



**METER**  
ENVIRONMENT

## METHOD A: SOIL-SPECIFIC CALIBRATIONS FOR METER SOIL MOISTURE SENSORS

### Contributors

METER soil sensor calibration method A (recommended for higher accuracy) is a method based on weighing the entire calibration sample. The following is a step-by-step instruction guide for performing this method.

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## METHOD A INSTRUCTIONS

### 1. Equipment needed

1.1 **Shovel and bulk soil container** for field soil collection and air drying soil (1 shovel, 1 container for each soil type)

1.2 **Calibration container** (1)

1.2.1 The calibration container should be large enough to pack the soil back to the field bulk density while maintaining enough soil depth to accommodate the full volume of influence of the METER sensor (including the electronics portion).

1.2.2 Different soil sensors may require different-sized containers due to differences in volume of influence and measurement orientation. See "[Measurement volume of METER volumetric water content sensors](#)" to determine container size.

1.2.3 It is best if the container is relatively rigid and allows clear access to the soil surface.

1.2.4 Measure the mass of the clean, dry, empty container

1.2.5 Record the tare mass in Table 1. ([Download Table 1 \[Method A\] here](#)).

### **1.3 METER sensor and data acquisition system (1 each)**

1.3.1 METER sensor output is very similar among sensors of the same type. You can calibrate with a single sensor and apply that calibration to other sensors of that type in your soil and maintain excellent accuracy.

1.3.2 Use whatever data acquisition system you plan to use in the field (ZSC, ProCheck, ZL6, EM60G, EM50, EM5B, Campbell Scientific data logger, etc.). Note: ZSC and Procheck should not be used to calibrate an analog sensor such as TEROS 10 or EC-5.

### **1.4 Large scale to weigh calibration container (1)**

1.4.1 The scale should be able to weigh up to 10 kg.

1.4.2 The scale should have resolution of 0.1 g or better for best possible soil-specific calibration.

### **1.5 Volumetric soil sampler (1)**

1.5.1 In METER soil sensor calibrations, it is possible to use a volumetric soil sampler, which is used to sample known volumes of soil from the calibration container in order to determine volumetric water content.

1.5.2 Use either a commercial soil sampler (such as the ESS Core N' One available from Environmental Sampling Supply) or a homemade sampler. The only requirement for the sampler is that it can collect a soil sample of known volume without changing the soil bulk density.

1.5.3 If you don't have a sampler, we recommend cutting a 3 to 5 cm long section of metal conduit or other small diameter (1.5 to 2.5 cm) metal or thin-walled, rigid plastic tubing.

1.5.4 Deburr both ends of the tubing.

1.5.5 Sharpen one end for easy insertion into the soil.

1.5.6 Precisely measure the length and inner diameter of the sampler.

1.5.7 Calculate the volume ( $\pi r^2 h$ ).

**1.6 Soil drying containers** (1 per soil type to determine bulk density and for initial subsample)

1.6.1 The drying containers can be any container that is suitable for oven drying and has a sealable lid (soil sampling tin, baby food jar).

1.6.2 Measure the mass of each of the clean, dry soil drying containers before adding soil to them.

1.6.3 Write down the tare mass in Table 1. ([Download Table 1 \[Method A\] here](#)).

**1.7 A smaller scale or mass balance** to weigh subsamples (1)

1.7.1 The scale should have resolution of 0.01 g or better for best possible soil specific calibration.

**1.8 Drying oven** (1)

1.8.1 Any oven that will maintain a relatively stable temperature of 105 to 110 °C will work.

## 2. Soil sample collection

2.1 Collect approximately four liters (one gallon) of bulk soil.

2.2 Make sure the soil is from the area/depth you wish to measure with your METER sensors.

2.3 You may wish to measure the field bulk density of the soil when you collect your sample.

2.3.1 Use the volumetric soil sampler (Section 1.5) to obtain a soil core of undisturbed soil.

2.3.2 Put a lid on the sample to avoid water loss.

2.3.3 Since you've used a volumetric sampler, you know the volume of the soil samples ( $V_{\text{soil}}$ ).

2.3.4 Oven dry the soil core.

2.3.5 Measure the mass of the dry soil ( $m_{\text{dry}}$ ).

2.3.6 Use Equation 6 below (section 5) to calculate the bulk density of the soil.

### 3. Soil preparation

3.1 Air dry the soil. Air drying is quickest if the soil is spread in a thin layer and air is moved over the soil.

3.2 Remove large objects from the soil.

3.2.1 The presence of large rocks or other objects can complicate the calibration process. We suggest breaking up large clods and running the soil through a 2 to 5 mm sieve before proceeding.

3.2.2 In some materials (e.g., compost, mulch), it will not be possible to remove large particulates without significantly altering the nature of the material.

### 4. Calibration method A

4.1 Pack the soil into the calibration container at approximately the field bulk density.

4.1.1 If you start with dry soil, control the bulk density by packing a known mass of soil into a known container volume.

4.1.2 It is generally necessary to add the soil in layers, packing each layer before adding the next.

4.2 Take one initial soil subsample.

4.2.1 Remove 5 to 10 grams of soil from the container using a scoopula (or similar tool).

4.2.5 Place the soil into a drying container.

4.2.6 To prevent water loss, immediately measure the mass of the soil + drying container (without lid).

4.2.7 Record the weight in Table 1 ([Download Table 1 \[Method A\] here](#)).

4.2.8 Put a lid on the container, and set the sample aside to be oven dried later.

4.3 Weigh the calibration container with soil before inserting the sensor.

4.3.1 Weigh the entire container of soil.

4.3.2 Record the mass in [Table 1](#).

4.3.3 For fine-textured soils like silt loam and clayey soils, take a height measurement from the lid down to the base of the soil.

4.3.3.1 Over time, the volume of finer-textured soils will change with the addition of water (sandy soils don't have this issue). If a height measurement is taken and the dimensions of the container are known, then it's possible to perform a volume change correction in the VWC calculation. For instructions on performing a volume change correction, contact [customer support](#) if needed.

4.4 Insert the sensor (EC-5, 5TE, 5TM).

4.4.1 The EC-5, 5TE, and 5TM can be inserted vertically directly into the full soil container.

4.4.2 **Important:** Insert the sensor tines in a straight line so as not to introduce any air gaps between the sensor tines and the soil.

4.4.3 Insert the sensor fully into the soil. This includes the black plastic base of the sensor.

4.4.4 If you cannot insert the black plastic portion fully into the soil, insert the sensor as far as possible, then take some additional soil and pack it around the remaining portion of the sensor base and a few cm of the cable if possible.

4.4 Insert the sensor (GS1, GS3, TEROS).

4.4.1 Move some soil to prepare a flat spot to insert the sensor into.

4.4.2 Push the sensor into the soil.

4.4.3 Pack soil over the exposed portion of the sensor, being careful to prevent air gaps while maintaining the desired bulk density.

4.4.4 Make sure there is one cm of soil over the top of the sensor.

4.4 Insert the sensor (10HS).

4.4.1 For the 10HS, remove a little over half of the soil before inserting the sensor.

4.4.2 Insert the 10HS sensor as far as possible in the soil container. For some soil types and moisture levels, it is possible to insert the entire length of the 10HS into the soil as with the other METER sensors.

4.4.3 For some soils, it is not possible to insert the full length of the 10HS into the soil column.

4.4.3.1 If you have a METER sensor insertion blade or other blade that is slightly thinner than the 10HS sensor, you can use it to make a pilot hole and insert the sensor fully.

4.4.3.2 If no pilot tool is available, insert the 10HS as far as possible into the soil column. Then, pack soil around the exposed portion of the sensor, being careful to prevent air gaps while maintaining the desired bulk density.

4.4.4 Be sure to get the black plastic portion of the 10HS surrounded by soil.

4.4.4.1 If you cannot insert the black plastic portion fully into the soil, insert the sensor as far as possible, then take some additional soil, and pack it around the remaining portion of the sensor base and a few cm of the cable if possible.

**4.5 NOTE: The sensor should be surrounded by continuous soil for the entire radius of whatever the volume of influence is for your particular sensor. See [Measurement volume of METER volumetric water content sensors](#).**

4.6 Plug the sensor into the data logger, and take a sensor reading.

4.6.1 If using non-METER data acquisition equipment, be sure you are exciting the sensor with the same excitation voltage you will use in the field for the EC-5.

4.6.2 All other METER sensors regulate their excitation voltage, so refer to the manual for the appropriate voltage range.

4.6.3 Collect the raw data from the sensor (no calibration applied).

4.6.4 It is a good idea to repeat steps 4.2 to 4.6 once or twice to be sure that you are achieving repeatable insertion quality.

4.6.4.1 Be careful not to insert the sensor into holes you've already made.

4.6.4.2 There will generally be some small variability (a few raw counts or mV), so an average reading can be taken.

4.6.5 Record the sensor readings in [Table 1](#).

4.7 Wet the calibration soil.

4.7.1 Add about 1 mL of water for every 10 mL of soil volume.

4.7.1.1 This will increase VWC by approximately 10%.

4.7.1.2 Add the water to the soil as evenly as possible.

4.7.2 Thoroughly mix the soil with your hands or a trowel until the mixture is again homogeneous.

4.8 Repeat 4.3 to 4.7 until the soil nears saturation.

4.8.1 This generally yields 4 to 6 calibration points.

4.8.2 Each point can take up to one hour.

4.8.3 Note that the bulk density of the sample can be maintained throughout the calibration process by packing the same soil sample to the same level on the calibration container at each water content.

4.9 Dry the initial soil subsample.

4.9.1 Place the already-weighed, moist sample into the 105 °C oven for 24 hours.

4.9.2 Note that soils with high organic matter content may lose significant volatile organics if dried at 105 °C, leading to error in the calibration. We recommend drying these soils at 60 to 70 °C for at least 48 hours.

4.10 Weigh the dry soil.

4.10.1 Remove the soil drying container from the oven.

4.10.2 Allow the soil and container to cool.

4.10.3 Measure the mass of dry soil + container (without lid).

4.10.4 Enter the value into [Table 1](#).

Soil + Container Weights		wet wt	water wt	w	q	Sensor Measurements	
Points	g	g	g	g g <sup>-1</sup>	m <sup>3</sup> m <sup>-3</sup>	Sensor 1 RAW	Sensor 2 RAW
Air dry	5903.9	5577.6	39.75	0.0072	0.0089	1917.5	1911.1
Point 2	6342.6	6016.3	478.45	0.0864	0.1069	2071.9	2049.1
Point 3	6792.1	6465.8	927.95	0.1676	0.2073	2264.2	2256.8
Point 4	7232.4	6906.1	1368.25	0.2471	0.3056	2575.8	2622.4
Point 5	7515.2	7188.9	1651.05	0.2981	0.3688	2781.9	2781.5

Gravimetric Water Content Calculations of Air Dry Sample		
	Values	Units
Wet Soil + Tin	30.3498	g
Dry Soil + Tin	30.1488	g
Tin Weight	1.9485	g
Gravimetric WC, w	0.007127584	g g <sup>-1</sup>

Table 1. Example [data collection table](#) for soil-specific METER sensor calibration

[Download Table 1](#) (with cell operations added) for your own use (click the method A tab).

## 5. Calculations

The volumetric water content is defined as the volume of water per volume of bulk soil

$$\theta = V_w / V_t$$

Equation 1

Where  $\theta$  is volumetric water content (cm<sup>3</sup>/cm<sup>3</sup>),  $V_w$  is the volume of water (cm<sup>3</sup>), and  $V_t$  is the total volume of the sample container (cm<sup>3</sup>) found in section 4.3. To calculate the volume of water, you will first have to find the initial amount of water in your sample is calculated by subtracting the total sample water weight obtained from multiplying the air dry sample weight by the gravimetric water content found using the volumetric sampler (section 4.2) from the weight of the air-dried sample.

$$M_{\text{soil, oven dry}} = m_{\text{soil, air dry}} - (m_{\text{soil, air dry}} \times w)$$

Equation 2



Where  $m_{\text{soil, air dry}}$  is the mass of the soil you started with and  $w$  is the gravimetric water content calculated from your subsampled volumetric sampler

$$w = \frac{m_{\text{soil, air dry}} - m_{\text{soil, oven dry}}}{m_{\text{soil, oven dry}}}$$

Equation 3

To find  $V_w$  for each calibration point, subtract the container weight and the mass of oven dry soil from the total sample weight

$$m_w = m_{\text{total}} - m_{\text{soil, oven dry}}$$

Equation 4

$$V_w = m_w / \rho_w$$

Equation 5

Where  $m_w$  is the mass of water,  $m_{\text{total}}$  is the mass of moist soil (g),  $m_{\text{container}}$  is the mass of the container (g),  $m_{\text{soil, oven dry}}$  is the mass of the oven dry soil, and  $\rho_w$  is the density of water (1 g/cm<sup>3</sup>). Using  $V_w$ , volumetric water content can be calculated using Equation 1. In addition to the volumetric water content, the bulk density of the soil sample can also be calculated. Bulk density ( $\rho_b$ ) is defined as the density of dry soil (g/cm<sup>3</sup>)

$$\rho_b = m_{\text{dry}} / V_{\text{soil}}$$

Equation 6

The calculations above are most easily done in a spreadsheet program such as MS Excel. The previous Table 1 shows the above calculations performed for method A.

The output of the METER sensors is not very sensitive to small differences in soil bulk density. However, if the bulk density of the soil during calibration is radically different from that of the field soil, it will introduce error into the calibration. If you measured the field bulk density as described in section 2.3, you can control the bulk density of the soil in the calibration container to that level (see section 4.1.1). If the soil is not packed to a known bulk density and the bulk density in the calibration container is different from the field bulk density by more than about 20%, consider repeating the calibration while packing the soil to a more realistic bulk density.

## 6. Finding and using the calibration function

If the above calculations are performed in a spreadsheet program, then finding the calibration function is quite easy. Simply make a scatter plot with the sensor output on the X-axis and the calculated VWC on the Y-axis (Figure 1). Then use the trendline or curve-fitting function to construct a mathematical model of the relationship. This relationship is often linear, but it is sometimes best fit with a polynomial equation as shown below, especially in soils with high organic matter content.

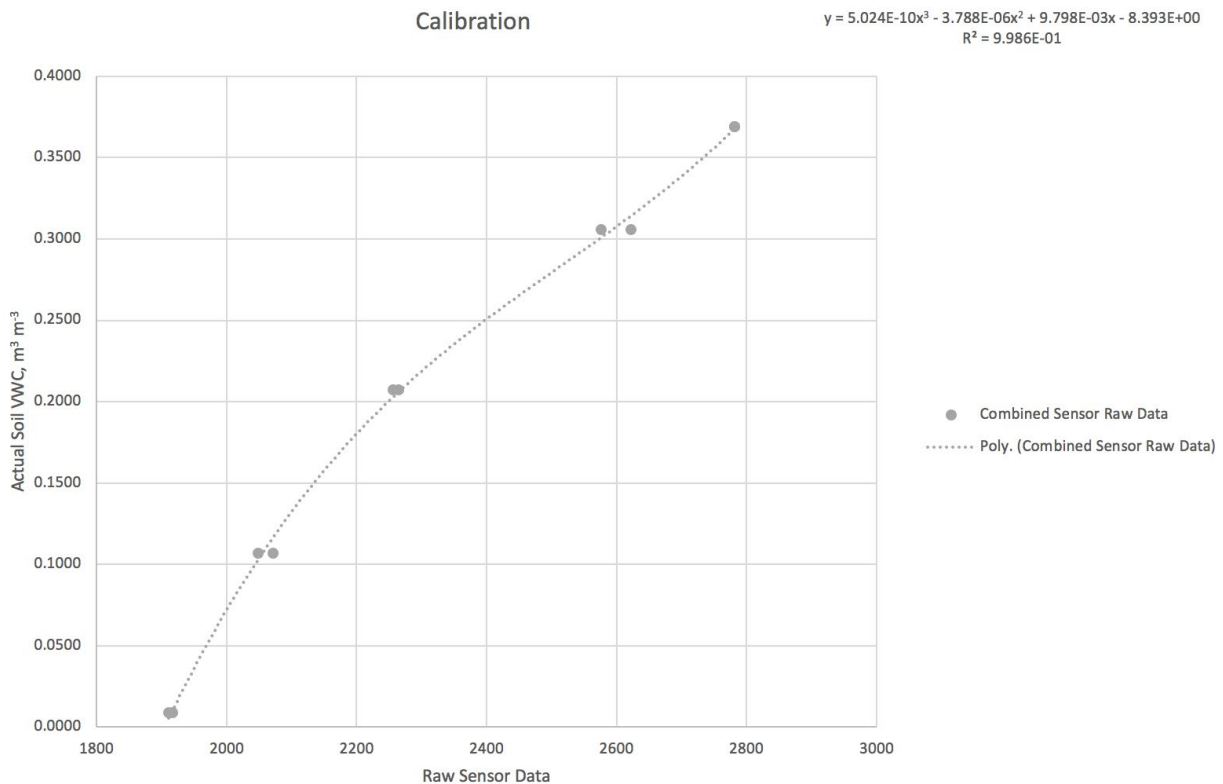


Figure 1. Plot of example calibration data. The soil specific calibration equation is shown in the upper right corner of the graph area.

Once the calibration function is constructed, apply it to the METER sensor data. When logging data with the ZL6, EM60G, EM50, and EM5B data loggers, apply this equation to the raw data downloaded from the logger. If using ZENTRA Cloud software, apply the calibration function under the System Settings tab in the Calibration Settings. Simply click the Add Calibration button and type in the coefficients. Remember to apply enough significant figures to the equation. If using the DataTrac software package, apply the calibration function under the setup tab. If using Campbell Scientific data loggers, apply the calibration in the data logger program or during post-processing.

## REFERENCES

Czarnomski, Nicole M., Georgianne W. Moore, Tom G. Pypker, Julian Licata, and Barbara J. Bond. "Precision and accuracy of three alternative instruments for measuring soil water content in two forest soils of the Pacific Northwest." *Canadian journal of forest research* 35, no. 8 (2005): 1867-1876. [Article link](#).

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