Soil-specific calibration procedure for volumetric water content sensors

Dirk V. Baker, Campbell Scientific

1. Materials needed

- Large tub or bucket for mixing the soil and water
- Trough large enough to accommodate the soil water-content sensor placed horizontally with at least 10 cm of space around the sensor
- Water content sensor, cable, and data logger
- Soil sample ring
- Microbalance accurate to at least 0.05 g (assuming a sample ring similar to that used in this document)
- Plastic bags
- Knife or spatula

2. Overview of major steps

- Obtain a large volume of air-dried soil
- Measure mass-based volumetric water content
- Develop the calibration and consider sources of uncertainty

> NOTE:
> Campbell Scientific recommends repeating the calibration process to ensure consistent and accurate results

3. Obtaining the soil samples

Obtain soil samples for at least five levels of volumetric water content (VWC) representing a wide water content range.

> NOTE:
> This method may not work well for fully saturated soil.

1. Set up in a location that can get dirty. To prevent evaporation, avoid locations that are too hot, dry, or in direct sunlight.
2. Starting with dry soil, sift and break up clods.
3. Place soil in a large tub or bucket, measure the volume of soil in the tub, and determine the amount of water needed to achieve the first (driest) volumetric water content. For example, if the total dry soil volume is 20 L and the first target VWC is 10%, add 2 L of water.
4. Add a small amount of water and thoroughly mix into the soil. Repeat process until all the water is mixed into the soil.
5. Add a layer of well-packed soil to the bottom of the trough deep enough to accommodate the probe and cable, and place the water content sensor on top. With the SoilVUE™10, the rods should face upward (FIGURE 3-1 (p. 1)).

FIGURE 3-1. SoilVUE™10 placed in a trough

6. Connect the sensor to the data logger and keep the cable away from where the samples are taken.
7. Add soil around and on top of the soil water content sensor, packing well to prevent air gaps around the rods. Add soil until the layer completely surrounds the sensor (FIGURE 3-2 (p. 1) and FIGURE 3-3 (p. 2)). Because the sensitive volume for the SoilVUE™10 extends 1.5 to 2 cm from the rods, the layer needs to be greater than 2 cm to ensure good measurements. After packing, mark or measure where the soil surface is to ensure the soil is packed to the same level each time.

FIGURE 3-2. Packing soil around the SoilVUE™10

FIGURE 3-3. SoilVUE™10 with 5 cm of soil packed on top of it

8. Use the data logger to take and store at least 10 sensor measurements. Since some sensors take longer than others, cover the trough to limit evaporation. Examine these measurements for outliers or trends that would indicate the need to repeat this step.
9. Carefully sample the soil next to the rods.
   a. Press a sample ring into the soil until the top of the ring is flush with the top of the soil (FIGURE 3-4 (p. 2) and FIGURE 3-5 (p. 2)).

FIGURE 3-4. Ring placed in trough next to rods

FIGURE 3-5. Ring flush with top of soil

   b. Remove the ring with the soil intact. Soil may need to be removed from outside the ring. Slide a knife or spatula under the ring and carefully lift it free (FIGURE 3-6 (p. 2) and FIGURE 3-7 (p. 2)).
      - Avoid disturbing the soil where additional samples will be taken.
      - Alternating the side of the sensor the sample is taken from can help with this.

FIGURE 3-6. Knife used to lift ring

FIGURE 3-7. Lifting ring out of soil

   c. Use a flat edge of a knife or spatula to remove soil extending beyond the ends of the ring so that the ring accurately contains the total volume of the sample (FIGURE 3-8 (p. 2)).

FIGURE 3-8. Soil sample taken

   d. Place the sample into a plastic bag, remove as much air as possible, seal, then label with location and VWC.
   e. For profilers, repeat this process next to each set of rods (5 cm, 10 cm, etc.)
10. Remove the water content sensor from the trough and return the soil to the mixing tub
11. Add the same volume of soil as was removed from the soil ring samples so that the density can be repeated when packing the soil to the previously measured level.
12. Add water to achieve the next water content amount and mix thoroughly.
13. Repeat the steps 4 through 12 until samples are obtained for the volumetric water content range of interest.

4. Measuring mass-based volumetric water content

1. Allow the ring samples to equilibrate to room temperature (if necessary).
2. Measure and record the (wet) mass of each sample using a microbalance.
3. Either air dry or oven dry each sample.
   a. To air dry, open each plastic bag, place the sample in a dry area that will not be disturbed, and allow the samples to dry over several days.
   b. If using an oven, ensure that the plastic bags can tolerate 105 to 110 °C (or remove the samples from the bags). Place the samples in the oven at a temperature of 105 to 110 °C for 24 hours, and check the samples periodically.
4. Allow the samples to equilibrate to room temperature (if necessary).
5. Measure and record the dry mass of each sample.
6. Dry each sample again (as previously described in steps 3 and 4) and measure the mass again. Repeat this process until the dry mass stabilizes.
7. Calculate mass-based volumetric water content.
   a. Calculate the volume of the sample ring (volume of a cylinder).
      - The ring used in the figures is 3 cm height and 5.4 cm diameter, so its volume is 68.7 cm^3 (and 1 cm^3 = 1 mL).
   b. For each soil sample, subtract the dry mass from the wet mass to obtain the mass of the water.
   c. Calculate the volume of water in each sample.
      - 1 mL of pure water weighs 1 g.
   d. The mass-based volumetric water content is the volume of the water divided by the volume of soil

      Example calculation:

      Wet mass = 91.88 g

      Dry mass = 80.31 g

      Water mass = 91.88 g – 80.13 g = 11.57 g

      Water volume = 11.57 mL of pure water

$$VWC = \frac{11.57\ cm^3}{68.7\ cm^3} = 0.162$$

5. Developing the calibration

1. Average the 10 VWC measurements at each moisture level.
2. Compare the mass-based VWC with the average of the sensor measurements.
3. If the mass-based and sensor measurements are significantly different, use one of the following methods to adjust the measurements.
   a. Compare the VWC from each method and analyze the relationship to develop an empirical correction.
   b. Analyze the relationship between the permittivity measured by the soil sensor and the mass-based VWC measurements to produce a calibration curve.

   Since the calibration curve uses the base soil measurement, it is more technically correct, but may take more work.
4. Both methods may require the comparison of multiple functional forms (e.g., linear and non-linear). The Topp[1] or Ledieu[2] models provide justifiable starting points.
5. Key sources of uncertainty:
   a. Evaporation
      - Especially if there is significant time between samples or between samples and soil sensor measurements
   b. Uneven or insufficient packing
   c. Insufficient soil volume surrounding rods

6. References

[1]Topp, G.C., J.L. Davis & A.P. Annan. 1980. Electromagnetic determination of soil water content: measurements in coaxial transmission lines. Water Resources Research, v. 16, No. 3:574-582

[2]Ledieu, J., P. De Ridder, P. De Clerck, and S. Dautrebande. 1986. A method of measuring soil moisture by time-domain reflectometry. J. Hydrol. 88:319-328.

INFO

Global Sales & Support Network

A worldwide network to help meet your needs

Campbell Scientific regional offices

Australia

Location: Garbutt, QLD Australia
Phone: 61.7.4401.7700
Email: info@campbellsci.com.au
Website: www.campbellsci.com.au

Brazil

Location: São Paulo, SP Brazil
Phone: 11.3732.3399
Email: vendas@campbellsci.com.br
Website: www.campbellsci.com.br

Canada

Location: Edmonton, AB Canada
Phone: 780.454.2505
Email: dataloggers@campbellsci.ca
Website: www.campbellsci.ca

China

Location: Beijing, P. R. China
Phone: 86.10.6561.0080
Email: info@campbellsci.com.cn
Website: www.campbellsci.com.cn

Costa Rica

Location: San Pedro, Costa Rica
Phone: 506.2280.1564
Email: info@campbellsci.cc
Website: www.campbellsci.cc

France

Location: Vincennes, France
Phone: 0033.0.1.56.45.15.20
Email: info@campbellsci.fr
Website: www.campbellsci.fr

Germany

Location: Bremen, Germany
Phone: 49.0.421.460974.0
Email: info@campbellsci.de
Website: www.campbellsci.de

India

Location: New Delhi, DL India
Phone: 91.11.46500481.482
Email: info@campbellsci.in
Website: www.campbellsci.in

South Africa

Location: Stellenbosch, South Africa
Phone: 27.21.8809960
Email: sales@campbellsci.co.za
Website: www.campbellsci.co.za

Spain

Location: Barcelona, Spain
Phone: 34.93.2323938
Email: info@campbellsci.es
Website: www.campbellsci.es

Thailand

Location: Bangkok, Thailand
Phone: 66.2.719.3399
Email: info@campbellsci.asia
Website: www.campbellsci.asia

UK

Location: Shepshed, Loughborough, UK
Phone: 44.0.1509.601141
Email: sales@campbellsci.co.uk
Website: www.campbellsci.co.uk

USA

Location: Logan, UT USA
Phone: 435.227.9120
Email: info@campbellsci.com
Website: www.campbellsci.com