



WATERMARK SOIL MOISTURE SENSORS: Characteristics and Operating Instructions

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INTRODUCTION

General Characteristics

The Watermark (Irrometer Company, Riverside, CA) is a granular matrix sensor, similar to a gypsum block. It consists of two concentric electrodes embedded in a reference matrix material, which is surrounded by a synthetic membrane for protection against deterioration. A stainless steel mesh and rubber outer jacket make the sensor more durable than a gypsum block. Movement of water between the soil and the sensor results in changes in electrical resistance between the electrodes in the sensor. The electrical resistance can then be converted to soil water potential.

Watermark sensors are inexpensive (about \$24 each) and can measure soil water potential over a wider range (0 to -2 bars or 0 to -200 kPa) than tensiometers. Watermarks are compact, easily installed, and low maintenance.

In the mid-1990s Irrometer upgraded the Watermark model 200 to the 200SS. The method used to compact the reference matrix material was changed to improve packing uniformity and the plastic outer mesh of the 200 was upgraded to stainless steel. The openings in the stainless steel mesh in the 200SS are larger and more numerous than in the 200. This gives the 200SS greater surface area for soil contact and therefore a faster response time. Researchers found that the model 200 had a slow response under rapid drying or partial rewetting conditions and a slow response at more negative water potentials (McCann et al., 1992). Others found that calibrations varied not only from soil to soil but also from sensor to sensor (Spaans and Baker, 1992). The 200SS is an improvement over the 200 but conversions from $k\Omega$ to kPa are still sensor- and soil-specific (Hanson et al., 2000b, Lieb et al., 2003). Several authors have reported that the sensors have poor response in wet (0 to -10 kPa range) soil (Irmak and Haman, 2001; Taber et al., 2002). Shock et al. (1998a) found that the 200SS had better accuracy with less sensor-to-sensor variation than the 200.

Reading Sensor Output

Watermark sensors can be spot-read with a hand-held meter (\$219 from Irrometer Company) or monitored continuously with a datalogger or with a datalogger in combination with a multiplexer. Sensors that can be read using the handheld meter or a multiplexer can be purchased directly from Irrometer

(Irrrometer Company model 200SS, \$24) or from Campbell Scientific, Inc. (CSI model 253, \$46). In order to directly connect a Watermark sensor to a datalogger, the sensor must be equipped with an in-line blocking capacitor (CSI model 257 sensor, \$90, see below). For those inexperienced with Watermark probes, the superior customer support offered by CSI is well worth the higher purchase price.

Sensor Calibration and Monitoring

The Watermark Digital Meter can be used to manually read individual Watermark probes. The digital meter converts the digital output of the Watermark from resistance (kΩ) to soil suction (kPa) using a non-linear equation developed by Shock et al. (1998a, Equation 1):

$$SMP = (4.093 + (3.213 * k\Omega)) / (1 - (0.009733 * k\Omega) - (0.01205 * T_s)) \quad [1]$$

where SMP is the soil matrix potential in kPa, kΩ is the sensor output, and T_s is the estimated or measured soil temperature in °C near the Watermark probe.

When a datalogger is used to monitor Watermark probes the conversion from kΩ to units of soil suction can be user-defined. Irmak and Haman (2001) reviewed several conversion equations from the literature. Figure 1 illustrates four different conversion equations. The manufacturer currently recommends using Equation 1 above.

The coefficients in each equation are soil-specific; coefficients that are appropriate for a loam soil may not be appropriate for a sandy soil or a clay soil. For optimum performance Watermark sensors should be calibrated in the soil in which they are to be used.

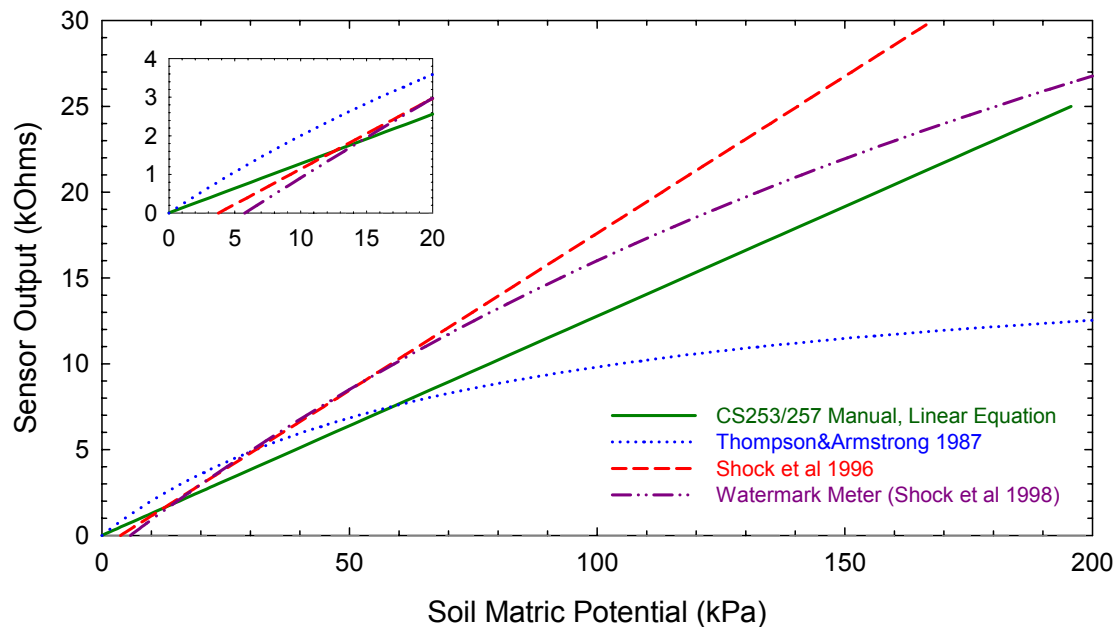


Figure 1. The relationship between soil water potential and the Watermark kΩ output at 24 °C using four conversion equations.

All conversion equations take into account the soil temperature, because as temperature increases resistance decreases (Spaans and Baker, 1992). Variations in soil temperature can affect water potential readings by 1 to 3% per degree Celsius (Irrrometer, 2005; Spaans and Baker, 1992). Shock et al. (1998a) found that as the soil dries, the temperature effect increases (Figure 2).

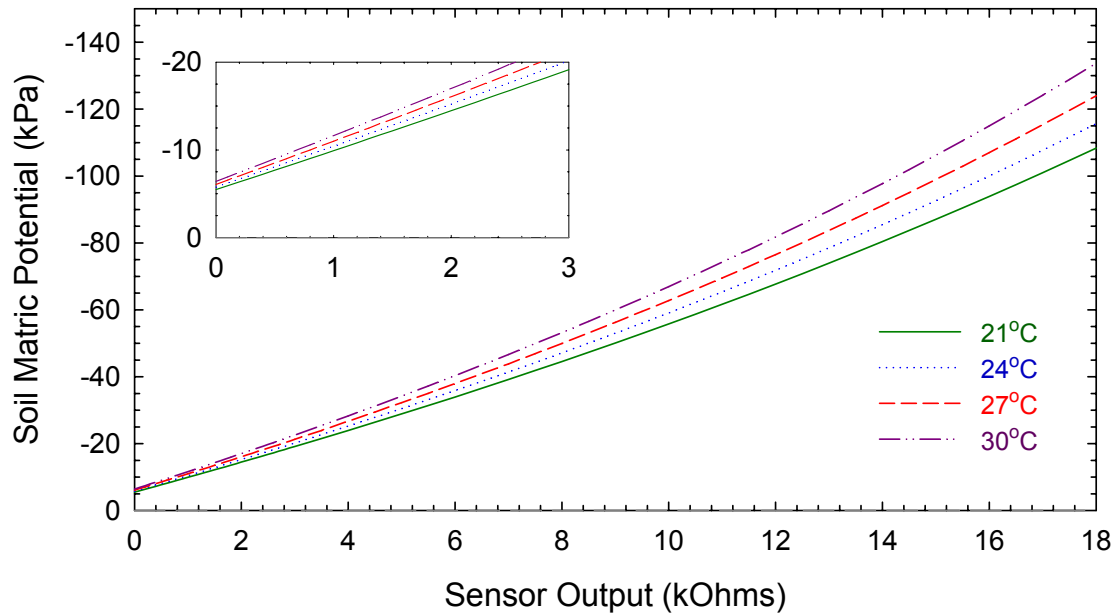


Figure 2. The effect of temperature on the conversion of $k\Omega$ to kPa using the Shock et al. 1998a equation (Equation 1).

Sensor Performance

Two 45-cm long soil columns constructed from 3" diameter PVC pipe were each equipped with two Watermark sensors and two electronic Irrrometer tensiometers (model RSU, Irrrometer Company, Santa Barbara, CA). One of each sensor type was positioned at 10 cm below the soil surface (upper sensors), and one each at 20 cm above the bottom of the column (lower sensors, Figure 3). The columns were saturated at the start of the experiment and drainage was achieved by applying 30 kPa of suction to a porous cup (1 bar, high flow, Soil Moisture Equipment Corp., Santa Barbara, CA) positioned in the bottom of the column. The columns were periodically watered and allowed to drain. After 17 days of data collection the column was planted with corn. Two days later the suction drainage was turned off. Figure 3 shows the data collected from the lower tensiometer and the adjacent (lower) Watermark probe in one of the two columns. The Watermark did not respond as rapidly as the tensiometer to watering events and failed to respond to a partial rewetting event on 4/16. Data from this set of sensors are similar to the other three sets of sensors. In general the Watermark showed good correlation with the tensiometer, and responded rapidly in the 0 to -80 kPa range.

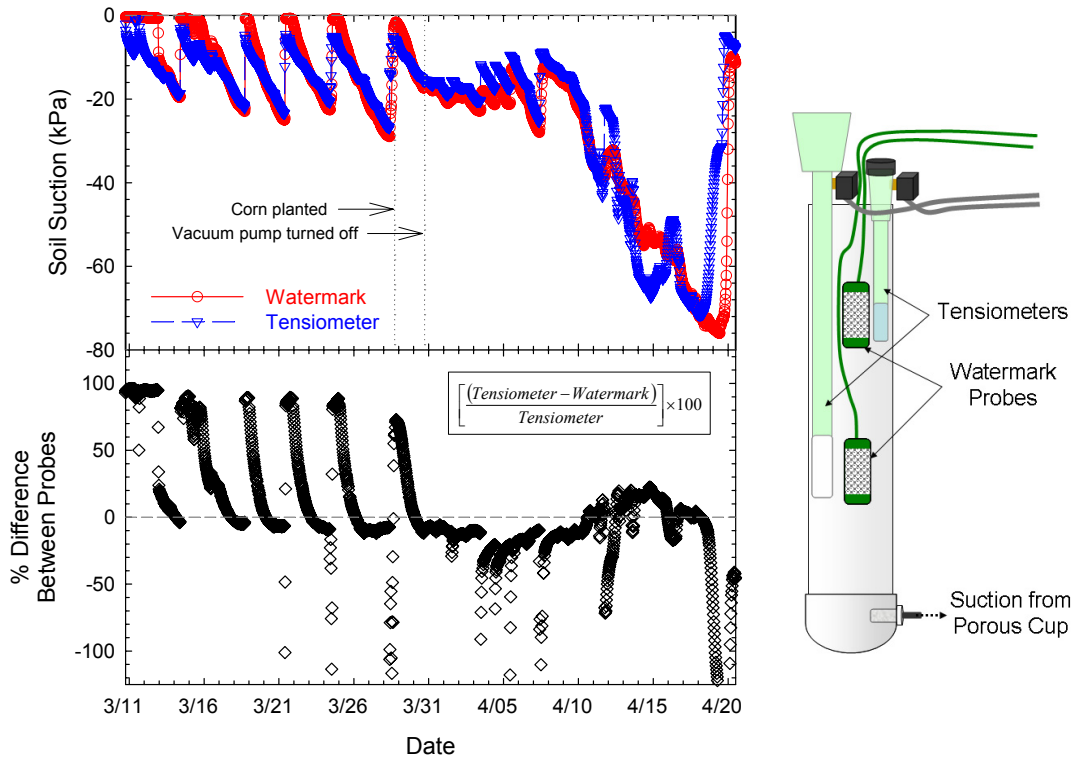


Figure 3. Tensiometer and Watermark probe data from a soil column. The linear equation from the CS 253/257 manual (Campbell Scientific, Inc.) was used to convert Watermark output to kPa.

A hanging column was used to generate data for a soil water release curve in a sandy loam soil. The data were input to the van Genuchten (1980) model to generate the curve. In a separate experiment a PVC column was filled with the sandy loam soil and equipped with four Watermark probes. Suction was applied as described previously. The column was periodically weighed to gravimetrically determine volumetric water content and Watermark data were plotted against the water content data (Figure 4). The soil water release curve generated by the van Genuchten model generally follows the curves generated by the Watermark probes and gravimetric water content measurements. Both the CSI linear equation and Equation 1 (Shock et al., 1998a) were used to convert k Ω to kPa.

Figure 5 illustrates the relationship between volumetric water content data generated gravimetrically and that generated using the van Genuchten model in conjunction with matrix potential data. Watermark output was converted to matrix potential using both the CSI linear equation and Equation 1 (Shock et al., 1998a). The Watermark output underestimates water content when the linear equation from the CSI manual is used to convert from k Ω to kPa (upper graph, Figure 5), but closely matches the gravimetric data when Equation 1 is used (lower graph, Figure 5). This indicates that for our fine sandy loam soil, Equation 1 more accurately approximates soil water potential from Watermark output.

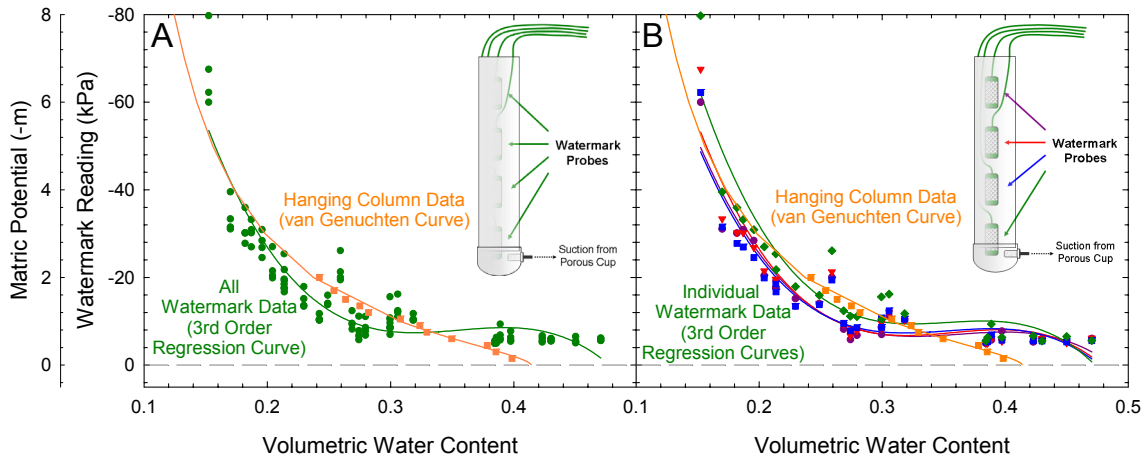


Figure 4. Soil water release curves for a sandy loam soil. Data collected from a hanging column test (orange squares) were entered into the van Genuchten (1980) model to generate the curve (orange line). Regression curves (green line in A; green, blue, red and purple lines in B) were fitted to data collected from the four Watermark probes. Equation 1 (Shock et al., 1998a) was used to convert Watermark output to kPa.

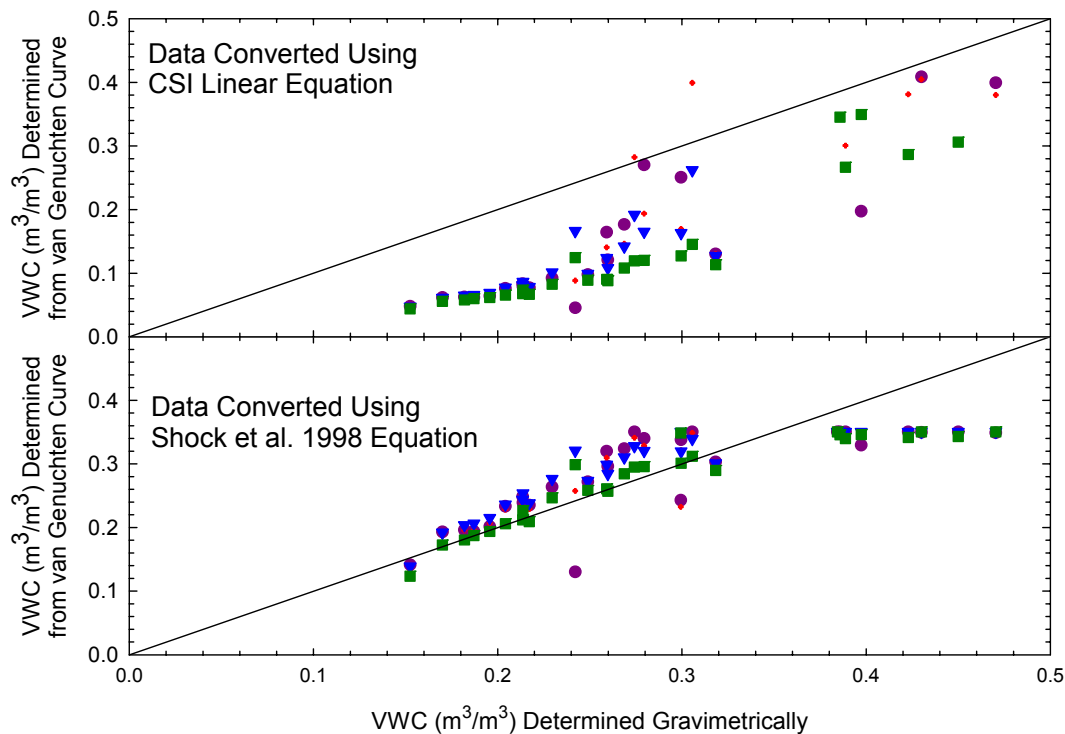


Figure 5. Volumetric water content (VWC) as determined gravimetrically (x axis) versus VWC as determined using the van Genuchten (1980) model to convert soil matrix potential (kPa) to VWC (y axes). The linear equation from the CS 253/257 manual (Campbell Scientific, Inc.) was used to convert Watermark output to kPa in the upper graph. Equation 1 (Shock et al., 1998a) was used to convert Watermark output to kPa in the lower graph.

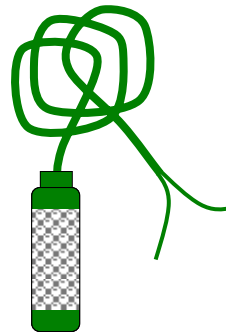
WIRING TO DATALOGGERS/MULTIPLEXERS

The CSI model 257 Watermark sensor has been equipped with blocking capacitors and may be wired directly to a CSI datalogger. This sensor is double the cost of the CSI model 253 sensor, which can be wired only to an AM416 or AM16/32 multiplexer. The CSI model 253 sensor is identical to the Irrometer Company model 200SS sensor, but costs almost twice as much.

Watermark sensors require excitation for operation. The instructions that follow are for CSI model 253 or Irrometer Company model 200-SS sensors connected to an AM416 multiplexer and CR21X datalogger, where the multiplexer is used both for Watermark sensors and for sensors that do not require excitation.

The multiplexer has two separate communication ports that connect to the datalogger; COM1 and COM2. One of the COM ports must be connected to an excitation port on the datalogger for operation of the Watermark sensors. A 1000-Ω resistor must be wired in line between the single-ended channel and the excitation port on the datalogger. The other COM port may be used for sensors that do not require excitation. If thermocouples are to be measured, the non-excited COM port must be connected to the datalogger with thermocouple wire, and the datalogger panel temperature should be used for reference. Wiring between a CR21X datalogger and AM416 multiplexer is as follows:

<u>CR21X</u>	<u>AM416</u>
12V -----	12V
± (ground) -----	GND
Control 1 -----	RES
Excitation 1 -----	CLK
1H -----	COM H1
Excitation 2 <i>~1K 0.1%~</i> -----	
AG -----	COM L1
2H ----- <i>type K TC wire</i> -----	COM H2
2L ----- <i>type K TC wire</i> -----	COM L2



With this arrangement, Watermark sensors are wired to COM1 ports and thermocouples and other non-excited sensors are wired to COM2 ports on the multiplexer. Each Watermark sensor is supplied with two green lead wires. The lead wires are almost identical, but can be differentiated by a tiny ridge along the low (L) lead wire, and no ridge along the high (H) lead wire. The lead wires are connected directly to the H1 (high, COM1) and L1 (low, COM1) inputs on the multiplexer.

DATALOGGER PROGRAM

Instruction 5 (P5, AC half bridge command) is used to excite and measure the Watermark sensors. A 250 mV or 500 mV (depending on the datalogger) fast excitation range should be used. Instruction 59 (P59, bridge transform) converts the sensor output to resistance. Refer to the CSI manual for additional wiring examples: <ftp://ftp.campbellsci.com/pub/outgoing/manuals/257.pdf>.

Sensor resistance is converted to soil water potential using a conversion equation from the literature (see discussion above) or by calibrating the sensors to the soil of interest. Sensor calibration can be accomplished via side-by-side operation with a more accurate water potential gauge (such as a tensiometer) or by placing a Watermark sensor in a hanging column filled with the soil of interest. The conversion equations in the Campbell Scientific CS 253/257 manual are outdated. The manufacturer recommends using the equation developed by Shock et al. (1998a) (Equation 1 in this paper). The difference among the various conversion equations is minimal in wet soils (0 to -30 kPa, Figure 1), but increases dramatically as soils dry.

SENSOR INSTALLATION

Proper preparation and installation of the Watermark sensor is vital to its operation. Sensors should be soaked overnight and installed wet. If time permits, condition the sensor with multiple wet/dry cycles: soak the sensor in irrigation water overnight, allow it to air dry for a day or two, then re-soak overnight. To install the sensor, make an access hole to the desired depth using a length of ½ or ¾" PVC pipe. Fill the hole with water, then seat the sensor firmly and snugly in the bottom of the access hole using the PVC pipe. Back fill the hole with soil and tamp firmly, but avoid compacting the soil.

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