10HS

Soil Moisture Sensor

Decagon Devices, Inc.

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1 Introduction

Thank you for choosing the 10HS soil water content sensor. This innovative sensor enables you to monitor volumetric water content of soil accurately and affordably. This manual helps you understand the sensors features and how to use this device successfully.

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 8am 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:
509-332-5158

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 the 10HS

The 10HS measures the dielectric constant of the soil in order to find its volumetric water content (VWC). Since the dielectric constant of water is much higher than that of air or soil minerals, the dielectric constant of the soil is a sensitive measure of volumetric water content. The 10HS has a low power requirement and very high resolution. This gives you the ability to make as many measurements as you want (i.e hourly) over a long period of time with minimal battery usage.

2.1 Background Info

In 2005, the Decagon research team optimized a sensor oscillator frequency for very high accuracy soil moisture measurements. The first sensor to incorporate the new frequency was our EC-5 sensor. The EC-5 quickly became Decagon's most popular soil moisture sensor. The new 10HS sensor uses the same 70 MHz oscillator frequency as the EC-5, but has a larger soil volume and requires no special calibration when you use it with other systems. The 10HS has two features that distinguish it from the EC-5.

- The on board voltage regulator allows you to power the sensor with a wide range of excitation voltages (3 to 15 VDC) without changing the calibration.
- Large sensing area (1,100 cubic centimeters) that provides a more representative measurement of soil VWC.

The 10HS sensor runs at the same oscillator frequency that has given the EC-5 exceptional performance in soils (Kizito et.al, 2008, Bogena et. al, 2007). We recommend the 10HS sensor for mineral soil applications where soil heterogeneity is a concern. However, we continue to recommend the smaller EC-5 sensor for soilless substrate applications or applications where VWC measurements on smaller scales (e.g. near surface measurements, laboratory column studies, greenhouse applications) are desired.

2.2 Specifications

Range:

Apparent Dielectric Permittivity (ε_a): 1 (air) to 50
Soil Volumetric Water Content (VWC) : 0 to 0.57 m^3/m^3 (0 to 57%VWC)

Accuracy:

ε_a: ± 0.5 from ε_a of 10 to 50 (VWC)
VWC: With standard calibration equation, ±0.03 m^3/m^3 (± 3% VWC) typical in mineral soils that have solution electrical conductivity < 10 dS/m

Note: With soil specific calibration, ± 0.02 m^3/m^3 (± 2% VWC) is typical in any soil.

Resolution:

ε_a: 0.1 from ε_a of 1 to 30, 0.2 from ε_a of 30 to 50
VWC: 0.0008 m^3/m^3 0.08% VWC) in mineral soils from 0 to 0.50 m^3/m^3 (0 to 50% VWC)

Measurement Time: 10 ms (milliseconds)

Power Requirements: 3 VDC @ 12 mA to 15 VDC @ 15 mA

Output: 300 to 1,250 mV, independent of excitation voltage

Operating Temperature: 0 to 50 °C

Survival Temperature: -40 to 50 °C

Connector types: 3.5 mm stereo plug or stripped and tinned leads.

Cable length: 5 m standard; custom cable lengths up to 40 m available upon request

Data Logger Compatibility (non-exclusive):

- Decagon: Em50, Em50R, Em5b, ProCheck handheld reader.
- Campbell Scientific: CR10X, 21X, 23X, CR850, 1000, 3000, etc
- Other: Data acquisition systems capable of switched 3 to 15 V excitation and single ended voltage measurement at $\geq$ 12 bit resolution

3 Theory

The 10HS sensor measures the volumetric water content of the soil using a capacitance technique. Rapidly charging and discharging a positive and ground electrode (capacitor) in the soil generates an electromagnetic field whose charge time t is related to the capacitance (C) of the soil by Equation 1.

$$t = RC\ \ln\left[\frac{V - V_f}{V_i - V_f}\right] \tag{1}$$

where R is the series resistance, V is voltage at time t, V$_i$ is the starting voltage and V_f is the applied or supply voltage. Further, for a capacitor with a geometrical factor of F, the capacitance is related to the dielectric permittivity (ε) of the medium between the capacitor electrodes by

$$C = \varepsilon_0 \varepsilon F \tag{2}$$

where ε_0 is the permittivity of free space. Thus, the ε of the soil can be determined by measuring the change time t of a sensor buried in the soil. Consequently, as water has a dielectric permittivity that is much greater than soil minerals or air, the charge time t in the soil of Equation 1 can be correlated with soil volumetric water content.

4 Installing the Sensor

When selecting a site for installation, it is important to remember that the soil adjacent to the sensor surface has the strongest influence on the sensor reading and that the sensor measures the volumetric water content 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 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.

Also, do not install the sensor adjacent to large metal objects such as metal poles or stakes. This can attenuate the senors electromagnetic field and adversely affect readings. In addition, the 10HS 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 10HS has gaps between its prongs, it is also important to consider the particle size of the medium 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 sideways force is used when pushing them in.

4.1 Procedure

When installing the 10HS it is imperative to maximize contact between the sensor and soil. For most accurate results, the sensor should be inserted into undisturbed soil. There are two basic methods to accomplish a high quality installation.

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 10HS 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 10HS.

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 of the sensor cable in the process.

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 you have difficulty inserting the sensor, you may need to wet the soil.

This will obviously result in inaccurate VWC measurements until the water added during installing redistributes into the surrounding soil.

Orientation

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. Keep in mind that the sensor measures the average VWC along its length, so a vertical installation will integrate VWC over a 10 cm depth wile a horizontal orientation will measure VWC at a more discrete depth.

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.

5 Connecting Sensors

Decagon designed the 10HS sensor for use with our Em50 series data loggers, the Em5b, 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 10HS 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.

The 10HS 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). The 10HS is accurate with cable lengthes up to 40 m.

Connecting to an Em50/Em50R Logger

The 10HS to works well 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 10HS and set the measurement interval.

Connecting to ECH2O Utility

Please check your software version to ensure it will support the 10HS. 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

3.5 mm Stereo Plug Wiring

Figure 1: Stereo Connector

The following software support the 10HS sensor:

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

Connecting to a non-Decagon Logger

Customers may purchase 10HS 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.

Pigtail End Wiring

Figure 2: Pigtail End Wiring

Connect the wires to the data logger as Figure 2 shows, with the supply wire (white) connected to the excitation, the analog out wire (red) to a analog input, the bare ground wire to ground as illustrated below.

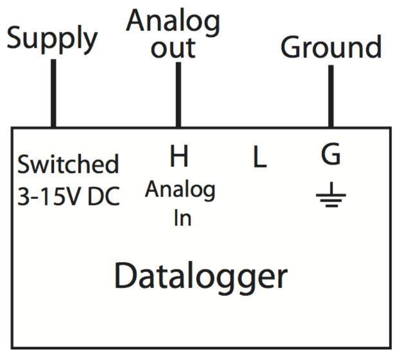

Figure 3: Pigtail End Wiring to Data Logger

Note: The acceptable range of excitation voltages is from 3 to 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 12 V port.

If your 10HS 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 Calibration

6.1 Dielectric calibration

The 10HS comes pre-calibrated to measure the dielectric permittivity of the soil with the accuracy stated in the specification section above.

With Decagon's Em50, Em50R, Em5B, and Pro Check readers, the following standard calibration function can be applied

$$\varepsilon_a = 7.449 \text{ x } 10^{-11} * \text{raw counts}^4 - 1.969 \text{ x } 10^{-7} * \text{raw counts}^3 + 1.890 \text{ x } 10^{-4} * \text{raw counts}^2 - 6.691 \text{ x } 10^{-2} * \text{raw counts} + 7.457 \quad (3)$$

With non-Decagon data acquisition equipment, the following calibration can be applied. Note the this calibration function is valid for any sensor excitation between 3 and 15 V DC.

$$\varepsilon_a = 2.589 \text{ x } 10^{-10} * mV^4 \text{ x } - 5.010 \text{ x } 10^{-7} * mV^3 + 3.523 \text{ x } 10^{-4} * mV^2 - 9.135 \text{ x } 10^{-2} * mV + 7.457 \quad (4)$$

6.2 Mineral Soil Calibration

For convenience, Decagon has also developed a standard calibration equation for mineral soils to be used with the 10HS. With this standard calibration equation and careful sensor installation, accuracy of better than ±3% VWC (0.03 m^3/m^3) is possible with most mineral soils. In these soils , it is generally not necessary to calibrate the 10HS for your particular soil type, and the standard mineral calibration below can be used. Em50, Em50R, Em5B and ProCheck:

$$VWC(m^3/m^3) = 1.17 \text{ x } 10^{-9} * \text{raw counts}^3 - 3.95 \text{ x } 10^{-6} * \text{raw counts}^2 + 4.90 \text{ x } 10^{-3} * \text{raw counts} - 1.9 \quad (5)$$

With non-Decagon data acqusition equipment, the following calibration can be applied. Note that this calibration function is valid for any sensor excitation between 3 and 15 V DC.

$$VWC(\mathrm{m}^3/\mathrm{m}^3) = 2.97\text{x}10^{-9} * mV^3 - 7.37 \text{ x } 10^{-6} * mV^2 + 6.69 \text{ x } 10^{-3} * mV - 1.92 \quad (6)$$

Due to the complexity of soils, the accuracy of the VWC measurement can be poor despite an accurate measurement for dielectric permittivity. Some examples of this are highly compacted soils, very low bulk density soils, soils with abnormally high organic matter content, and soils with high-dielectric mineral composition (e.g. TiO2 sands). Additionally, the accuracy of the 10HS may suffer in soils with very high electrical conductivity ($>$ 10 dS/m solution EC). In these soils, it may be necessary to calibrate the 10HS to your specific soil type. With a soil-specific calibration, the accuracy of the VWC measurements will be improved to 1 to 2% in any soil or other porous medium.

If you are interested in a soil-specific calibration for your 10HS, there are two options available. You can create your own sensor calibration by following the directions in our application note titled Calibrating ECH2O soil moisture probes from the Decagon website (http://www.decagon.com) and following the step-by-step instructions for calibrating your soil moisture sensors. Since some users do not have the time or equipment to conduct their own calibration, Decagon now offers a service providing soil specific calibrations to our customers.

This calibration service also applies to non-soil materials, such as compost, potting materials, etc. Contact Decagon for more information on this service (sales@decagon.com).

7 Sample Programs

You can use the following examples with data loggers from Campbell Scientific. The first program is for a CR1000 data logger, but can be easily adapted for other "CRBasic" type loggers. The second program is for a CR10X data logger, but can be easily adapted to other Edlog type loggers. The 10HS needs 3 to 15 V DC excitation, and therefore cannot be excited with the 2.5 V excitation port of many Campbell Scientific data loggers. We recommend that the switched 12 V or CAO port be used to excite the 10HS.

Cr Basic type data logger

```
"CR1000 Series Datalogger
'program to read one Decagon 10HS sensor
'
'wiring
'white - SW - 12
'red - SE CH1
'bare - gnd

Public tenHSmV, VWC

DataTable (Table1,1,-1)
DataInterval (0,60,Min,10)
    Average (1,VWC,FP2,False)

BeginProg
    Scan(10,Sec,0,0)
        SW12(1)
        Delay (0,10,mSec)
VoltSe (tenHSmV,1,mV2500,1,1,0,_60Hz,1.0,0)
SW12 (0)
VWC = $2.97e-9 * tenHSmV^3 - 7.37e-6 *
tenHSmV^2 + 6.69e-3 * tenHSmV - 1.92 'mineral soil calibra-
tion updated 8/09
CallTable Table1
NextScan
EndProg
```

Edlog type data logger

```
;{CR10X}
;
;program to read 10HS sensor with CR10X
;
;wiring:
;Jumper from C1 to SW 12V CTRL - C1 is used to turn on the
switched 12V port
;10HS white - excitation - SW 12V
;10HS red - Vout - SE CH1
;10HS bare - gnd - G or AG


*Table 1 Program
 01:10      Execution Interval (seconds)

;set C1 high to pull SW 12 port high
;
1: Do (P86)
 1: 41      Set Port 1 High

;delay program 10 ms and measure SE channel 1 in units of
volts
;
\: Excite-Delay (SE)(P4)
 1: 1      Reps
 2: 5      2500 mV Slow Range
 3: 1      SE Channel
 4: 1      Excite all reps w/Exchan 1
 5: 1      Delay (0.01 sec units)
 6: 0000      mV Excitation
 7:1      Loc [ ten_HS_V ]
 8:.001      Multiplier
 9:0.0      Offset

;turn off excitation
;
3:  Do (P86)
```

```
 1: 51      Set Port 1 Low

;apply calibration (updated 8/09)
;
4:  Polynomial (P55)
 1: 1      Reps
 2: 1      X Loc [ ten_HS_V ]
 3: 2      F(X) Loc [ VWC ]
 4: -1.92      C0
 5: 6.69      C1
 6: -7.37      C2
 7: 2.97      C3
 8: 0.0      C4
 9: 0.0      C5

5:  If time is (P92)
 1: 0000      Minutes (Seconds --) into a
 2: 60      Interval (same units as above)
 3: 10      Set Output Flag High (Flag 0)

6: Real Time (P77)^18390
 1: 1110      Year,Day,Hour/Minute (midnight = 0000)
7: Average (P71)^12836
 1:1      Reps
 2:2      Loc [ VWC ]


*Table 2 Program
 02: 0.0000      Execution Interval (seconds)


*Table 3 Subroutines

End Program
```

8 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:	10HS
Year of First Manufacture:	2008

This is to certify that the 10HS dielectric soil moisture sensor, 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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