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Advancing Precision Agriculture in Southern California, Number 5

PC-PTF—An AI-Powered Tool for Estimating Soil Water Retention Curves

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Introduction

Reliable information about soil hydraulic properties is essential for nearly all aspects of agricultural water management. Many critical decisions—including irrigation scheduling, estimating plant-available water, simulating infiltration and drainage, and assessing groundwater recharge—depend on accurate estimates of how soil holds and releases water. The soil water retention curve (SWRC) is one of the foundational concepts in soil physics and hydrology. SWRC is defined as the relationship between soil water content and soil water tension. It characterizes the unique ability of a soil to retain and release water and has a wide range of practical applications. For example, widely used thresholds such as field capacity (FC) and permanent wilting point (PWP) for irrigation scheduling are derived from the SWRC.

For growers, SWRC information can help determine when to start and stop irrigation, how much water can be stored in the crop root zone, and how quickly the soil may dry between irrigations. This information is especially important in California, where improving irrigation efficiency while maintaining profitable yield is a major water-management priority.

Although SWRCs are widely used, they are difficult and expensive to measure directly. Laboratory determination typically requires intact soil cores and specialized equipment such as pressure plates or the HYPROP-WP4C system (Hydraulic Property Analyzer, Meter Group Inc., Pullman, WA). These procedures can take days to weeks and, for traditional methods such as pressure plates, must be repeated across multiple tension points to characterize the full curve. As a result, direct measurement of the SWRC is rarely feasible for routine field management, and many growers lack access to specialized testing equipment. This creates a need for easy-to-use tools that can accurately estimate SWRC in a fast and practical manner and are suited to local soils. To address these limitations, researchers developed pedotransfer functions (PTFs), which estimate SWRC from basic soil information such as texture, bulk density, and organic matter content.

Pseudo-continuous (PC)-PTF is a free, web-based PTF tool that uses modern artificial intelligence (AI) models to estimate the SWRC from basic soil data (Singh and Verdi 2024). The performance of the tool was evaluated against the widely used Rosetta PTF (Schaap et al. 2001) and showed improved accuracy for soil samples collected from inland and coastal regions of Southern California.

This publication is the fifth in a series on *Advancing Precision Agriculture in Southern California*. It provides guidance on how to use PC-PTF and presents example soil moisture estimates for heavy and coarse soils in Southern California.

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Common terms and definitions

Artificial intelligence (AI): AI models are advanced statistical modeling approaches that are typically trained using large datasets to perform specific tasks. Artificial neural networks (ANNs) are among the most widely used AI models in environmental and agricultural applications.

Field capacity (FC): FC is the soil moisture level after excess water has drained and is commonly used as the upper target for irrigation scheduling.

Management allowable depletion (MAD): MAD is the maximum percentage of plant-available soil water that a grower allows the crop to use from the root zone before irrigation is applied.

Pseudo-continuous pedotransfer function (PC-PTF): PC-PTF is an AI-based pedotransfer function that predicts soil moisture across a continuous range of soil water tensions using basic soil data (Haghverdi et al. 2012, 2014, 2018).

Pedotransfer function (PTF): A PTF is a mathematical model used to estimate difficult-to-measure soil properties, typically soil hydraulic properties, using readily available soil characteristics such as texture and bulk density.

Permanent wilting point (PWP): PWP is the soil moisture level at which plants can no longer extract water and cannot recover from water stress.

Soil tension: Soil tension, also called soil matric potential, describes the energy state of water in the soil and indicates how tightly water is held by soil particles and how easily it can be taken up by plant roots.

Soil volumetric water content: Soil volumetric water content is the volume of water per unit volume of soil.

Soil water retention curve (SWRC): The soil water retention curve describes the unique relationship between soil water content and soil water tension for a given soil type. It explains how volumetric water content changes with soil water tension and influences plant-available water, water movement through soil pores, and soil response to irrigation or rainfall.

Approach and elements of PC-PTF

PC-PTF was first introduced in 2012 using ANN models, and its performance was later evaluated for soils from different parts of the world (Haghverdi et al. 2012; 2015; Nguyen et al. 2017). The accuracy of different AI algorithms was also tested to identify the most reliable modeling approach (Haghverdi et al. 2014). The PC-PTF approach was subsequently modified to take advantage of large datasets generated using the HYPROP-WP4C system, a cutting-edge benchtop instrument for laboratory measurement of soil hydraulic properties (Haghverdi et al. 2018). In a more recent study, PC-PTF was retrained at UC Riverside, using an international HYPROP dataset consisting of more than 12,000 measured water retention data points from 153 soils worldwide (Singh et al. 2020, 2021). The performance of the retrained PC-PTF was later evaluated for soils from Southern California, where the model showed promising results (Singh and Verdi 2024).

To make PC-PTF models available for widespread use, a web-based PC-PTF tool was developed, and the models were retrained using more than 20,000 data points from a modified international dataset. PC-PTF was designed for ease of use by growers, consultants, and researchers to obtain accurate estimates of soil water retention using basic soil properties. The tool is also suitable for scientific applications, and its high-resolution soil water retention estimates help bridge the gap between practical soil management needs and advanced modeling approaches.

PC-PTF can be used with soil moisture sensors for soil moisture-based irrigation scheduling. The tool can estimate FC as the upper refill target for the root zone, while the lower irrigation threshold can be selected based on crop type and management allowable depletion (MAD). In addition, soil moisture sensors may report either soil water content, such as time-domain reflectometry (TDR), or soil water tension, such as Watermark. Because PC-PTF provides a continuous relationship between soil water content and soil water tension, it can help users interpret and compare different types of sensor data. Example 1 in appendix 1 shows a simple calculation for using PC-PTF output in irrigation scheduling.

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How to access and use PC-PTF

PC-PTF is available through the Verdi Water Management Group website. Users begin by uploading a CSV file containing the available input data (fig. 1). Once the data are submitted, the tool checks the file to ensure that all required information is provided. The next step is to select a model, and four model options are available. Model 1 uses soil texture, bulk density, and organic matter content as inputs. Model 2 uses only soil texture information, while models 3 and 4 require bulk density and organic matter content as additional inputs, respectively. At a minimum, soil texture information, including percentages of sand, silt, and clay, must be provided to run PC-PTF. When additional information, such as bulk density and organic matter content, is available, users can select more advanced models.

Once a model is selected, the tool generates results for the submitted soils. The output includes predicted volumetric water content across a range of soil water tensions, representing the full SWRC. Because the full curve is predicted, users can directly derive FC, PWP,

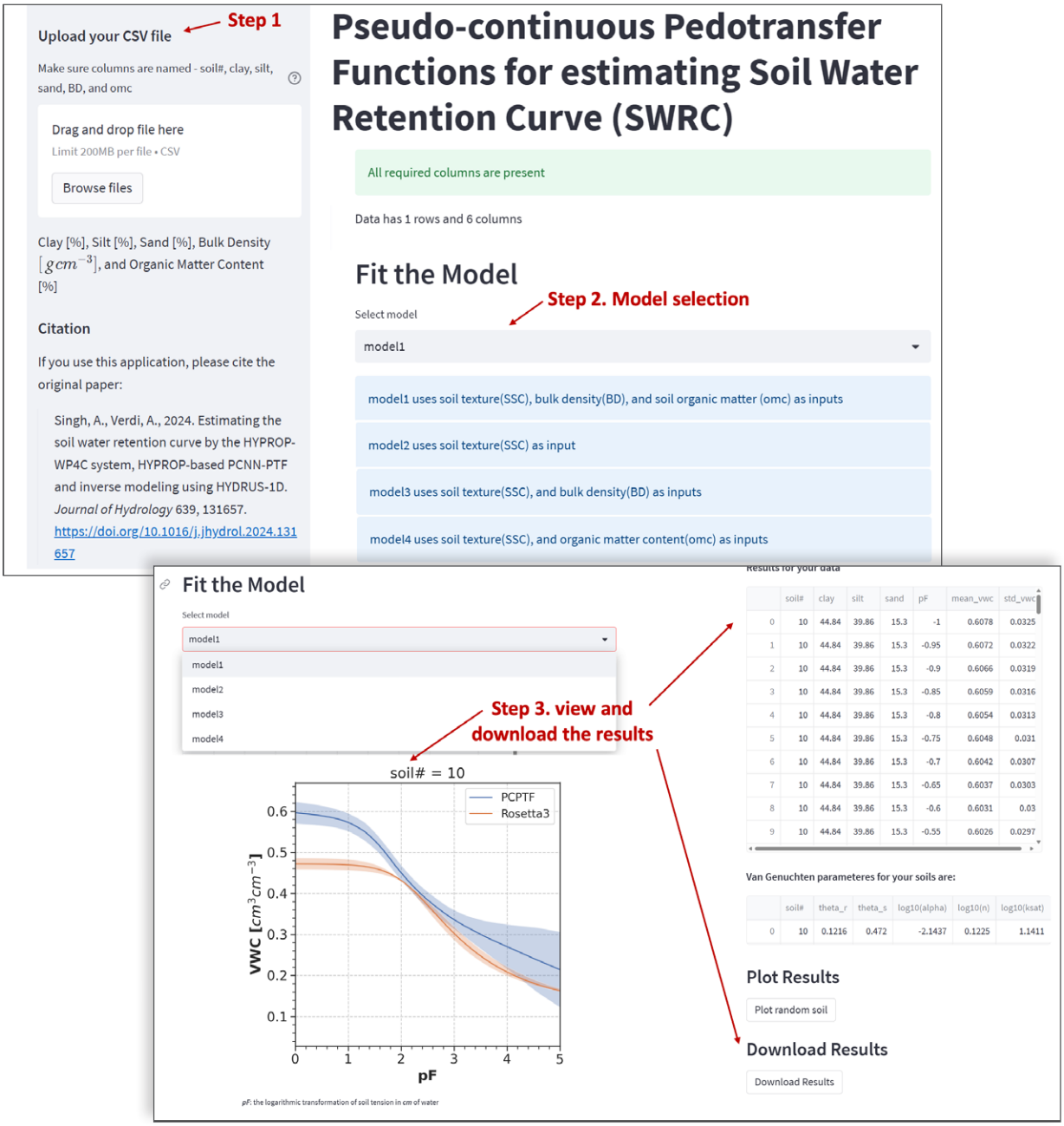


Figure 1. Snapshots of PC-PTF showing the steps for uploading data and accessing results. PC-PTF can be accessed through the Verdi Water Management Group website.

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and plant-available water from the output rather than relying on generalized tabulated values. Users can view the results online and generate example SWRCs or download the data as CSV files for further analysis using spreadsheet software such as Microsoft Excel.

Example SWRCs estimated for Southern California soils

PC-PTF was used to estimate soil water retention for multiple soil samples collected from the UC Riverside Agricultural Experiment Station and the UC ANR South Coast Research and Extension Center in Irvine. Figure 2 compares SWRCs predicted by PC-PTF with measured curves obtained using the HYPROP-WP4C system. PC-PTF performed well for most soil samples, demonstrating its accuracy for soils in Southern California. The predicted curves captured the expected decrease in soil moisture as soil water tension increased from saturation to the PWP.

These curves were used to derive FC and PWP, which can be directly applied for irrigation scheduling. Table 1 summarizes the derived soil water retention parameters. FC is shown at two soil water tensions, 10 and 33 kPa. For coarse-textured soils, FC is typically assumed at 10 kPa, and the water retained at this tension is often referred to as soil water-holding capacity. This value is commonly used as the upper threshold for refilling the soil profile when soil moisture-based irrigation scheduling is applied. A higher soil water tension of 33 kPa is typically used to define FC for finer-textured soils.

Water content at PWP ranged approximately from 3 to 13 percent volumetric water content, depending on soil texture. Water held at this level is not available for plant uptake because it is retained too tightly by soil particles. The difference between FC and PWP is commonly referred to as plant-available water. A fraction of this water, known as readily available water, can be used as the lower irrigation threshold to avoid plant stress and yield reduction. This fraction is defined by MAD, for which crop-specific values are available in the literature.

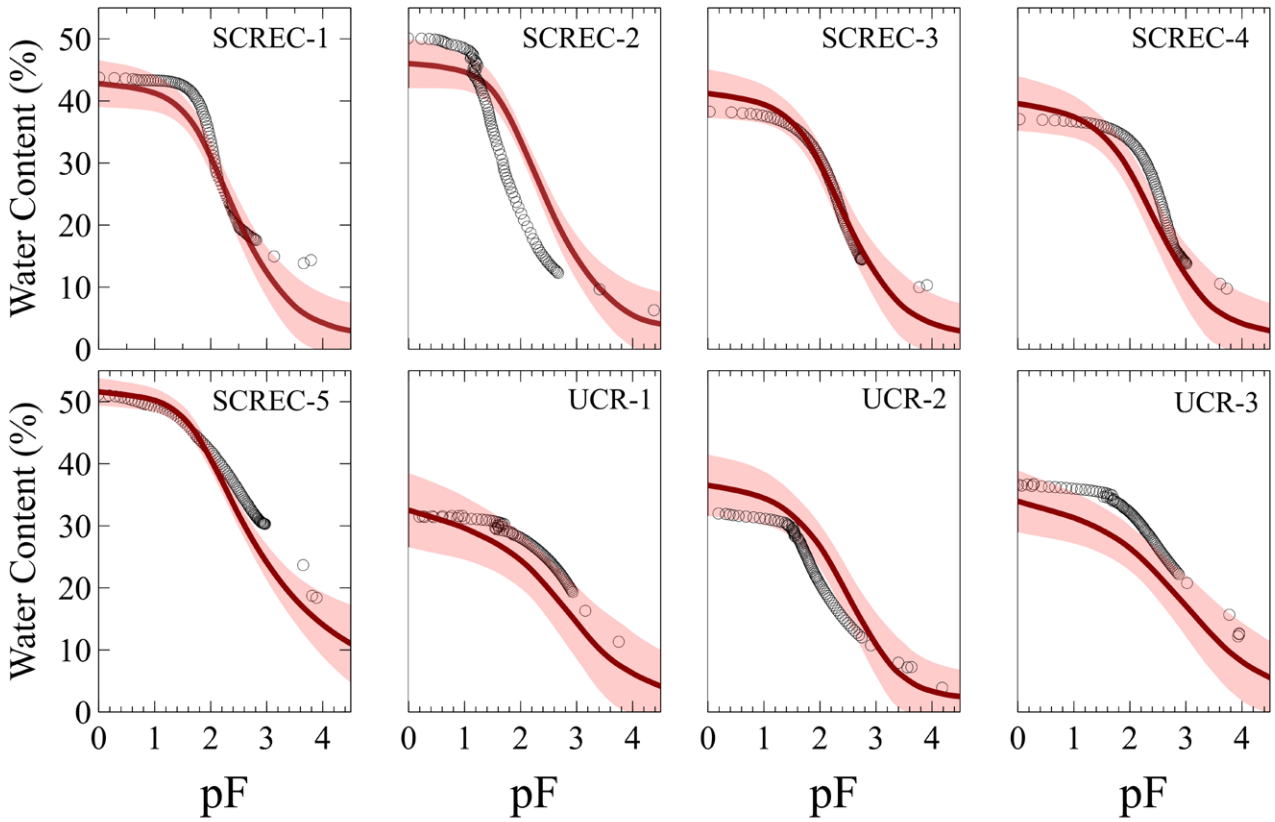


Figure 2. SWRCs measured in the laboratory using the HYPROP-WP4C system (black circles) and estimated using the PC-PTF tool (red line) for multiple soil samples collected from the UCR Agricultural Experiment Station in Riverside and the UC ANR South Coast Research and Extension Center (SCREC) in Irvine, California. For these samples, the PC-PTF model using soil texture and bulk density (model 3) as inputs was applied. pF is a logarithmic measure of soil tension. Higher pF values indicate drier soil and water that is more difficult for plants to extract.

Table 1. Soil moisture estimates (%) generated by the PC-PTF tool at field capacity (FC) and permanent wilting point (PWP) for multiple soil samples

Sample	Texture	BD (g cm^{-3})	FC (10 kPa)	FC (33 kPa)	PWP (1,500 kPa)
SCREC-1	Sandy loam	1.44	30.98	20.28	3.68
SCREC-2	Sandy loam	1.23	33.57	22.80	4.80
SCREC-3	Sandy loam	1.53	29.94	19.80	3.64
SCREC-4	Sandy loam	1.62	28.64	19.42	3.68
SCREC-5	Sandy clay loam	1.24	40.72	31.37	12.9
UCR-1	Sandy loam	1.90	24.48	19.59	5.43
UCR-2	Loamy sand	1.73	26.68	18.34	2.95
UCR-3	Sandy loam	1.82	26.39	21.85	7.10

KEY: BD = (dry) bulk density / FC = field capacity / PWP = permanent wilting point / SCREC = UC ANR South Coast Research and Extension Center, Irvine / UCR = Agricultural Experiment Station, Riverside / g cm^{-3} = gram per cubic centimeter / kPa = kilopascal

Note: Collected from UCR and SCREC. For these samples, the PC-PTF model using soil texture and bulk density as inputs was applied.

Summary and concluding remarks

SWRCs are central to irrigation management and hydrologic modeling, yet direct measurement is costly and time-consuming. PC-PTF provides a practical and easy-to-use tool for obtaining reliable soil water retention information when laboratory measurements are not feasible. It is particularly valuable when rapid mapping or point estimation of FC and PWP is required.

Although PC-PTF provides robust and accurate predictions, it remains a model whose performance depends on the quality and representativeness of input data. Users should consider differences in soil sampling methods, sampling depth, and spatial variability within a field. Field operations and management practices, such as soil compaction and tillage, can alter bulk density and, therefore, soil water retention. Soil salinity and sodicity, soil amendments, and plant root activity can also modify soil structure and contribute to variability in water-holding capacity.

As with all pedotransfer functions, field verification is recommended. Observations of infiltration behavior, soil moisture response to irrigation, and plant performance can help assess whether predicted soil water retention values are reasonable. PC-PTF may produce inaccurate results for soil samples that differ substantially from those used to train the models. Therefore, predicted water retention should be evaluated against local field knowledge and, when possible, validated using direct measurements from a limited number of representative soil samples.

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Appendix 1.

Example 1. Using PC-PTF output for irrigation scheduling

A grower has a 1-acre field with sandy loam soil and a measured bulk density of 1.44 grams per cubic centimeter (g cm^{-3}). The grower wants to use field capacity (FC) at 10 kilopascal (kPa) as the upper irrigation target. Based on PC-PTF, the estimated volumetric water content at FC is 30.98 percent. The current average soil moisture in the root zone measured by time-domain reflectometry (TDR) sensors is 25 percent, and the active rooting depth is 0.5 meters (m).

First, calculate the soil water deficit:
Soil water deficit = FC − current soil water content
Soil water deficit = 30.98% − 25.00% = 5.98%
= 0.0598 m^3 m^{-3}

Then calculate the depth of water needed to refill the root zone:
Water depth = soil water deficit × rooting depth
Water depth = 0.0598 × 0.5 m = 0.0299 m
This is equal to 29.9 mm of water.

For a 1-acre field:
Field area = 4,046.9 m^2
Water volume = 0.0299 m × 4,046.9 m^2 = 121.0 m^3

Convert cubic meters to gallons:
121.0 m^3 × 264.17 gallons m^{-3} = 31,964 gallons

Convert gallons to acre-feet:
31,964 gallons ÷ 325,851 gallons acre-$foot^{-1}$ = 0.098 acre-feet

Therefore, approximately 32,000 gallons, or 0.10 acre-feet, of water would be needed to refill the 0.5 meter root zone from 25 percent soil moisture back to FC, assuming uniform application and no losses. If irrigation efficiency is less than 100 percent, the applied irrigation amount should be adjusted accordingly.

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During the preparation of this work the author used the AI chatbot Claude. The authors and editor reviewed and edited any content obtained with AI.