5TM

Water Content and Temperature Sensors

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Trademarks

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1 Introduction

Thank you for choosing Decagon's 5TM Soil Moisture and Temperature sensor. This manual can help you understand the sensor features and ensure successful sensor operation. We hope you find the contents of this manual useful in understanding your instrument and maximizing its benefit to you.

There are several ways to contact Decagon if you ever need assistance with your product, have any questions, or feedback. Decagon has Customer Service Representatives available to speak with you Monday through Friday, between 7am and 5pm Pacific time.

Note: If you purchased your sensor through a distributor, please contact them for assistance.

Email:
support@decagon.com or **sales@decagon.com**

Phone:
509-332-5600

Fax:
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If contacting us by email or fax, please include as part of your message your instrument serial number, your name, address, phone, fax number, and a description of your problem or question.

Please read these instructions before operating your sensor to ensure that it performs to its full potential.

1.1 Warranty

The sensor has a 30-day satisfaction guarantee and a one-year warranty on parts and labor. Your warranty automatically validates upon receipt of the instrument.

1.2   Seller's Liability

Seller warrants new equipment of its own manufacture against defective workmanship and materials for a period of one year from the date of receipt of equipment.

Note: We do not consider the results of ordinary wear and tear, neglect, misuse, accident as defects.

The Seller's liability for defective parts shall in no event exceed the furnishing of replacement parts "freight on board" the factory where originally manufactured. Material and equipment covered hereby which is not manufactured by Seller shall be covered only by the warranty of its manufacturer. Seller shall not be liable to Buyer for loss, damage or injuries to persons (including death), or to property or things of whatsoever kind (including, but not without limitation, loss of anticipated profits), occasioned by or arising out of the installation, operation, use, misuse, nonuse, repair, or replacement of said material and equipment, or out of the use of any method or process for which the same may be employed. The use of this equipment constitutes Buyer's acceptance of the terms set forth in this warranty. There are no understandings, representations, or warranties of any kind, express, implied, statutory or otherwise (including, but without limitation, the implied warranties of merchantability and fitness for a particular purpose), not expressly set forth herein.

2 About 5TM

We designed the 5TM to measure the water content, electrical conductivity, and temperature of soil. 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.

2.1 Specifications

Volumetric Water Content

Range: Apparent dielectric permittivity (ε_a): 1 (air) to 80 (water)

Resolution: ε_a: 0.1 ε_a (unitless) from 1 to 20, < 0.75 ε_a (unitless) from 20 to 80 VWC: 0.0008 $\mathrm{m^3/m^3}$(0.08% VWC) from 0 to 50% VWC

Accuracy: ε_a: ± 1 ε_a (unitless) from 1 to 40 (soil range), $\pm 15\%$ from 40 to 80 (VWC)

- Using Topp equation: ± 0.03 $\mathrm{m^3/m^3}$($\pm 3\%$ VWC) typical in mineral soils that have solution electrical conductivity < 10 dS/m

- Using medium specific calibration, ± 0.01 to $0.02\,\mathrm{m^3/m^3}$(± 1 to 2% VWC) in any porous medium.

Temperature

Range: -40 to 60 °C

Resolution: 0.1 °C

Accuracy: ± 1 °C

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[1]Customers may use sensors at higher temperatures under some conditions, please contact Decagon for assistance.

General

Dimensions: 10 cm (1) x 3.2 cm (w) x 0.7 cm (d)

Prong Length: 5.2 cm

Dielectric Measurement Frequency: 70 MHz

Measurement Time: 150 ms (milliseconds)

Power requirements: 3.6 to 15 VDC, 0.3 mA quiescent, 10 mA during 150 ms measurement

Output: RS232 (TTL) or SDI-12

Operating Temperature: -40 to 60 °C[1]

Connector Types: 3.5 mm (stereo) plug or stripped & tinned lead wires (Pigtail)

Cable Length: 5 m standard; Maximum 75 m. Please contact Decagon if you need longer cable lengths.

Data logger Compatibility (not exclusive):

- Decagon: Em50, Em50R, and Em50G

- Campbell Scientific: Any logger with serial I/O (CR10X, CR850, 1000, 3000, etc.)

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[1]Customers may use sensors at higher temperatures under certain conditions, please contact Decagon for assistance.
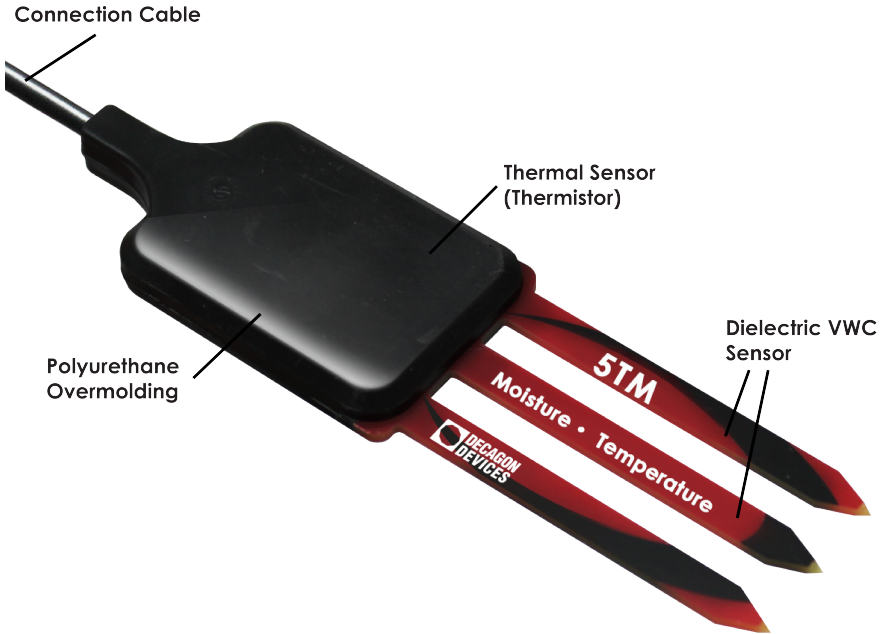
Figure 1: 5TM Components

2.2 Background

In 2006, Decagon incorporated research from its EC-5 volumetric water content sensor into the EC-TM, a sensor that measures volumetric water content and temperature. The new 5TM uses the same theory as the EC-TM, but has an improved calibration procedure and SDI-12 capabilities the 5TM utilizes a five point dielectric calibration to provide more accurate dielectric permittivity measurements than the previous EC-TM. In 2014, we changed the overmolding on the sensor circuitry from macromelt to polyurethane to extend the life of the sensor.

3   Theory

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 volumetric water content. The 5TM microprocessor measures the charge and outputs a value of dielectric permittivity from the sensor.

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 °C unless otherwise stated in DataTrac 3 or ECH2O Utility preferences file.

It is important to note that if the black polyurethane overmold of the sensor is in direct sunshine, the temperature measurement may read high. We do not recommend that the sensor be installed with the overmold in the sun.

Note: Do not install the sensor with the overmold exposed to the sun.

4   Calibration

4.1   Dielectric Permittivity

Decagon 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 $\varepsilon_a * 50$. 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, $\varepsilon_a * 100$).

4.2   Mineral Soil Calibration

Numerous researchers have studied the relationship between dielectric permittivity and volumetric water content (VWC) in soil. As a result, numerous transfer equations that predict VWC from measured dielectric permittivity. You are free to use any of these various transfer equations to convert raw dielectric permittivity data from the 5TM into VWC. If you choose the mineral soil calibration option in Decagon's ProCheck reader, DataTrac 3, or ECH2O Utility, they convert raw dielectric permittivity values with the Topp equation (Topp et al. 1980).

$$\text{VWC} = 4.3 * 10^{-6} \varepsilon_a{}^3 - 5.5 * 10^{-4} \varepsilon_a{}^2 + 2.92 * 10^{-2} \varepsilon_a - 5.3 * 10^{-2}$$

Our 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 $\pm 3\%$ VWC of the actual soil VWC. If you require more accurate VWC than $\pm 3\%$, are working in a soil with very high electrical conductivity, or non-normal mineralogy, then it may be necessary to conduct a soil specific calibration for your 5TM sensor to improve the accuracy to 1 to 2% for any soil. For more information on how to perform your own soil-specific calibration, or to have Decagon's calibration service perform one for you, visit us online at http://www.decagon.com/services/soil-moisture-sensor-custom-calibration.

Calibration in Non-Soil Media

Decagon has performed calibrations with the 5TM in several non-soil growth media. The following are suggested calibration equations for some common materials.

Potting Soil

$$VWC = 2.25 * 10^{-5}{\varepsilon_a}^3 - 2.06 * 10^{-3}{\varepsilon_a}^2 + 7.24 * 10^{-2}\varepsilon_a - 0.247$$

Rockwool

$$VWC = -1.68 * 10^{-3}{\varepsilon_a}^2 + 6.56 * 10^{-2}\varepsilon_a + 0.0266$$

Perlite

$$VWC = -1.07 * 10^{-3}{\varepsilon_a}^2 + 5.25 * 10^{-2}\varepsilon_a - 0.0685$$

Decagon continually develops additional calibration equations for various other growth media as opportunities arise. Please check the Decagon website http://www.decagon.com/pdfs/app_notes/Measuring WaterContentinSoil-lessMedia.pdf (case sensitive) or contact Decagon for the status of this ongoing research.

The 5TM can accurately read VWC in virtually any porous medium if a custom calibration is performed. For information on how to perform your own medium-specific calibration, or to have Decagons calibration service perform one for you, visit http://www.decagon.com.

Reference

Topp, G.C., J.L. David, and A.P. Annan 1980. Electromagnetic, Determination of Soil Water Content: Measurement in Coaxial Transmission Lines. *Water Resources Research* 16:3. p. 574-582.

5 Connecting Sensors

Decagon designed the 5TM sensor for use with our Em50 series data loggers or the ProCheck handheld reader. The standard sensor (with a 3.5 mm "stereo plug" connector) quickly connects to and is easily configured within a Decagon logger or ProCheck.

The 5TM sensor incorporates several features that also make it an excellent sensor for use with third party loggers. Customers may purchase the sensor with stripped and tinned wires (pigtail) for terminal connections. Visit www.decagon.com/support/literature to get extensive directions on how to integrate the 5TM sensor into third party loggers.

The 5TM sensor comes standard with a five meter cable. Customers may purchase sensors with custom cable lengths for an additional fee (on a per-meter fee basis). Obtaining custom length cables eliminates the need for splicing the cable (a possible failure point).

Connecting to an Em50/Em50R Logger

Decagon designed the 5TM to work specifically with the Em50 data logger. Simply plug the 3.5 mm stereo plug connector directly into one of the five sensor ports. Next, configure the logger port for the 5TM and set the measurement interval.

Connecting to ECH2O Utility

Please check your software version to ensure it will support the 5TM. To update your software to the latest version, please visit Decagon's software download site at www.decagon.com/support/downloads.

Note: You must use the ECH2O Utility, DataTrac 3 or a terminal program on your computer to download data from the logger to your computer.

5.1   Wiring

Figure 2: Stereo Connector

The following software support the 5TM sensor:

- ECH2O Utility 1.12 or greater
- ECH2O DataTrac 2.77 or greater

Connecting to a non-Decagon Logger

Customers may purchase 5TM sensors for use with non-Decagon data loggers. These sensors typically come configured with stripped and tinned (pigtail) lead wires for use with screw terminals. Refer to your distinct logger manual for details on wiring. Our Integrator's Guide gives detailed instructions on connecting the 5TM sensor to non-Decagon loggers. Please visit www.decagon.com/support/literature for the complete Integrator's Guide.

Pigtail End Wiring

Figure 3: Pigtail End Wiring

Connect the wires to the data logger as Figure 3 shows, with the supply wire (white) connected to the excitation, the digital out wire

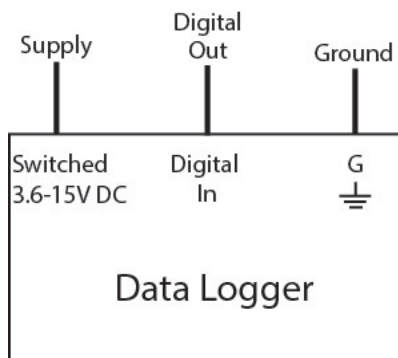(red) to a digital input, the bare ground wire to ground as illustrated below.

Figure 4: Pigtail End Wiring to Data Logger

Note: The acceptable range of excitation voltages is from 3.6-15 VDC. If you wish to read your Decagon sensor with the Campbell Scientific Data Loggers, you will need to power the sensors off of the switched 12V port.

If your 5TM is equipped with the standard 3.5 mm plug and you want to connect it to a non-Decagon data logger, you have two options. First, you can clip off the plug on the sensor cable, strip and tin the wires, and wire it directly into the data logger. This has the advantage of creating a direct connection with no chance of the sensor becoming unplugged; however, it cannot be easily used in the future with a Decagon readout unit or data logger.

The other option is to obtain an adapter cable from Decagon. The 3-wire sensor adapter cable has a connector for the sensor jack on one end, and three wires on the other end for connection to a data logger (this type of wire is often referred to as a "pigtail adapter"). Both the stripped and tinned adapter cable wires have the same termination as seen above; the white wire is excitation, red is output, and the bare wire is ground.

6   Communication

The 5TM sensor communicates using two different methods, Serial (TTL) and SDI-12. Please visit www.decagon.com/support/literature for the complete Integrator's Guide, which gives more detailed explanations and instructions.

6.1   Serial Communication

When excitation voltage is applied, the 5TM makes a measurment. Within about 120 ms of excitation three measurement values are transmitted to the data logger as a serial stream of ASCII characters. The serial out is 1200 baud asynchronous with 8 data bits, no parity, and one stop bit. The voltage levels are 0-3.6V and the logic levels are TTL (active low). The power must be removed and reapplied for a new set of values to be transmitted.

The ASCII stream contains 3 numbers separated by spaces. The stream is terminated with the carriage return character. The first number is raw dielectric output. The second number is 0 (ignore this value) and the third number is raw temperature. The following explains how to convert the raw values into their standard units.

6.2   Dielectric Permittivity

The raw dielectric value (ε_{Raw}), is valid in the range 0 to 4094. This corresponds to dielectric permittivity values 0.00 to 81.88. The 5TM uses the ε_{Raw} value of 4095 to indicate the dielectric permittivity portion of the sensor is not working as expected.

The ε_{Raw} value is converted to dielectric permittivity with the following equation:

Dielectric Permittivity $=\varepsilon_a = \varepsilon_{Raw} \ / \ 50$

6.3 Temperature

The raw temperature value, (T_{Raw}), is valid in the range 0 to 1022. The 5TM uses a compression algorithm to extend the range of temperatures that can be represented by a 10-bit value. The sensor sends temperature with 0.1 of a degree Celsius resolution for the range -40 to 50.0 °C. For the range 50.5 to 111.0 the sensor sends temperature with a 0.5 of a degree resolution. Temperatures outside this range are truncated to the maximum or minimum values as appropriate. The 5TM uses the T_{Raw} value of 1023 to indicate the temperature portion of the sensor is not working as expected.

If $T_{Raw} \leq 900$ then $T_{Raw2} = T_{Raw}$

If $T_{Raw} > 900$ then $T_{Raw2} = 900 + 5\,(T_{Raw}\text{ - }900)$

Temperature(°C)=$(T_{Raw2}$ - 400)/10

The 5TM sensor also communicates using SDI-12 protocol, a three-wire interface where all sensors are powered (white wire), grounded (bare wire), and communicate (red wire) on shared wires (for more info, go to www.sdi-12.org). If you plan on using SDI-12 for communication with the 5TM, please see our Integrator's Guide at www.deca gon.com/support/literature for detailed instructions.

7   Installing the Sensors

Decagon has a few helpful reminders to consider before beginning to use your sensor.

- If you are installing sensors in a lightning prone area with a grounded data logger, please see our Application Note at www.decagon.com/lightning.

- Decagon advises that you test the sensors with your data logging device and software before going to the field.

Before you select a site for installation, remember that the soil next to the sensor surface has the strongest influence on its readings. It is important to avoid air gaps or extremely compact soil around the sensor, which can skew readings. Do not install the 5TM next to large metal objects, which can attenuate the sensor electromagnetic field and distort output readings.

Because the sensors have gaps between their prongs, it is also important to consider the size of the media where you insert the sensor. 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 you apply excessive force when pushing them into the soil.

7.1   Procedure

Customers can insert the 5TM directly into growing media or soil. We have sharpened the tip of each prong to make it easier to push the sensor into the soil. Remember to be careful around the sharpened tips. The sensor needs to be completely covered by soil, as shown in Figure 5.
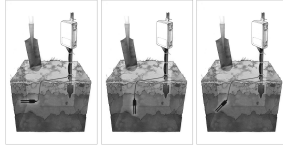
Figure 5: 5TM Proper Installation

The sensors may be difficult to insert into extremely compact or dry soil. If you have difficulty inserting the sensor, try loosening the soil somewhat or wetting the soil. Never pound the sensor into the soil, as you could damage the instrument.

7.1.1   Horizontal Installation

Excavate a hole or trench a few centimeters deeper than the depth at which the sensor is to be installed. At the installation depth, shave off some soil from the vertical soil face exposing undisturbed soil. Insert the sensor into the undisturbed soil face until the entire sensing portion of the sensor. The tip of each prong has been sharpened to make it easier to push in the sensor. Be careful to avoid the sharp tips. Backfill the trench taking care to pack the soil back to natural bulk density around the black polyurethane portion of the sensor.

7.1.2   Vertical Installation

Auger a 4-inch hole to the sensor installation depth. Insert the sensor into the undisturbed soil at the bottom of the auger hole using your hand or another implement to 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. 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 plastic portion of the sensor or the sensor cable in the process.

7.2   Orientation

Users can orient Decagon sensors in any direction. Because the sensors have prongs instead of a blade (like the EC-10 and EC-20), you can place them in any orientation that meets your requirements.

7.3   Removing the Sensors

When removing the 5TM sensor, do not pull it by the cable. This could break the internal wires and cause the sensor to malfunction or not function at all.

8 Troubleshooting and Sensor Care

Before contacting Decagon about sensor malfunctions, follow the data logger and sensors troubleshooting steps 1 through 3.

8.1 Data Logger

1. Check to make sure the connections to the data logger are both correct and secure.

2. Ensure that your data logger batteries are not dead or weakened.

3. Check the configuration of your data logger in ECH2O Utility or ECH2O DataTrac to make sure you have selected 5TM.

8.2 Sensors

1. Ensure that your sensors are installed according to the "Installation" section of this manual.

2. Check sensor cables for nicks or cuts that could cause a malfunction.

9   Declaration of Conformity

Application of Council Directive:	2004/108/EC and 2011/65/EU
Standards to which conformity is declared:	EN 61326-1:2013 and EN 50581:2012
Manufacturer's Name:	Decagon Devices, Inc. 2365 NE Hopkins Ct. Pullman, WA 99163 USA
Type of Equipment:	Dielectric Soil Moisture Sensor
Model Number:	ECH2O-TE/EC-TM/5TM/5TM
Year of First Manufacture:	2005

This is to certify that the ECH2O-TE, EC-TM, 5TE, and 5TM dielectric soil moisture sensors, manufactured by Decagon Devices, Inc., a corporation based in Pullman, Washington, USA meets or exceeds the standards for CE compliance as per the Council Directives noted above. All instruments are built at the factory at Decagon and pertinent testing documentation is freely available for verification.

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