Calibrating ECH_2O Soil Moisture Sensors Application Note

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Introduction

Onset adds smart sensor adapters to the ECH_2O probes so that they are plug-and-play compatible with HOBO® RX3000, U30, and Micro Stations. The S-SMC-M005 incorporates the EC-5 and the S-SMD-M005 incorporates the 10HS.

ECH_2O probes measure the volumetric water content of the soil by measuring the dielectric constant of the soil, which is a strong function of water content. However, not all soils have identical electrical properties. Due to variations in soil bulk density, mineralogy, texture and salinity, the generic mineral calibration for current ECH_2O sensors (EC-5, 10HS) results in approximately ±3-4% accuracy for most mineral soils and approximately ±5% for soilless growth substrates (potting soil, rock wool, cocus, etc.). However, accuracy increases to ±1-2% for all soils and soilless substrates with soil-specific calibration. It is recommended that you conduct a soil-specific calibration for best possible accuracy in volumetric water content measurements. Studies performed by independent researchers (Czarnomski et al., 2005) indicate that soil-specific calibration of ECH_2O sensors achieves performance results similar to that of TDR instruments - at a fraction of the price. Note that the resolution, precision, repeatability, and sensor-to-sensor agreement of the ECH_2O sensors are excellent, so the soil specific calibration of one sensor can be applied to all other sensors of that type in that particular soil. The purpose of this application note is to provide a step-by-step guide for performing a soil specific calibration on ECH_2O sensors.

Calibration Method

ECH_2O calibration generally follows the standard procedure for calibrating capacitance sensors outlined by Starr and Palineanu (2002). The following is a step-by-step instruction guide for performing a soil specific calibration.

Step 1: Equipment Needed

- Shovel and bulk soil container (1 shovel, 1 container for each soil type) – for field soil collection and air drying soil.
- Calibration container (1). The calibration container should allow you to pack the soil back to the field bulk density while maintaining enough soil depth to accommodate the full length of the ECH_2O sensor (including the electronics portion) plus a few cm beyond the end of the prongs and a few cm of cable. It is best if the container is relatively rigid, and allows clear access to the soil surface.
- ECH_2O probe and logger (1 each)
  - ECH_2O sensor output is very similar among sensors of the same type. So, you can calibrate with a single sensor and apply that calibration to other sensors of that type in your soil and maintain excellent accuracy.
- Volumetric soil sampler (1)
  - To perform an ECH_2O probe calibration, you must have a volumetric soil sampler, which is used to sample known volumes of soil from the calibration container in order to determine volumetric water content. This can either be 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 you can collect a soil sample of known volume without changing the soil bulk density.
  - If you don't have a sampler, cut a 3 - 5 cm long section of metal conduit or other small diameter (1.5 - 2.5 cm) metal or thin walled, rigid plastic tubing. De-burr both ends of the tubing, and sharpen one end for easy insertion into the soil.
  - Precisely measure the length and diameter of the sampler, and calculate the volume ($\pi r^2 h$).

- Soil drying containers (5-7 per soil type)
  - The drying container can be any container that is suitable for oven drying and has a sealable lid (soil sampling tin, baby food jar).
  - Measure the mass of each of the clean, dry soil drying containers before adding soil to them. Write down the tare mass in Table 1.
- Scale or mass balance (1) – The scale must have resolution of 0.01 g or better for best possible soil specific calibration.
- Drying oven (1) – Any oven that will maintain a relatively stable temperature of 105 – 110 C will work.

Step 2: Soil Sample Collection

1. Collect approximately 4 liters (1 gallon) of bulk soil.
2. Be sure that the soil is from the area/depth where you wish to measure with your ECH_2O sensors.
3. You may wish to measure the field bulk density of the soil when you collect your sample.
   A. Use your volumetric soil sampler to collect several soil cores of undisturbed soil.
   B. Since you've used a volumetric sampler, you know the volume of the soil sample (V_{soil}).
   C. Oven dry the soil cores and measure the mass of the dry soil (m_{dry}).
   D. Use equation 4 below to calculate the bulk density of the soil.

Step 3: Soil Preparation

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.
2. Remove large objects from the soil.
   A. 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 2-5 mm sieve before proceeding.
   B. In some materials (e.g. compost, mulch, soilless growth substrates), it will not be possible to remove large particulates without significantly altering the nature of the material.

Step 4: Calibration

1. Pack the soil into the calibration container at approximately the field bulk density.
   A. If you start with dry soil, you can control the bulk density by packing a known mass of soil into a known container volume.
   B. It is generally necessary to add the soil in layers, packing each layer before adding the next.
   C. For the 10HS, only pack a little over half of the soil into the container before inserting the sensor.
   D. For the EC-5, pack the full soil volume into the container.
2. Insert the ECH_2O sensor (EC-5).
   A. The EC-5 can be inserted vertically directly into the full soil container.
   B. **Important:** Be sure to insert the sensor tines in a straight line so as not to introduce any air gaps between the sensor tines and the soil.
   C. Insert the sensor fully into the soil. This includes the black plastic base of the sensor. 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.
3. Insert the ECH_2O sensor (10HS).
   A. 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 ECH_2O sensors.

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

C. Use a blade that is slightly thinner than the 10HS sensor to make a pilot hole and insert the sensor fully.

D. 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.

E. Be sure to get the black plastic portion of the 10HS surrounded by soil. If you cannot insert the black plastic portion fully into the soil, insert the sensor as far as possible, and 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. **Important note:** The sensor should be surrounded by continuous soil for a radius of at least 5 cm from the flat sensing portion of the sensor, except in the case of the 10HS which should have a minimum of 10 cm.

5. Take a sensor reading.

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

   B. It is a good idea to repeat steps 2–5 in this section once or twice to be sure that you are achieving repeatable insertion quality. There will generally be some small variability so an average reading can be taken.

   C. Record the sensor readings in Table 1.

6. Collect a volumetric soil sample.

   A. Without removing the ECH_2O probe, insert the volumetric soil sampler fully into the undisturbed soil near the sensor.

   B. Remove the sampler, making sure that the soil core inside is intact. Shave excess soil from the end(s) with a flat edge, and re-fill any small voids that may have occurred.

   C. Place the entire soil core into a drying container and cap the container. Any water loss from the soil between sampling and the first weighing introduces error to the volumetric water content calculation.

   D. Repeat steps A–C at least once. This helps to reduce the effects of spatial variability in your sample.

7. Measure the mass of the wet soil + container (no lid) – record the mass in Table 1.

8. Wet the calibration soil.

   A. Add about 1 mL of water for every 10 mL of soil volume (increased VWC by 10%). Add the water to the soil as evenly as possible

   B. Thoroughly mix the soil with your hands or a trowel until the mixture is again homogenous.

9. Repeat steps 1–8 until the soil nears saturation. This generally yields 4-6 calibration points. 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.

10. Dry the volumetric soil samples

    A. Place all of the already-weighed, moist samples into the 105 C oven for 24 hours.

    B. 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 – 70 C for at least 48 hours.

11. Weigh the dry soil.

    A. Remove the soil drying containers from the oven and replace covers while still hot.

    B. Allow the soil and containers to cool.

    C. Measure the mass of the dry soil + containers (without lids).

    D. Enter the values into Table 1.

Table 1. Example data collection table for soil specific ECH_2O sensor calibration.

Sample number	Avg. sensor reading (m^3/m^3)	Drying container tare mass (g)	Sample volume (cm^3)	mass of container + moist soil (g)	mass of container + dry soil (g)
1	0.0844	70.605	15.31	94.836	94.215
2	0.1694	72.245	15.31	96.433	95.194
3	0.2867	71.713	15.31	96.923	94.785
4	0.3955	74.45	15.31	101.979	98.834
5	0.6403	70.997	15.31	100.402	95.873
6	0.6879	71.48	15.31	101.060	95.886

Step 5: Calculations

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

$$\theta = V_w/V_t \qquad (1)$$

Where θ is volumetric water content (m^3/m^3), V_w is the volume of water (cm^3) and V_t is the total volume of bulk soil sample (cm^3). You already know V_t of your sample, because you used a volumetric sampler to collect your soils samples (see section 1.4). To find V_w, we calculate the volume of the water that is lost from the soil sample during oven drying:

$$m_w = m_{wet} - m_{dry} \qquad (2)$$

$$V_w = m_w/\rho_w \qquad (3)$$

Where m_w is the mass of water, m_{wet} is the mass of moist soil (g), m_{dry} is the mass of the dry soil, and ρ_w is the density of water (1 g/cm^3). In addition to the volumetric water content, the bulk density of the soil sample can also be calculated. Bulk density (ρ_b) is defined as the density of dry soil (g/cm^3):

$$\rho_b = m_{dry}/V_{soil} \qquad (4)$$

The calculations above are most easily done in a spreadsheet program such as MS Excel. Table 2 shows an Excel spreadsheet with the data from Table 1, and the above calculations performed. The cell operations used to perform the calculations are shown in Row 3.

The output of the ECH_2O 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 your field soil, you may introduce error into your 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 step 1-A in the Step 4 Calibration section). If you do not pack to a known bulk density and the bulk density in your calibration container is different from the field bulk density by more than about 25%, you should consider repeating the calibration while packing the soil to a more realistic bulk density.

Table 2. Excel spreadsheet with example calibration data. Note that Row 2 shows the variables names used in calculation section, and Row 3 shows the cell operations used to calculate VWC from the calibration data.

	A	B	C	D	E	F	G	H	I	J
1	sample number	sensor reading (m^3/ m^3)	Jar mass (g)	sample volume (cm^3)	wet soil mass + container (g)	dry soil mass + container (g)	Mass & volume of water (cm^3)	Dry soil mass (g)	soil bulk density (g/cm^3)	VWC (cm^3/cm^3)
2				V_t			(m_w, V_w)	m_{dry}	ρ_b	θ
3							=E3-F3	=F3-C3	=H3/D3	=G3/D3
4	1	0.0844	70.605	15.31	94.836	94.215	0.621	23.610	1.54	0.0406
5	2	0.1694	72.245	15.31	96.433	95.194	1.239	22.949	1.50	0.0809

	A	B	C	D	E	F	G	H	I	J
1	sample number	sensor reading (m^3/ m^3)	Jar mass (g)	sample volume (cm^3)	wet soil mass + container (g)	dry soil mass + container (g)	Mass & volume of water (cm^3)	Dry soil mass (g)	soil bulk density (g/cm^3)	VWC (cm^3/cm^3)
6	3	0.2867	71.713	15.31	96.923	94.785	2.138	23.072	1.51	0.1396
7	4	0.3955	74.45	15.31	101.979	98.834	3.145	24.384	1.59	0.2054
8	5	0.6403	70.997	15.31	100.402	95.873	4.529	24.876	1.62	0.2958
9	6	0.6879	71.48	15.31	101.060	95.886	5.174	24.406	1.59	0.3379

Step 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 probe 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 as shown below, but is sometimes best fit with a quadratic equation, especially in soils with high organic matter content.

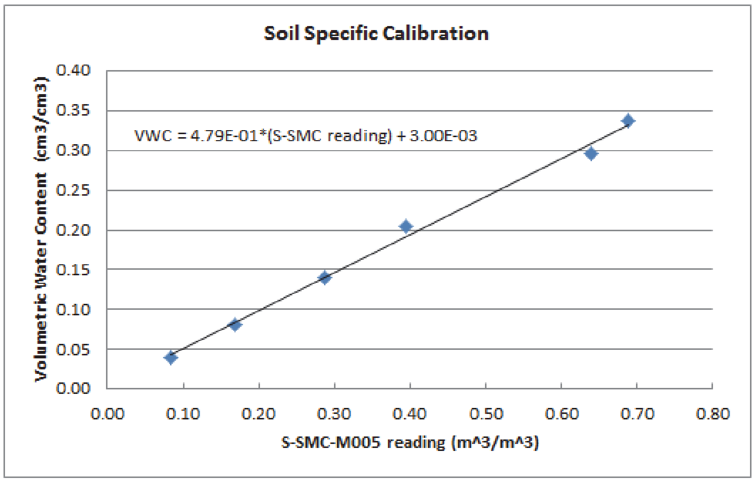

Figure 1. Plot of example calibration data. The soil specific calibration equation is shown in the upper left corner of the graph area.

Once you have constructed your calibration function, you need to apply it to the ECH_2O sensor data that you collect. If you are using soil moisture sensors with a RX3000 or U30 Station logger and the calibration data is linear, then you can enter the calibration directly into the sensor scaling in HOBOlink. Non-linear calibration would require post-processing in Excel or similar program. If you are using HOBOware to view the soil moisture data, then you will need to use post-processing to apply the custom calibration to the data.

Reference

1. Czarnomski, N. G. Moore, T. Pypker, J. Licata, and B. Bond. 2005. Precision and accuracy of three alternative instruments for measuring soil water content in two forest soils of the Pacific Northwest Can. J. For. Res. 35(8): 1867-1876.
2. Starr, J.L., and I.C.Paltineanu. 2002. Methods for Measurement of Soil Water Content: Capacitance Devices. p. 463-474. In J.H.Dane, and G.C.Topp (ed.) Methods of Soil Analysis: Part 4 Physical Methods. Soil Science Society of America, Inc., Soil Science Society of America, Inc.