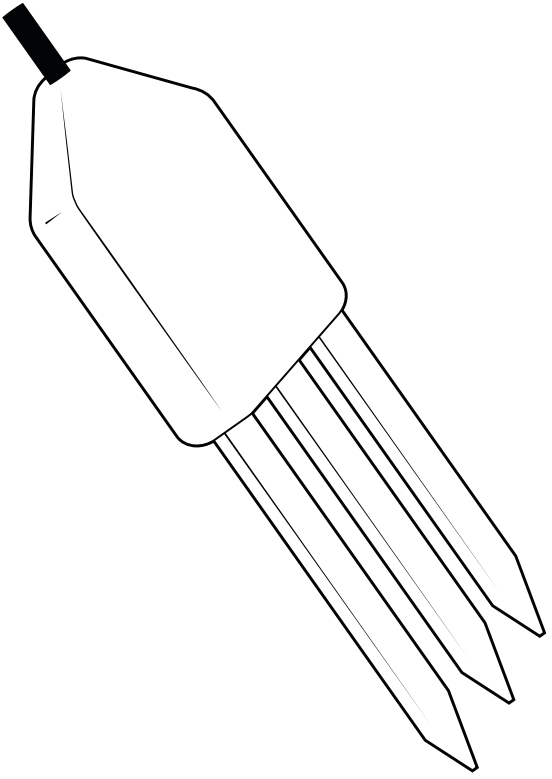
TABLE OF CONTENTS



1. INTRODUCTION

Thank you for choosing the ECH_2O 5TM Volumetric Water Content (VWC) and Temperature sensor from METER Group.

This manual guides the customer through the sensor features and describes how to use the sensor successfully. METER hopes the contents of this manual are useful in understanding the instrument and maximizing its benefit.

Prior to use, verify the 5TM arrived in good condition.

2. OPERATION

Please read all instructions before operating the 5TM to ensure it performs to its full potential.

⚠ PRECAUTIONS

METER sensors are built to the highest standards, but misuse, improper protection, or improper installation may damage the sensor and possibly void the manufacturer's warranty. Before integrating 5TM into a system, make sure to follow the recommended installation instructions and have the proper protections in place to safeguard sensors from damage.

2.1 INSTALLATION

When selecting a site for installation, remember that the soil adjacent to the sensor surface has the strongest influence on the sensor reading and that the sensor measures the VWC of the soil. Therefore, any air gaps or excessive soil compaction around the sensor and in between the sensor prongs can profoundly influence the readings.

- If installing sensors in a lightning-prone area with a grounded data logger, please read Lightning surge and grounding practices.
- Test the sensors with the data logging device and software before going to the field.

Do not install the sensor adjacent to large metal objects such as metal poles or stakes. This can attenuate the sensor's electromagnetic field and adversely affect readings. In addition, the 5TM sensor should not be installed within 5 cm of the soil surface, or the sensing volume of the electromagnetic field can extend out of the soil and reduce accuracy.

Because the 5TM has gaps between its prongs, it is also important to consider the particle size of the medium. It is possible to get sticks, bark, roots or other material stuck between the sensor prongs, which will adversely affect readings. Finally, be careful when inserting the sensors into dense soil, as the prongs can break if excessive sideways force is used when pushing them in.

When installing the 5TM, it is imperative to maximize contact between the sensor and soil. The sensor needs to be completely covered by soil (Figure 1).

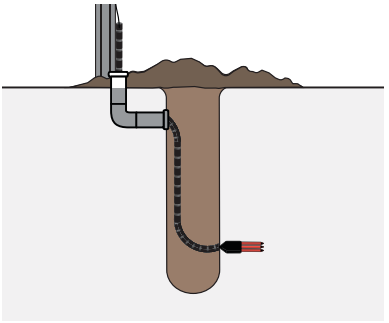


Figure 1 Example of 5TM proper installation

For most accurate results, the sensor should be inserted into undisturbed soil. There are two basic methods to accomplish a high-quality installation.

With either of these methods, the sensor may still be difficult to insert into extremely compact or dry soil.

NOTE: Never pound the sensor into the soil! If there is difficulty inserting the sensor, loosen or wet the soil. This will result in inaccurate VWC measurements until the water added during installing redistributes into the surrounding soil

METHOD 1. HORIZONTAL INSTALLATION

1. Excavate a hole or trench a few centimeters deeper than the depth at which the sensor is to be installed.
2. At the installation depth, shave off some soil from the vertical soil face exposing undisturbed soil.
3. Insert the sensor into the undisturbed soil face until the entire sensor is inserted. The tip of each prong has been sharpened to make it easier to push the sensor into the soil. Be careful with the sharp tips!
4. Backfill the trench taking care to pack the soil back to natural bulk density around the sensor body of the 5TM.

METHOD 2. VERTICAL INSTALLATION

1. Auger a 3-in hole to the depth at which the sensor is to be installed.
2. Insert the sensor into the undisturbed soil at the bottom of the auger hole using a hand or any other implement that will guide the sensor into the soil at the bottom of the hole. Many people have used a simple piece of PVC pipe with a notch cut in the end for the sensor to sit in, with the sensor cable routed inside the pipe.
3. After inserting the sensor, remove the installation device and backfill the hole taking care to pack the soil back to natural bulk density while not damaging the black overmolding of the sensor and the sensor cable in the process.

View a visual demonstration on proper installation of the sensor in How to install soil moisture sensors.

The sensor can be oriented in any direction. However, orienting the flat side perpendicular to the surface of the soil will minimize effects on downward water movement. The sensor measures the average VWC along its length, so a vertical installation will integrate VWC over a 10-cm depth while a horizontal orientation will measure VWC at a more discrete depth.

This problem occurs regardless of which logging system is being used if the ground wires are connected at all times. If sensors must be close together (e.g., column experiments), consider a multiplexing option that would isolate the ground wires.

If installing sensors vertically at short depth intervals, do not bury them directly over the top of each other. Although at times the vertical distance may be less than 20 cm, the sensors can be staggered horizontally so they are not directly above each other, thus meeting the distance requirement.

2.2 REMOVING THE SENSOR

When removing the sensor from the soil, do not pull it out of the soil by the cable! Doing so may break internal connections and make the sensor unusable.

2.3 CONNECTING

The 5TM works seamlessly with METER data loggers. The 5TM can also be used with other data loggers, such as those from Campbell Scientific, Inc. For extensive directions on how to integrate the sensors into third-party loggers, refer to the 5TM Integrator Guide.

5TM sensors require an excitation voltage in the range of 3.0 to 15 .0 VDC. 5TM can be integrated using DDI serial or SDI-12 protocol. See the 5TM Integrator Guide for details on interfacing with data acquisition systems.

The 5TM sensors come with a 3.5-mm stereo plug connector (Figure 2) to facilitate easy connection with METER loggers. 5TM sensors may be ordered with stripped and tinned wires to facilitate connecting to some third-party loggers (Section 2.3.2).

Figure 2 Stereo plug connector

The 5TM sensor comes standard with a 5-m cable. It may be purchased with custom cable lengths for an additional fee (on a per-meter basis). METER has successfully tested digital communication on cable lengths up to 1,000 m (3,200 ft). This option eliminates the need for splicing the cable (a possible failure point). However, the maximum recommended length is 75 m.

2.3.1 CONNECT TO METER DATA LOGGER

The 5TM sensor works most efficiently with METER ZENTRA series data loggers. Check the METER download webpage for the most recent data logger firmware. Logger configuration may be done using either ZENTRA Utility (desktop and mobile application) or ZENTRA Cloud (web-based application for cell-enabled ZENTRA data loggers).

1. Plug the stereo plug connector into one of the sensor ports on the logger.
2. Use the appropriate software application to configure the chosen logger port for the 5TM. METER data loggers will automatically recognize 5TM sensors.
3. Set the measurement interval.

   METER data loggers measure the 5TM every minute and return the minute-average data across the chosen measurement interval.

5TM data can be downloaded from METER data loggers using either ZENTRA Utility or ZENTRA Cloud. Refer to the logger user manual for more information about these programs.

2.3.2 CONNECT TO NON-METER DATA LOGGER

The 5TM sensor can be used with non-METER (third-party) data loggers. Refer to the third-party logger manual for details on logger communications, power supply, and ground ports. The 5TM Integrator Guide also provides detailed instructions on connecting sensors to non-METER loggers.

5TM sensors can be ordered with stripped and tinned (pigtail) wires for use with screw terminals. Refer to the third-party logger manual for details on wiring.

Connect the 5TM wires to the data logger as illustrated in Figure 3 and Figure 4, with the power supply wire (brown) connected to the excitation, the digital out wire (orange) to a digital input, and the bare ground wire to ground.

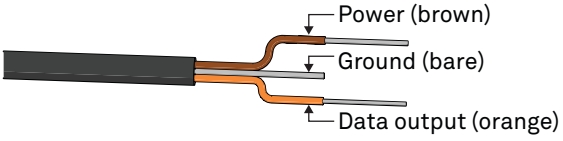


Figure 3 Pigtail wiring

NOTE: Some 5TM sensors may have the older Decagon wiring scheme where the power supply is white, the digital out is red, and the bare wire is ground.

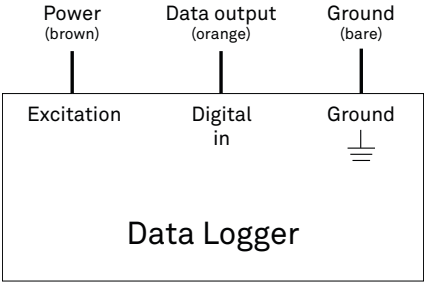


Figure 4 Wiring diagram

NOTE: The acceptable range of excitation voltages is from 3 to 15 VDC. To read 5TM sensors with Campbell Scientific data loggers, power the sensor from a switched 12-V port or a 12-V port if using a multiplexer.

If the 5TM cable has a standard stereo plug connector and needs to be connected to a non-METER data logger, use one of the following two options.

Option 1

1. Clip off the stereo plug connector on the sensor cable.
2. Strip and tin the wires.
3. Wire it directly into the data logger.

This option has the advantage of creating a direct connection and minimizes the chance of the sensor becoming unplugged. However, it then cannot be easily used in the future with a METER readout unit or data logger.

Option 2

Obtain an adapter cable from METER.

The adapter cable has a connector for the stereo plug connector on one end and three wires (or pigtail adapter) for connection to a data logger on the other end. The stripped and tinned adapter cable wires have the same termination as in Figure 4: the brown wire is excitation, the orange is output, and the bare wire is ground.

NOTE: Secure the stereo plug connector to the pigtail adapter connections to ensure the sensor does not become disconnected during use.

Because 5TM sensors use digital communication, they require special considerations when connecting to an SDI-12 data logger. Read SDI-12 example programs to view sample Campbell Scientific programs.

2.4 COMMUNICATION

The 5TM sensor communicates using two different methods, DDI serial and SDI-12. Please see the 5TM Integrator Guide for detailed instructions.

3. SYSTEM

This section describes the 5TM sensor.

3.1 SPECIFICATIONS

MEASUREMENT SPECIFICATIONS

Volumetric Water Content (VWC)	
Range	
Mineral soil calibration	0.0–1.0 m^3/m^3
Soilless media calibration	0.0–1.0 m^3/m^3
Apparent dielectric permittivity (ε_a)	1 (air) to 80 (water)
Resolution	0.0008 m^3/m^3 from 0%–50% VWC
Accuracy	
Generic calibration	± 0.03 m^3/m^3 typical
Medium-specific calibration	±0.02 m^3/m^3
Apparent dielectric permittivity (ε_a)	1–40 (soil range), ±1 ε_a (unitless) 40–80, 15% measurement
Temperature	
Range	–40 to +60 °C
Resolution	0.1 °C
Accuracy	±1 °C

COMMUNICATION SPECIFICATIONS

Output
DDI serial or SDI-12 communication protocol
Data Logger Compatibility
Data acquisition systems capable of 3.6- to 15.0-VDC power and serial or SDI-12 communication

PHYSICAL SPECIFICATIONS

Dimensions	
Length	10.9 cm (4.3 in)
Width	3.4 cm (1.3 in)
Height	1.0 cm (0.4 in)

Prong Length
5.0 cm (1.9 in)

Operating Temperature Range	
Minimum	–40 °C
Typical	NA
Maximum	+60 °C

NOTE: Sensors may be used at higher temperatures under certain conditions; contact Customer Support for assistance.

Cable Length
5 m (standard) 75 m (maximum custom cable length)

NOTE: Contact Customer Support if a nonstandard cable length is needed.

Connector Types
3.5-mm stereo plug connector or stripped and tinned wires

ELECTRICAL AND TIMING CHARACTERISTICS

Supply Voltage (VCC to GND)	
Minimum	3.6 VDC
Typical	NA
Maximum	15.0 VDC

Digital Input Voltage (logic high)	
Minimum	2.8 V
Typical	3.0 V
Maximum	3.9 V

Digital Input Voltage (logic low)	
Minimum	–0.3 V
Typical	0.0 V
Maximum	0.8 V
Power Line Slew Rate	
Minimum	1.0 V/ms
Typical	NA
Maximum	NA
Current Drain (during measurement)	
Minimum	0.5 mA
Typical	3.0 mA
Maximum	10.0 mA
Current Drain (while asleep)	
Minimum	NA
Typical	0.03 mA
Maximum	NA
Power-Up Time (DDI serial)	
Minimum	NA
Typical	NA
Maximum	100 ms
Power-Up Time (SDI-12)	
Minimum	100 ms
Typical	150 ms
Maximum	200 ms
Measurement Duration	
Minimum	NA
Typical	150 ms
Maximum	200 ms

COMPLIANCE
Manufactured under ISO 9001:2015
EM ISO/IEC 17050:2010 (CE Mark)

3.2 ABOUT 5TM

The 5TM is designed to measure the water content and temperature of soil (Figure 5). The 5TM uses an oscillator running at 70 MHz to measure the dielectric permittivity of soil to determine the water content. A thermistor in thermal contact with the sensor prongs provides the soil temperature. The polyurethane coating on the 5TM circuit board protects the components from water damage and gives the sensor a longer life span.

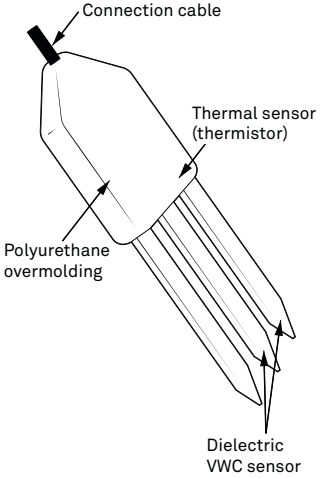


Figure 5 5TM components

3.3 THEORY

The following sections explain the theory of VWC and temperature measured by 5TM.

3.3.1 VOLUMETRIC WATER CONTENT

The 5TM sensor uses an electromagnetic field to measure the dielectric permittivity of the surrounding medium. The sensor supplies a 70 MHz oscillating wave to the sensor prongs that charges according to the dielectric of the material. The stored charge is proportional to soil dielectric and soil VWC. The 5TM microprocessor measures the charge and outputs a value of dielectric permittivity from the sensor.

3.3.2 TEMPERATURE

The 5TM uses a surface-mounted thermistor to take temperature readings. The thermistor is underneath the sensor overmold, next to one of the prongs, and it reads the temperature of the prong surface. The 5TM outputs temperature in degrees Celsius unless otherwise stated in the software preferences file.

If the black polyurethane overmold of the sensor body is in direct sunshine, the temperature measurement may read high. Do not install the sensor with the overmold in the sun.

4. SERVICE

This section contains calibration and recalibration information, calibration frequencies, cleaning and maintenance guidelines, troubleshooting guidelines, customer support contact information, and terms and conditions.

4.1 CALIBRATION

METER software tools automatically apply factory calibrations to the sensor output data. However, this general calibration may not be applicable for all soil types. For added accuracy METER encourages customers to perform soil-specific calibrations.

4.1.1 DIELECTRIC PERMITTIVITY

METER factory calibrates each 5TM sensor to measure dielectric permittivity (ε_a) accurately in the range of 1 (air) to 80 (water). The unprocessed raw values reported by the 5TM in standard serial communication have units of 50ε_a. When used in SDI-12 communication mode, the unprocessed values have units of ε_a (for 5TM board versions R2.04 and older, units are 100ε_a).

4.1.2 MINERAL SOIL CALIBRATION

Numerous researchers have studied the relationship between dielectric permittivity and VWC in soil. As a result, numerous transfer equations that predict VWC from measured dielectric permittivity. Use any of these various transfer equations to convert raw dielectric permittivity data from the 5TM into VWC. If using the mineral soil calibration option in METER ProCheck reader, DataTrac 3, or ECH2O Utility, they convert raw dielectric permittivity values with the Topp equation (Topp et al. 1980).

$$VWC = 4.3 \times 10^{-6} \varepsilon_a^3 - 5.5 \times 10^{-4} \varepsilon_a^2 + 2.92 \times 10^{-2} \varepsilon_a - 5.3 \times 10^{-2} \quad \textbf{Equation 1}$$

METER tests show that in a properly installed 5TM sensor in a normal mineral soil with saturation extract electrical conductivity <10 dS/m, the Topp equation results in measurements within 3% VWC of the actual soil VWC. If a more accurate VWC is required, such as working in a soil with very high EC or nonnormal mineralogy, then it may be necessary to conduct a soil-specific calibration for the 5TM sensor to improve the accuracy to 1% to 2% for any soil.

There are two options for soil-specific calibration.

- Follow the step-by-step instructions for calibrating soil moisture sensors in the application note Soil-specific calibrations for METER soil moisture sensors.
- METER offers a service providing soil specific calibrations.

This calibration service also applies to soilless materials, such as compost or potting materials. Contact Customer Support for more information.

4.1.3 CALIBRATION IN SOILLESS MEDIA

METER has performed calibrations with the 5TM in several soilless growth media. The following are suggested calibration equations for some common materials.

Potting Soil

$$VWC = 2.25 \times 10^{-5} \varepsilon_a^3 - 2.06 \times 10^{-3} \varepsilon_a^2 + 7.24 \times 10^{-2} \varepsilon_a - 0.247 \quad \text{Equation 2}$$

Rockwool

$$VWC = 1.68 \times 10^{-3} \varepsilon_a^2 + 6.56 \times 10^{-2} \varepsilon_a + 0.0266 \quad \text{Equation 3}$$

Perlite

$$VWC = -1.07 \times 10^{-3} \varepsilon_a^2 + 5.25 \times 10^{-2} \varepsilon_a - 0.0685 \quad \text{Equation 4}$$

METER continually develops additional calibration equations for various other growth media as opportunities arise. Contact Customer Support for the status of this ongoing research.

The 5TM can accurately read VWC in virtually any porous medium if a custom calibration is performed (Section 4.1.2). Contact Customer Support for more information.

4.2 TROUBLESHOOTING

If problems with the 5TM are encountered, they most likely manifest themselves in the form of incorrect or erroneous readings. Review the information in Table 1 and the Troubleshooting METER soil moisture sensors video to identify the problem. Contact Customer Support for more information.

Table 1 Troubleshooting the 5TM

Problem	Possible Solution
Sensor not responding	Check power to the sensor. Check sensor cable and stereo plug connector integrity. Check data logger wiring to ensure brown is power supply, orange is digital out, and bare is ground. **NOTE: Some 5TM sensors may have the older Decagon wiring scheme where the power supply is white, the digital out is red, and the bare wire is ground.**
Sensor reading too low (or slightly negative)	Check for air gaps around sensor needles. These could be produced below the surface of the substrate when the needle contacts a large piece of material and pushes it out of the way, or if the sensor is not inserted perfectly linearly. Ensure the calibration equation being used is appropriate for the media type. There are significant differences between substrate calibrations, so be sure to use the one specific to the substrate.

Table 1 Troubleshooting the 5TM (continued)

Problem	Possible Solution
Sensor reading too high	Check to make sure that the media was not packed excessively or insufficiently during sensor installation. Higher density can cause sensor reading to be elevated. Ensure the calibration equation being used is appropriate for the media type. There are significant differences between calibrations, so be sure to use the one most suitable to the substrate, or consider developing a substrate-specific calibration for the particular medium. Some substrates have an inherently high dielectric permittivity (soils of volcanic origin or high titanium, for instance). If the substrate has a dry dielectric permittivity above 6, a custom calibration may need to be performed. Soils with a bulk EC >10 dS/m require substrate-specific calibrations (Section 4.1).
Cable or stereo plug connector failure	If a stereo plug connector is damaged or needs to be replaced, contact Customer Support for a replacement connector and splice kit. If a cable is damaged, follow these guidelines for wire splicing and sealing techniques.

4.3 CUSTOMER SUPPORT

NORTH AMERICA

Customer service representatives are available for questions, problems, or feedback Monday through Friday, 7:00 am to 5:00 pm Pacific time.

Email: support.environment@metergroup.com
sales.environment@metergroup.com

Phone: +1.509.332.5600

Fax: +1.509.332.5158

Website: metergroup.com

EUROPE

Customer service representatives are available for questions, problems, or feedback Monday through Friday, 8:00 to 17:00 Central European time.

Email: support@metergroup.de
sales@metergroup.de

Phone: +49 89 12 66 52 0

Fax: +49 89 12 66 52 20

Website: metergroup.de

If contacting METER by email, please include the following information:

Name	Email address
Address	Instrument serial number
Phone	Description of the problem

NOTE: For products purchased through a distributor, please contact the distributor directly for assistance.

4.4 TERMS AND CONDITIONS

By using METER instruments and documentation, you agree to abide by the METER Group, Inc. USA Terms and Conditions. Please refer to metergroup.com/terms-conditions for details.

REFERENCES

Topp, G. Clarke, J.L. Davis, and A. Peter Annan. 1980. "Electromagnetic Determination of Soil Water Content: Measurement in Coaxial Transmission Lines." *Water Resources Research* 16, no.3: 574–582.

INDEX