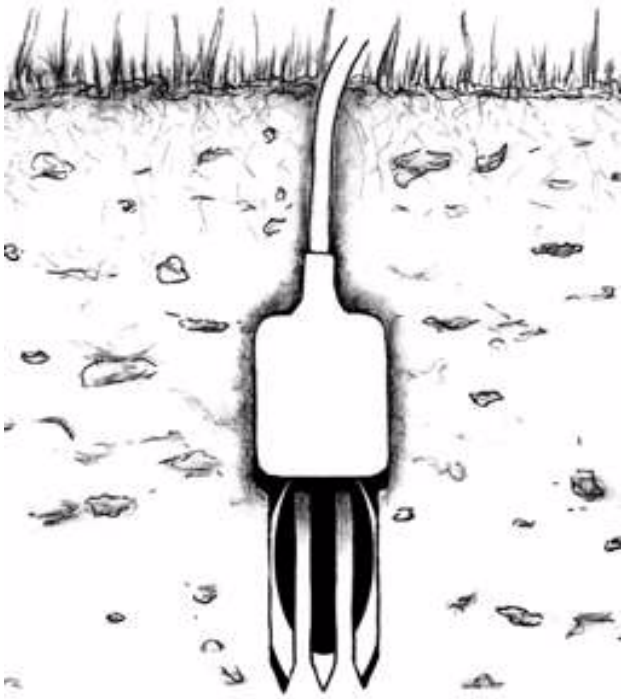
5TM

Water Content
and Temperature Sensors



Operator's Manual

Version 0

DECAGON DEVICES

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Contents

1. Introduction

Thank you for choosing Decagon's 5TM for measuring volumetric water content (VWC) and temperature. This manual is designed to help you understand the sensor's features and how to use this device successfully.

Specifications

Volumetric water content

Range:
Apparent dielectric permittivity (ε_a): 1 (air) to 80 (water)
Resolution:
ε_a: 0.1 ε_a (unitless) from 1-20; <0.75 ε_a (unitless) from 20-80
VWC: 0.0008 m^3/m^3 (0.08% VWC) from 0 to 50% VWC
Accuracy:
(ε_a): ±1 ε_a (unitless) from 1-40 (soil range), ±15% from 40-80 (VWC):

- Using Topp equation: ±0.03 m^3/m^3 (±3% VWC) typical in mineral soils that have solution electrical conductivity < 10 dS/m
- Using medium specific calibration, ±0.01 - 0.02 m^3/m^3 (± 1-2% VWC) in any porous medium

Temperature

Range: -40 to 50 °C
Resolution: 0.1 °C
Accuracy: ±1 °C

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 - 15 VDC, 0.3 mA quiescent, 10 mA during 150 ms measurement
Output: RS232 or SDI-12
Operating Temperature: -40-50 °C
Connector types: 3.5 mm (stereo) plug or stripped and tinned (Pigtail) lead wires
Cable Length: 5m standard; custom cable length available upon request
Datalogger Compatibility (not exclusive):
Decagon: Em50, Em50R
Campbell Scientific: Any logger with serial I/O (CR10X, CR850, 1000, 3000, etc.)

Customer Support

f you have questions or ever need assistance with your 5TM, there are several ways to contact us. If you live outside the US and Canada, please contact our authorized representative in your country (if applicable) for local customer service.

If you need to contact Decagon:

- **Call us** at 800-755-2751 or (509) 332-2756
- **Fax us** at (509) 332-5158
- **E-mail us** at support@decagon.com.

If you are sending a fax or email, please include as part of your message your instrument's serial number, your name, address, phone, fax number, and return e-mail address.

Warranty Information

All Decagon products have a 30-day satisfaction guarantee and a one-year warranty.

Seller's Liability

Seller warrants new equipment of its own manufacture against defective workmanship and materials for a period of one year from date of receipt of equipment (the results of ordinary wear and tear, neglect, misuse, accident and excessive deterioration due to corrosion from any cause are not to be considered a defect); but Seller's liability for defective parts shall in no event exceed the furnishing of replacement parts F.O.B. 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 the 5TM

The 5TM is designed to measure the volumetric water content and temperature of soil and growing media. Using an oscillator running at 70 MHz, it measures the dielectric permittivity of soil to determine the volumetric water content. A thermistor in thermal contact with the sensor prongs provides the soil temperature.

Background Info

In 2006, Decagon incorporated research from its EC-5 volumetric water content sensor into the EC-TM, a sensor which measured volumetric water content and temperature. The new 5TM uses the same theory as the EC-TM, but has an improved calibration prodedure and SDI-12 capabilities. The 5TM utilizes a 5 point calibration to provide dielectric permittivity measurements that are more accurate than the previous EC-TM.

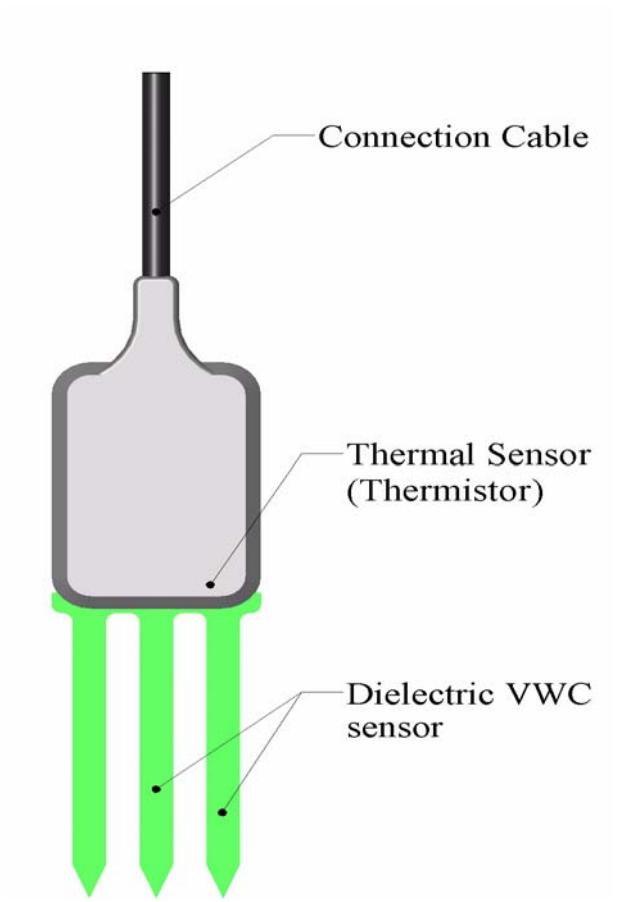


Figure 1: 5TM Components

3. Theory

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.

Temperature

The 5TM uses a surface-mounted thermistor to take temperature readings. It is located underneath the sensor overmold, next to one of the prongs, and will read the temperature of the prong surface. The 5TM will output temperature in °C unless otherwise stated in your preferences settings in either the ECH_2O DataTrac or ECH_2O Utility programs.

It is important to note that if the black plastic overmold of the sensor is in direct sunshine, the temperature measurement may read high. Exposure of the overmold to solar radiation will also drastically decrease the life expectancy of the sensor.

Note: We do not recommend that the sensor be installed with the overmold in the sun.

4. Calibration

Dielectric Permittivity

Each 5TM sensor has been calibrated 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 mode has units of ε_a*50. When used in SDI-12 communication mode, the unprocessed values have units of ε_a.

Mineral Soil Calibration

Numerous researchers have studied the relationship between dielectric permittivity and volumetric water content (VWC) in soil. As a result, the soil science literature is littered with various transfer equations used to 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. In Decagon's ProCheck reader and DataTrac and ECH$_2$O Utility software packages, if the mineral soil calibration option is chosen, raw dielectric permittivity values from the sensor are converted to VWC using the well known Topp equation (Topp et al. 1980):

$$VWC = 4.3x10^{-6}\ \varepsilon_a^3 - 5.5x10^{-4}\ \varepsilon_a^2 + 2.92x10^{-2}\ \varepsilon_a - 5.3x10^{-2}$$

Our tests have shown that a properly installed 5TM sensor installed in a normal mineral soil with solution (saturation extract) electrical conductivity <10 dS/m, the Topp equation

will result in measurements within ±3% VWC of the actual soil VWC. If you require more accurate VWC than ±3% or are working in a soil with very high solution electrical conductivity, or abnormal mineralogy, then it may be necessary to conduct a soil specific calibration for your 5TM sensor which will improve the accuracy to 1-2% 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/soil_moisture/accessories/.

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

$$VWC = 2.25x10^{-5} \varepsilon_a^3 - 2.06x10^{-3} \varepsilon_a^2 + 7.24x10^{-2} \varepsilon_a - 0.247$$

Rockwool

$$VWC = -1.68x10^{-3} \varepsilon_a^2 + 6.56x10^{-2} \varepsilon_a + 0.0266$$

Perlite

$$VWC = -1.07x10^{-3} \varepsilon_a^2 + 5.25x10^{-2} \varepsilon_a - 0.0685$$

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/MeasuringWaterContentinSoil-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 Decagon's 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. Connections

The 5TM sensor was designed to be used with Decagon's Em50, Em50R or the ProCheck handheld reader. The standard sensor (with 3.5 mm stereo connector) quickly connects to and is easily configured within a Decagon logger or selected in ProCheck.

The 5TM sensor incorporates several features that also make it an excellent sensor for use with third party loggers. The sensor may be purchased 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.

5TM sensors come standard with a 5 meter cable. Sensors may be purchased with custom cable lengths for an additional fee (on a per-foot fee basis). Decagon has tested its digital sensor successfully up to 1000 meters (3200 ft). This option eliminates the need for splicing the cable (a possible failure point).

Connecting to an Em50/Em50R logger

The 5TM was designed to work specifically with the Em50 datalogger. Simply plug the 3.5mm "stereo plug" connector. directly into one of the five sensor ports.

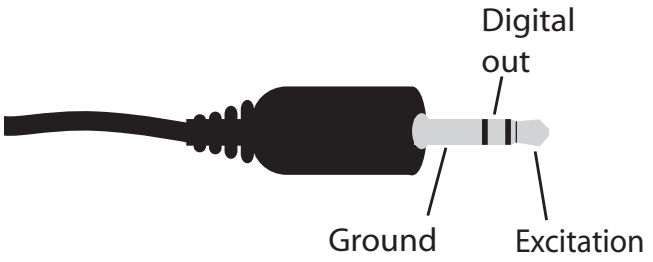
The next step is to configure your logger port for the 5TM and set the measurment interval, this may be done using either

ECH_2O Utility or ECH_2O Utility Mobile (see respective manuals). 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: www.decagon.com/support/downloads.

The following software versions support the 5TM sensor:
ECH_2O Utility 1.12 or greater
ECH_2O Utility Mobile 1.18 or greater

To download data from the logger to your computer, you will need to use the ECH_2O Utility, ECH_2O DataTrac or a terminal program on your computer.

3.5 mm Stereo Plug Wiring

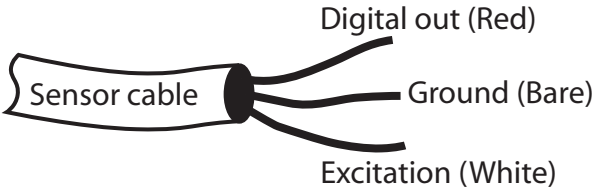


Connecting to a Non-Decagon Logger

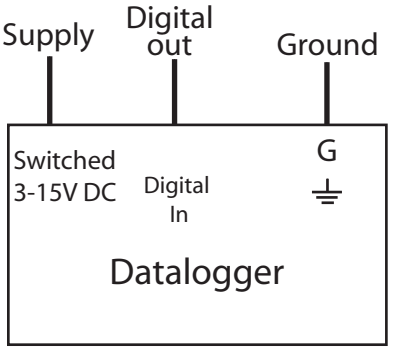
5TM sensor may be purchased for use with non-Decagon data loggers. These sensors typically come pre-configured with stripped and tinned (pigtail) lead wires for use with screw ter-

minals. 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



Connect the wires to the data logger as shown, 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.



NOTE: The acceptable range of excitation voltages is from 3.6-15 VDC. If you wish to read the 5TM with the Campbell Scientific Data Loggers, you will need to power the sensors from the switched 12V port.

If your 5TM is equipped with the standard 3.5mm plug, and you wish to connect it to a non-Decagon datalogger, 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 datalogger. This has the advantage of creating a direct connection with no chance of the sensor becoming un-plugged; however, it cannot be easily used in the future with a Decagon datalogger or handheld Procheck reader.

The other option is to obtain an adapter cable from Decagon. The 3-wire or adapter cable has a connector for the sensor jack on one end, and three wires on the other end for connection to a datalogger (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 illustrated above; the white wire is excitation, red is output, and the bare wire is ground.

6. Communication

The 5TM sensor can communicate using two different methods, Serial (TTL) and SDI-12. In this chapter we will briefly discuss the specifics of each of these communication methods. Please visit www.decagon.com/support/literature for the complete integrator's guide, which gives more detailed explanations and instructions.

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.

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

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 $T_{Raw2} = 900 + 5 (T_{Raw} - 900)$

Temperature(°C)$=(T_{Raw2} - 400)/10$

SDI-12 Communication

The 5TM sensor can also communicate using the 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). Below is a brief description of SDI-12 for communication. If you plan on using SDI-12 for communication with the 5TM, please see our integrator's guide at www.decagon.com/support/literature for detailed instructions.

Sensor Bus

There are both positive and negative elements of the SDI-12 protocol. On the positive side, up to 62 sensors can be connected to the same 12 V supply and communication port on the datalogger. This simplifies wiring because no multiplexer is necessary. On the negative side, one sensor problem can bring down the entire array (through a short circuit, etc.). To avoid this problem, we recommend the user make an independent junction box with wire harnesses where all sensor wires are wired to wire lugs so sensors can be disconnected if a problem arises. A single three-wire bundle can be run from the junction box to the datalogger.

Address

The SDI-12 protocol requires that all sensors have a unique address. 5TM sensors come from the factory with an SDI-12 address of 0. To add more than one SDI-12 sensor to a system, the sensor address must be changed. Address options include {0…9, A…Z, a…z}. The best and easiest way to change an address is to use Decagon's ProCheck (if the option is not available on your ProCheck, please upgrade to the latest version of firmware). SDI-12 addressing can be accessed in the "CONFIG" menu by selecting "SDI-12 Address". Addresses may

then be changed by simply pressing the up or down arrows until you see the desired address and pushing "Enter".

Power

The sensor can be powered using any voltage from 3.6 to 15 VDC, but 12 V is optimal. Although SDI-12 protocol allows the sensors to be continuously powered, you may connect the power (white wire) to a switching source. This can help reduce power use (although the 5TM sensors use very little power).

Reading

SDI-12 communication allows many parameters to be communicated at once. This allows you to see information such as the sensor model, SDI-12 version, temp, etc.

Reading the 5TM sensor in SDI-12 mode requires function calls. An example program from Edlog and CRBasic can be found in our software section online at http://www.decagon.com/support/downloads.

The dielectric permittivity (ε) is the first number output by the sensor. It is converted to volumetric water content (VWC) using Topp et al. (1980): $\theta\ (m^3/m^3) = 4.3 \times 10^{-6} * \varepsilon^3 - 5.5 \times 10^{-4} * \varepsilon^2 + 2.92 \times 10^{-2} * \varepsilon - 5.3 \times 10^{-2}$. The second number is the temperature in Celsius.

The SDI-12 communication protocol is supported in Campbell Scientific dataloggers like the CR10X, CR200, CR1000, CR3000, etc. Direct SDI-12 communication is supported in the "Terminal Emulator" mode under the "Tools" menu on the "Connect" screen. Detailed information on setting the address using CSI dataloggers can be found on our website at http://www.decagon.com/support/downloads.

7. Installation

NOTE 1: If you are installing sensors in a lightning prone area with a grounded data logger, please see our application note at www.decagon.com/sensorappnotes.

NOTE 2: 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 sensors' 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 you are inserting the sensor into. 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 force is used when pushing them in.

Procedure

The 5TM can be inserted directly into growing media or soil. The tip of each prong has been sharpened to make it easier to push the sensor in. *Be careful around the sharpened tips!* The sensor needs to be completely covered by soil, as shown in Figure 2.

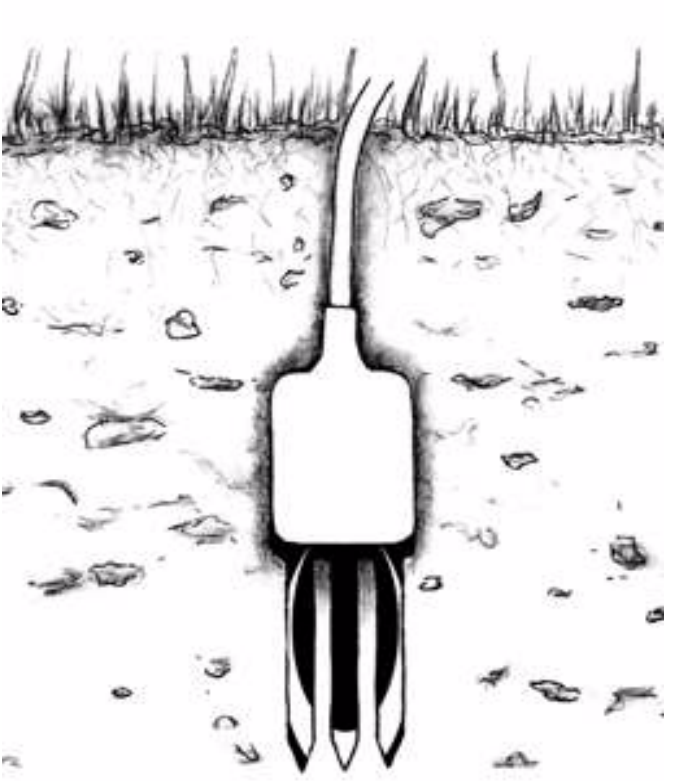


Figure 2: 5TM installed correctly

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 in.

Method 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 5TM is inserted. The tip of each prong has been sharpened to make it easier to push the sensor in. Be careful with the sharp tips! Backfill the trench taking care to pack the soil back to natural bulk density around the black plastic portion of the sensor.

Method 2.: Vertical Installation
Auger a 4-inch hole to the depth at which the sensor is to be installed. Insert the sensor into the undisturbed soil at the bottom of the auger hole using your 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. 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.

Orientation

The 5TM may be oriented in any direction. This is because the sensors has prongs instead of a blade (like the EC-10 and EC-20), the sensor can be placed in any orientation that meets your requirements.

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. Campbell Scientific Programs

Because the sensors uses digital rather than analog communication, they require special considerations when connecting to a Campbell Scientific datalogger. Please visit our website at http://www.decagon.com/support/downloads to view sample Campbell Scientific programs.

9. Troubleshooting&Sensor Care

If you encounter problems with the 5TM sensor, they will most likely manifest themselves in the form of incorrect or erroneous readings. Before contacting Decagon about the sensor, do the following:

Datalogger

1. Check to make sure the connections to the data logger are both correct and secure.
2. Ensure that your data logger's batteries are not dead or weakened.
3. Check the configuration of your data logger in ECH_2O Utility or to make sure you have selected the 5TM.

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.

Declaration of Conformity

Application of Council Directive:89/336/EE6

Standards to Which Conformity is Declared:	EN61326 : 1998 EN51022 : 1998
Manufacturer's Name:	Decagon Devices, Inc. 2365 NE Hopkins Court Pullman, WA 99163 USA
Type of Equipment:	Dielectric soil moisture sensor
Model Number:	ECH_2O-TE/EC-TM/5TE/5TM
Year of First Manufacture:	2005

This is to certify that the ECH_2O-TE, EC-TM, 5TE and 5TM dielectric soil moisture sensors, manufactured by Decagon Devices, Inc., a corporation based in Pullman, Washington, USA meet or exceed 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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