value can be affected by swelling; R^2 – coefficient of determination

Localities were usually sampled in replicates and these replicates are stored separately. The replicates of samples were sorted out and averaged (using a geometric mean) when necessary. The original number of 707 entries (including replicates) suitable for PTFs derivation was finally reduced to only 159 unique soil horizons (for arable lands only). The textures of the unique soil horizons are presented in Figure 3. Forest soil entries were similarly reduced to 106 unique soil horizons and will be used in future studies.

As for the hydraulic conductivity data, there are about 200 entries containing saturated hydraulic conductivity, but they come from 13 locations only. These values were usually measured in the laboratory, except for two locations for which good-quality field measurements are available. Unsaturated hydraulic conductivity was measured in the field in three locations only. These data are stored in the database but no reliable estimations can be derived from them yet. More data will have to be added to them in future.

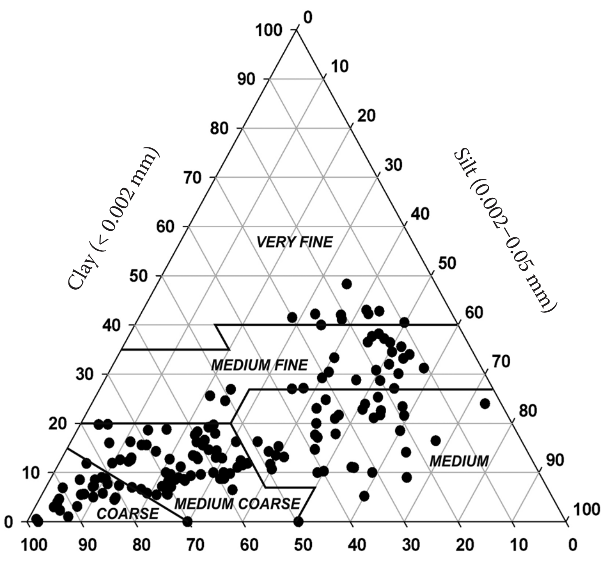

Figure 3. Texture triangle with data points of the unique soil horizons; soil textural groups are according to Němeček *et al.* (2011)

The data stored in the HYPRESCZ database were used for deriving continuous pedotransfer functions for the estimation of retention curves of soils in the Czech Republic, based on the parametric nonlinear regression model by Wösten *et al.* (1999). The continuous pedotransfer functions may better characterize a particular location, because they use predictors measured in the same location. However, the estimations targeted at larger areas may be problematic because of soil heterogeneity. The Statistica Cz code (StatSoft CR s.r.o., www.statsoft.cz) was employed to calculate the new model coefficients using the nonlinear least-squares estimation procedure (Levenberg-Marquardt) algorithm. Van Genuchten's parameters θ_r, θ_s, α and n were estimated by these newly calculated model coefficients and were subsequently used for the calculation of retention curve points at characteristic pressure heads 0, –10, –20, –50, –100, –200, –250, –500, –1000, –2000, –5000, –10 000, –15 000 and –16 000 cm. Wösten *et al.* (1999) did not estimate the parameter θ_r at all and used a fixed value 0.01 cm^3/cm^3 instead. In this study, θ_r was independently estimated, using the same form of model equation as the one used for θ_s estimation.

The uncertainty of the estimated model parameters and the estimated retention curve points was evaluated. The coefficient of determination (R^2) was used to evaluate the quality of estimation of model parameters, while in addition, the root mean squared error (RMSE) was used for evaluation of the quality of estimation of retention curve points.

RESULTS AND DISCUSSION

The continuous parametric pedotransfer functions according to the model by Wösten *et al.* (1999) were derived from the data for unique soil horizons in the HYPRESCZ database. These pedotransfer functions can be used for the estimation of soil water retention curves in the Czech Republic. They are presented in Table 4. The uncertainty of van Genuchten's parameter estimation was expressed as the coefficient of determination R^2 (see the same Table 4). These data made a comparison with the work by Wösten *et al.* (1999) possible. The HYPRES-derived parameters were characterized by the following values of R^2: 76% for θ_s, 20% for a* and 54% for n*. The parameters derived from the new PTFs developed in this study show higher values of R^2 for a* but lower R^2 for the other parameters. In particular, a very low coefficient of determination was obtained for θ_r. This is because the estimation of this parameter is difficult in principle: the approximately normal distribution of data cannot be ensured due to an optimisation procedure, but it is highly recommended for regression models. However, ensuring the normal distribution is rather difficult in some physical data sets (Helsel & Hirsch 2002; Vereecken & Herbst 2004). The residual water content parameter θ_r was discussed in many studies. E.g. Fayer and Simmons (1995) added the adsorption equation by Campbell and Shiozawa (1992) to Eq. (1) to replace the rigid parameter θ_r. This procedure led to a slight change in the other parameters. Štekauerová *et al.* (2002) measured the retention curves up to the pressure head $h = -1300$ cm. Instead of optimizing the parameter θ_r globally, they applied a locally derived equation relating this parameter to the content of the first particle fraction according to Kopecký (below 0.01 mm). No similar correlation was unfortunately found across the HYPRESCZ database. Doležal *et al.* (2008) mathematically simulated the laboratory procedure proposed by Váša (the so-called technical method) for obtaining the permanent wilting point, which made it possible to relate it to van Genuchten's parameters, especially θ_r.

The estimated van Genuchten's parameters were used to estimate the points of retention curves at characteristic pressure heads (see the Materials and Methods chapter). The number of 519 entries which were sorted out as replicates were used as predictors in this case. As these predictors were now different from those used for the direct regression analysis, this procedure led to the evaluation of reliability, rather than accuracy, according to the terminology introduced by Wösten *et al.* (2001). The uncertainty of these estimations was characterized by the root mean squared error RMSE =

Table 4. The continuous parametric pedotransfer functions for the estimation of retention curves of soils in the Czech Republic (according to the model by Wösten *et al.* (1999))

Parameter	Pedotransfer function	R^2 (%)
θ_r =	$0.195\,843 - 0.000\,722 \times C + 0.005\,066 \times D + 0.000\,030 \times S^2 + 0.002\,455 \times \mathrm{OM}^2 + 0.000\,005 \times C^{-1} - 0.212\,134 \times S^{-1} - 0.062\,058 \times \ln S + 0.000\,302 \times \mathrm{OM} \times C + 0.000\,814 \times D \times C - 0.005\,955 \times D \times \mathrm{OM} + 0.000\,392 \times \mathrm{topsoil} \times S$	14
θ_s =	$0.715\,461 + 0.000\,643 \times C - 0.225\,473 \times D + 0.000\,009 \times S^2 + 0.001\,927 \times \mathrm{OM}^2 + 0.000\,029 \times C^{-1} - 0.032\,066 \times S^{-1} - 0.010\,971 \times \ln S - 0.000\,439 \times \mathrm{OM} \times C + 0.000\,586 \times D \times C + 0.006\,418 \times D \times \mathrm{OM} - 0.000\,185 \times \mathrm{topsoil} \times S$	49
α* =	$7.182\,45 - 0.020\,57 \times C + 0.023\,91 \times S - 0.342\,44 \times \mathrm{OM} - 13.034\,1 \times D - 0.513\,94 \times \mathrm{topsoil} + 4.329\,369 \times D^2 - 0.000\,15 \times C^2 + 0.016\,511 \times OM^2 + 0.002\,085 \times \mathrm{OM}^{-1} + 0.054\,612 \times \ln S + 0.337\,137 \times \ln \mathrm{OM} - 0.042\,72 \times D \times S + 0.156\,857 \times D \times \mathrm{OM} + 0.018\,578 \times \mathrm{topsoil} \times C$	37
n* =	$-19.085\,53 - 0.0138\,45 \times C + 0.026\,597\,9 \times S - 0.474\,625 \times \mathrm{OM} + 516.840\,82 \times D - 52.492\,39 \times D^2 - 0.000\,629 \times C^2 + 0.029\,569 \times \mathrm{OM}^2 - 447.810\,6 \times D^{-1} + 1.145\,905 \times S^{-1} + 0.000\,400\,4 \times \mathrm{OM}^{-1} - 0.465\,839 \times \ln S - 0.020\,784 \times \ln \mathrm{OM} - 839.107\,8 \times \ln D + 0.0175\,405 \times D \times C + 0.163\,137\,4 \times D \times \mathrm{OM} + 0.015\,858\,2 \times \mathrm{topsoil} \times C$	26

q_r ,q_s –model parameters; α*, n* – transformed model parameters (α* = ln α; $n^* = \ln(n - 1)$); C – percentage of clay; S – percentage of silt; OM – percentage of organic matter; D – bulk density (g/cm^3); topsoil – qualitative variable reaching the value 1 (for topsoil layers) or 0 (for subsoil layers); R^2 – coefficient of determination; ln – natural logarithm

0.059 cm^3/cm^3 and R^2 = 71%, when comparing the estimated and the directly fitted retention curves. These results are comparable with those obtained in similar studies worldwide and summarized e.g. by Wösten *et al.* (2001). Then the original PTFs by Wösten *et al.* (1999) (derived from the HYPRES database to be valid for European soils) were used for estimation of the same retention curves points. In this way their reliability for the soils of the Czech Republic could be characterized. The results are as follows: RMSE = 0.11 cm^3/cm^3 and R^2 = 36%. Generally, the prediction force of all tested PTFs was higher in the part of the retention curve near to saturation, compared to its dry end.

When commenting on the uncertainty of a PTFs model, it must be mentioned that there are always several other sources of uncertainty which play their role when fitting the measured data with Eq. (1), see Figure 2. In particular, one usually has to mix the data of different quality and coming from different sources.

CONCLUSION

The database of soil hydrophysical properties in the Czech Republic, called HYPRESCZ, was built within this study and filled with available data. The structure of the database respects the structure of the HYPRES database. Some modifications to the database structure were necessary and are described above. The data collected were used for the derivation of continuous parametric pedotransfer functions, based on the non-linear regression model by Wösten *et al.* (1999). The retention curves were estimated using both the newly derived PTFs and the original PTFs by Wösten *et al.* (1999). The two estimations were compared in terms of RMSE and R^2. It was found that a significant improvement was achieved when the newly derived PTFs were used for the soil data across the Czech Republic. However, even though PTFs can be a useful tool for obtaining the data required e.g. for simulation modelling, the origin of the data and the purpose for which they will be used must always remain in the focus. The HYPRESCZ database is open to new data entries, which in future may further improve the quality of estimations based on it.

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