International Congress on Environmental Modelling and Software

4th International Congress on Environmental Modelling and Software - Barcelona, Catalonia, Spain - July 2008

Jul 1st, 12:00 AM

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Marco Acutis

Marcello Donatelli

G. Lanza Filippi

iEMSs 2008: International Congress on Environmental Modelling and Software
Integrating Sciences and Information Technology for Environmental Assessment and Decision Making
4th Biennial Meeting of iEMSs, http://www.iemss.org/iemss2008/index.php?n=Main.Proceedings
M. Sànchez-Marrè, J. Béjar, J. Comas, A. Rizzoli and G. Guariso (Eds.)
International Environmental Modelling and Software Society (iEMSs), 2008

PTF: an Extensible Component for Sharing and Using Knowledge on Pedo-Transfer Functions

M. Acutis[a], M. Donatelli[b, **, †], G. Lanza Filippi[a]

[a] *Department of Produzione Vegetale, University of Milano, Italy*
[b] *Agriculture Research Council, 40128 Bologna, Italy;*
[**] *currently seconded to European Commission Joint Research Centre, Institute for the Protection and Security of the Citizen, Agriculture Unit, Agri4cast Action, Ispra, Italy*
[†] *Corresponding author, marcello.donatelli@jrc.it*

Abstract: Soil data availability for modelling purposes is often insufficient for the application of physical or semi-empirical models simulating soil hydrology. Standard soil surveys frequently do not include hydrological characteristics of the soil, such as either parameters of water retention and conductivity functions or, simpler than the former, estimates of soil water content at field capacity and wilting point. Even when at least part of such data is available, a quality control is needed to ensure not only that values fit within expected ranges, but also to check for consistency across parameters in a specific soil. The use of pedotransfer functions (PTF) allows estimating "what we need from what we have", that is, it allows estimating soil hydrological parameters from soil data often available. The literature makes available a large number of PTF, and new ones are being proposed. Such PTF range from very simple empirical functions, to complex soil physical models. Users must select a PTF to be used based on both available data and their a-priori knowledge about the soil to be simulated. Still, the choice of the PTF to be used is at times controversial, and users may want to compare the estimate made by several PTF against the same data. Also, users may want to test their own PTF, may be specific for a set of soils and thus perfectly adequate for application in a specific contest, against well known ones. An extensible and easily reusable library encapsulating a collection of PTF can be an important tool to support development and operational use of soil-related models, and to share the increasing knowledge about PTF. The objective of this paper is to illustrate the free available component PTF (PedoTransfer Functions). The component is available for both Windows .NET and JAVA platforms, and it is made available with some proof of concept applications (inclusive of source code) in C#, VB.NET and Java, which show how to extend the component and how to use it. The software component presented in this paper meets the following main requirement: i) easy to reuse; ii) with a clear ontology of the variables used in each PTF, where units, value range, and significance, are unambiguously defined; iii) extensible by third parties independently, allowing for an open system to which scientists can contribute; iv) freely available for non-commercial use.

Keywords: soil hydrologic characteristics, soil water retention, soil water conductivity, software components.

1. INTRODUCTION

The application of physical or semi-empirical approaches in all models that involve soil as one of the sub-system to be simulated (e.g. crop growth, nutrients and pollutants dynamics, CO_2 sequestration, soil organic matter dynamics) require soil data (in particular hydrological parameters) that are often unavailable. Consequently, since a long time [e.g. Nielsen et al., 1986] there has been an interest in methods to estimate soil hydrological parameters from commonly available soil data. More recently, the term "pedotransfer function" (PTF) was introduced by Bouma and van Lanen (1987), and become of common use after the work of Bouma [1989]. In this paper, the link between soil surveys and soil hydrology is emphasized, but it is also shown that several soil variables, such as soil erodibility [Renard et al, 1997] or parameters for solute transport [Gonçalves et al, 2001], can be estimated from basic data,. Nowadays a large number of procedures to estimate soil hydrological parameters has been developed, using different methods. Such methods are based on regression as in the classic work of Gupta and Larson (1979) and in more recent EU HYPESS project [Wösten et al, 1999], or the Vereecken et al. PTF [1989], on either physically based or physical-empirical approaches [e.g. Aria e Parish, 1981, Mishra et al, 1989], or on neural networks [e.g. Shaap et al, 2001, Minasny and McBratney, 2002].

It can be very difficult for a user to select what is the more appropriate method for a specific application in a specific environment [Acutis and Donatelli, 2003], considering that the different procedures can produce very different results [Gijsman et al., 2003], so there is a need for a tool that offers the possibility to estimate the unknown variables with several methods on the basis of available data. Assuming that some laboratory or field measurements of the desired hydrological parameters are available, multiple estimates can be evaluated against such data, allowing the selection of the best performing method. Such evaluation can be done using also composite metrics specifically developed for soil PTF [Donatelli et al., 2004].

Some software tools have been developed implementing PTF. Several of them run in a web browser, but offer only a single or few methods of estimation; examples of such software are Pedon-E [Ungaro et al., 2001] and SWLIMITS [Ritchie et al., 1999, Suleiman and Ritchie, 2001]. Some already existing stand alone software, i.e. SoilPAR2 [Acutis and Donatelli, 2003] present a collection of pedo-transfer functions (PTF), with some possibility to store and visualize soil data, compare estimation against measured data, and evaluate the performance of different PTF. Main limit of SoilPar2 and similar software is that they are close applications, hence it is not possible to add other PTF not included in the application. Also, there is no quality control on data used.

To overcome the limitations above, a software component with the following main requirements is presented in this paper: i) easy to reuse, in stand alone or web application, in Windows .NET and Java platforms; ii) with a clear ontology of the variables used in each PTF, where units, allowed value range, and significance are unambiguously defined; iii) extensible by third parties independently, and in a transparent way, without recompiling the code, allowing for an open system to which scientists can contribute; iv) freely available for non-commercial use. The PTF component was developed to match the requirements above and others.

2. IMPLEMENTED PTF METHODS

The component implements a range of PTF methods:

1. to estimate water content at some specific vales (defined Point PTF in Acutis and Donatelli, 2003) and notably for field capacity and wilting point;
2. to estimate parameters of different types of retention functions and for conductivity functions;
3. to estimate saturated conductivity and bulk density.

The modelling background is essentially based on the approaches published in Pachepsky and Rawls [2004]. The list the PTF currently made available in the component, and their inputs and outputs, is reported in table 1. The equations of the implemented PTF are not reported here, but reference to the source is provided with the documentation. When possible, each implementation was tested against other existing software (unit tests were made and are made available in the documentation of the component).

Table 1. Pedotransfer function currently implemented in PTF, with their input and output .

	Pedo-transfer function										
Variable	**H**	**V**	**B**	**BSS**	**MJ**	**H**	**HM**	**J**	**MQJ**	**S**	**C**
IsTopSoil	in	-	-	in	-	-	-	-	-	in	-
Clay	in	in	in	in	in	in	in	in	-	in	in
Silt	in	in	in	in	in	in	in	in	-	in	in
Sand	-	in	in	in	in	-	-	-	-		in
Organic carbon	in	in	in	in	in	-	-	-	in		in
BulkDensity	in	in	in	in	in	in	-	in	out	out	in
SWC field capacity	out	out	out	out	out	out	out	-	-		out
SWC wilting point	out	out	out	out	out	out	out	-	-		out
SWC at various pressures	-	-	out	out	-	out	out	-	-		-
Van Genuchten N	out	out	-	-	-	-	-	-	-		-
Van Genuchten M	out	out	-	-	-	-	-	-	-		-
Van Genuchten theta saturation	out	out	-	-	-	-	-	-	-	out	-
Van Genuchten theta residual	out	out	-	-	-	-	-	-	-		-
Campbell A	-	-	-	-	out	-	-	-	-		out
Campbell B	-	-	-	-	out	-	-	-	-		out
Mualem *l*	out	-	-	-	-	-	-	-	-	-	-
K saturation	out	out	-	-	-	-	-	out	-	out	out

H = HYPRESS (Wösten et al, 1999) ; **V** = Veerecken et al (1989); **B** = Brakensiek et al. (taken from Hutson and Wagenet, 1992) ; **BSS** = British Soil Survey (taken from Hutson and Wagenet, 1992) ; **MJ** = Mayr and Jarvis (1999); **H** = Huston (Hutson and Cass, 1987); **HM** = Huston modified (Hutson and Cass, 1987); **J** = Jabro (Jabro, 1992) ; **MQJ** = Manrique and Jones (1991) ; **S**= Saxton et al. (1986); **JT**=Jaynes and Tyler (Jaynes and Tyler, 1984) ; **C** = Campbell (1985)

3. UTILITY TOOLS

Two tools are also included in the PTF component, one to convert across soil particle size distributions classification systems, and the second for fitting retention functions to pressure-soil water content data couples.

Different standards for the description of soil particle size distribution (PSD) are adopted in different countries, and some of these are also internationally adopted. The large part of PTF is based on the FAO [1999] standards, but also the ISSS is widespread, and in the UK, another standard is adopted. So, there is a need to convert across PSD classification schemes, also to use a specific PFT developed for another classification schema to avoid errors using an apparently similar one, as pointed out by Nemes and Rawls [2006]. The tool for particle size classification conversion is based on log-normal interpolation. Even if is the simpler and a low performing method [Nemes et al., 1999], it was chosen because it can be used also when data are based on only 3 textural classes, which makes it usable on most database; other methods require four textural classes in our knowledge.

The tool for fitting the retention functions to pressure-soil water content data couples (not available in the Java version) uses the multi-start simplex approach [Duan et al., 1992] to fit these highly non-linear functions. It does not require a set of coherent initial values as the traditionally used Marquardt's method. Because the direct method adopted (derivatives are not computed), standard errors of the functions coefficients and correlation among themselves are computed using a boot-strap-based approach [Shao and Tu, 1995].

4. SOFTWARE COMPONENT DESIGN

The software component PTF (PedoTransfer Functions) contains functions for the computation of different pedo-transfer methods. Each method is implemented as a class called "strategy". Data are provided as inputs using data-types called "domain classes". Domain classes implement a description of the domain being modelled via variables and a set of attributes associated to each variable (minimum, maximum, and default values; units; description; URL). Domain classes can be extended, and new strategies can be built implementing the interface exposed, thus allowing the extension of the component independently by third parties. Transparency and ease of maintenance are granted, also providing functionalities such as the test of input data versus their definition prior to using the PTF; same tests can be run on outputs. Such tests are run via a component called Preconditions, available both in .NET and Java, which allows sending the output to screen, a text file, and XML, or to a trace listener defined by the PTF clients (http://www.apesimulator.org/help/utilities/preconditions). The software architecture of this component further develops the one used in previously developed components and is fully described by Donatelli and Rizzoli [2008]. The component is freely available to scientists and institutions developing component-oriented models and applications in the agro-ecological field. There are two versions of the component, one is written in C# for .NET (extensions can be written in any .NET language), and the second is written in Java. The component is deployable and reusable in any application developed using the Microsoft .NET framework, or Java. The PTF software development kit includes sample projects (in VB.NET, C# and Java) which show how to use and extend the component. A proof of concept application is also made available in the Java software development kit (SDK). The .NET SDK includes also two proofs of concept projects to show how to use the component in a web application and to build web services. Code documentation is also provided and the online help file is available at: http://www.apesimulator.it/help/utilities/ptf.

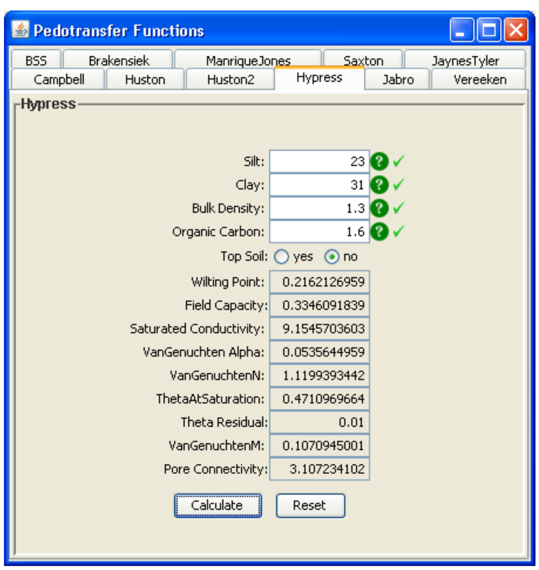

Figure 1 Screen shoot of a proof of concept application implemented in Java.

5. DISCUSSION

PTF are increasingly used to surrogate difficult and time consuming measures of soil hydrological parameters. However, because of the characteristics, behaviour and performance of different PTF are difficult to assess, there is no clear or unique path for their use and evaluation. An example of this difficulty is showed in figure 2, where some PFT offer good estimation in some case and not in other, and not in relation to soil textural classes.

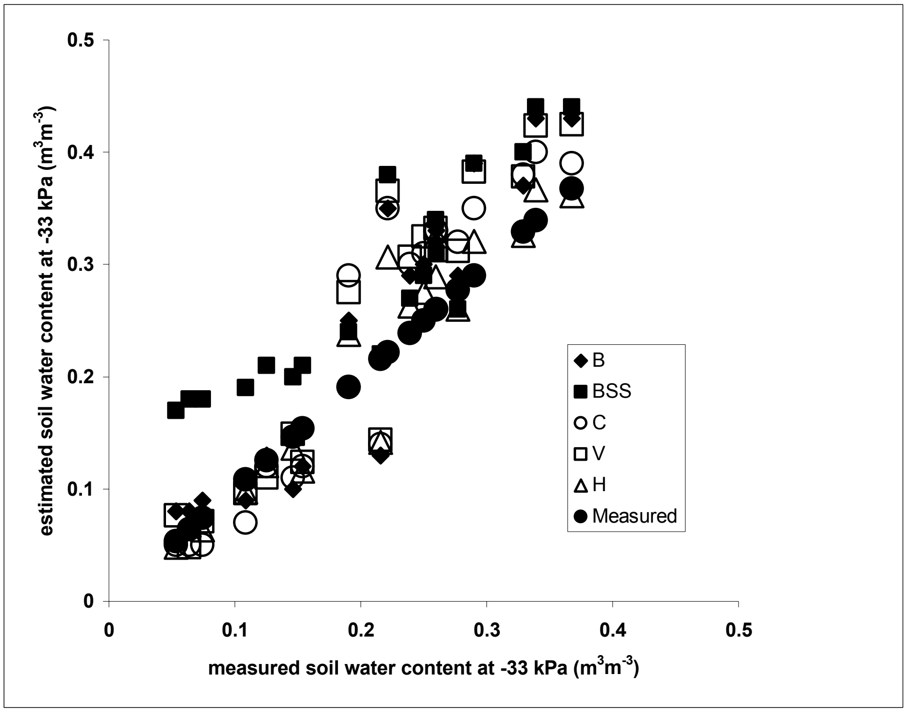

Figure 2 Examples of estimation of soil content at -33 kPa using different PTF function in several soil agains measured valure. PTF: B=Brakensiek; BSS=British Soil Survey; C=Campbell; V=Veerecken; H=HYPRESS

Moreover, given that currently there is not a PTF approach that has shown a consistent superiority when compared to others, several researcher are working in developing new PTF methods. From the previous consideration, a software tool like the PTF component, which is developed targeting reusability and extendibility, can give an important contribution to both operational and scientific applications. Several agricultural and environmental models require soil data, and frequently these data are unavailable from direct measurement, so, the application of some PTF is needed, frequently re-implementing them; the PTF component offers an opportunity to provide such model packages of rich features with minimum effort. Also, the component PTF, that enables the use of several approaches, allows separating the effect of data estimation from the real ability of the model, and allows an easy functional evaluation of the PTF itself [Wösten et al, 2004].

Linking the PTF component with the IRENE (Integrated Resources for Evaluating Numerical Estimates), which shares the same architecture [Bellocchi et al., 2008], allows building composite indices for an articulated testing of PTF methods [Donatelli et al., 2004].

The first feedback received by the users of the prototype is strongly positive. The PTF SDK can be downloaded from http://www.apesimulator.org/public/downloads/ptf/ .

6. CONCLUSIONS

The component PTF makes available a number of Pedotransfer Functions in a discrete software unit. Its extensibility, also independently by third parties, allows easy maintenance and stimulates further development. The goal of PTF is to be a way to share knowledge among scientist and model users, via effective cost-benefit re-use and allowing an easier cross-testing of PTF.

ACKNOWLEDGEMENTS

This publication has been partially funded by the SEAMLESS integrated project, EU 6th Framework Programme for Research, Technological Development and Demonstration, Priority 1.1.6.3. Global Change and Ecosystems (European Commission, DG Research, contract no. 010036-2).

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