

Methods for Calibrating Decagon 10-HS and EC-5 Soil Moisture Sensors for the Interactive Roaring Fork Observation Network (iRON)

E. C. Osenga
Aspen Global Change Institute
Basalt, Colorado

Abstract:

The Aspen Global Change Institute (AGCI) operates and manages a network of long term monitoring stations in the Roaring Fork Valley of Colorado. In addition to basic weather sensors, each station is equipped with a set of EC-5 and 10-HS Decagon dielectric soil moisture sensors operated by either an RX-3000 Onset logger box or a Datagarrison satellite logger box. The EC-5 sensors are deployed at a 5cm depth in the soil, and the 10-HS sensors at 20cm, and 50cm depths. In order to assess accuracy of readings by the soil moisture sensors, in-lab calibration tests were performed. Readings from the sensors were generally found to be accurate within $0.02 \text{ m}^3/\text{m}^3$ for the EC-5 sensors and within $.05 \text{ m}^3/\text{m}^3$ for 10-HS sensors, a result consistent with manufacturer standards.

1.0 Introduction

The Aspen Global Change Institute (AGCI) manages a community-driven long-term monitoring network in the Southern Rockies of Colorado. The network, collectively called the interactive Roaring Fork Observation Network (iRON), consists of 9 stations spread across the elevational span of the Roaring Fork Watershed. Stations were installed between 2012 and 2017. Instrumentation measures soil moisture at 5cm, 20cm, and 50cm, as well as meteorological variables. For all stations, Decagon EC-5 dielectric soil moisture sensors are used at the 5cm depths and Decagon 10-HS soil moisture sensors are used at 20cm, 50cm, and 100cm depths. (Only one station has a 100cm depth measurement.) Soil moisture probes are calibrated prior to shipment by the manufacturer. However, due to variations in soil texture and mineral composition, Decagon recommends that additional calibration be performed for sensors using soil samples collected from the exact locations where the sensors will be installed (Cobos & Chambers, 2011).

The Roaring Fork Watershed, across which the iRON is distributed, is comprised of a $3,758 \text{ km}^2$ area, and soil types are heterogenous across the landscape. In order to improve accuracy of soil moisture readings at each station, soil-specific calibrations were conducted for soil collected from each station site. Calibrations were conducted using a variation of the methods outlined by Cobos and Chambers (2011). Results were comparable to the manufacturer standard (Cobos & Chambers, 2011) and consistent with values found in other in-lab tests (Kizito et al., 2008), an accuracy of ± 0.01 - 0.02 for EC-5 Decagon dielectric sensors and ± 0.03 - 0.05 for 10-HS Decagon dielectric sensors.

2. 0 Methods

The initial approach for sensor calibration for the Decagon dielectric EC-5 and 10-HS sensors followed a variation of the gravimetric methods outlined in methods recommendations generated by Decagon (sensor manufacturer) and Onset (logger manufacturer) (Campbell, n.d.; Cobos & Chambers, 2011).

2.1 Initial Calibration Methods

Prior to installation of each iRON monitoring station (taking place between 2012 and 2016), approximately 1 gallon of soil was collected from each site. At stations where soil texture changed visibly at different depths, separate 1 gallon soil samples were collected for each differently textured soil at that site. Soils were then brought to the lab and were spread to dry in large, shallow tubs. Soil was allowed to air dry for a period of several weeks or until soil moisture probes showed a reading of near or below zero, indicating that the soil was dry.

Once the soil had been dried, readings at a variety of soil moisture levels were taken using the logger box¹ and EC-5 and 10HS sensors designated for use at the site from which the soil had been collected. All stations use onset cellular logger boxes¹ with the exception of the Independence Pass station (Site 9), which uses a Datagarrison satellite² capable logger box. Regardless of logger box type, methods for conducting calibration were consistent.

After drying was complete, the soils were sifted by hand to remove root matter, sticks, and all rocks over ~1cm in size. The remaining sifted soil was then measured out into a large tub to determine the exact volume of soil being used for calibration. In most instances, the volume was around 2,360mL of soil. A subsample of this soil was then tightly packed into a large glass or plastic jar, so better simulated in-situ soil conditions—where soil is more compressed. A sensor was then inserted into the soil and remained inserted for several minutes, and the sensor's soil moisture reading was recorded. The jars allowed at least 3.8cm distance of soil between any part of the sensor and the edge of the jar, and sensors were fully inserted until soil covered the rubber portion of the sensor. The sensor was then removed from the jar, and water was added into the soil sample at a volume of 10% of the soil sample's volume. The soil was thoroughly mixed to incorporate the water throughout and another soil moisture reading was taken using the above methods. Water continued to be added at 10% volume intervals until the soil reached saturation, as determined by visual assessment of the soil's incapacity to take up further water and a plateauing of soil moisture values in readings by the dielectric soil moisture sensors.

¹ All logger boxes installed prior to 2015 were Onset U30 cellular capable logger boxes. In summer of 2015, due to a change from 2G to 3G cellular service in the area, all Onset U30 boxes had to be replaced Onset RX3000 cellular capable logger boxes. At the time of replacement, an in-lab test was used to compare dielectric probe readings between the U30 and RX3000 boxes and found consistency in EC-5 readings but a discrepancy in 10-HS readings across the U30 and RX3000 boxes. Onset technicians found a post data-collection calculation to be the source of the discrepancy, and the error has since been corrected. All calibrations conducted with RX3000 boxes prior to the correction have been discarded, and current calibrations use data from the corrected RX3000 readings.

² At time of purchase, an in-lab test was conducted comparing 10-HS and EC-5 soil moisture sensor readings from the Datagarrison and U30 logger boxes. Readings were found to be comparable.

10-HS or EC-5 readings were then graphed against the volume of soil that had been added to the sample for that reading (e.g. 0%, 5%, 10%), and a best fit line was used to generate an equation for equipment calibration.

2.2 Calibration Revision 2018

In order to confirm calibration results, calibration was re-conducted for several iRON sites in Spring of 2018, following the method described above, with the following alterations:

- (1) Water was added back to the dry soil at 5% rather than 10% intervals to yield a greater number of data points to use in generating a calibration equation.
- (2) To allow a greater portion of the soil to be used in taking a sensor reading, a ½ gallon milk carton was used to hold the compacted soil during sensor insertion.
- (3) Because all soil moisture stations had already been installed in-situ by this time, the equipment used calibrations experiments consisted of spare Onset U30 logger boxes and spare Decagon 10-HS and EC-5 soil moisture sensors available in the lab. Prior experiments had already confirmed that Onset U-30, Onset RX3000, and Datagarrison logger boxes yielded comparable readings from the soil moisture sensors.

As before, 10-HS or EC-5 readings were then graphed against the volume of soil that had been added to the sample for that reading (e.g. 0%, 5%, 10%), and a best fit line was used to generate an equation for equipment calibration. Recalibrations have not yet been completed for all sites. A complete set of calibrations using a smaller interval of water additions are anticipated to be available by September of 2018.

3.0 Results

Results from these calibration methods revealed an accuracy for the EC-5 sensor readings of +/- .01-0.02m³/m³ and 10-HS accuracy of +/- .05-.07m³/m³ at dry to moderate soil moisture conditions (Table 1)³. At soil conditions nearing saturation, the EC-5 sensors became less accurate.

³ The exception to these results is for the soil from Glassier Ranch (Site 3), where shifted soil moisture values by .08-.12m³/m³ from EC-5 soil moisture sensor readings. Because separate tests of this soil type yielded similar results, it is assumed that the results is not an error but rather an actual representation of conditions and is likely a result of mineral and organic composition of this soil.

Site ID	Site Name	Soil Type	2018-revised calibration	R ² Fit (EC-5, 10HS)	EC-5 Calibration	10-HS Calibration (20cm depth)	10-HS Calibration (50cm depth)
1	Sky Mtn	Loam	Yes	0.998, 0.995	$y = 1.1619x - 0.0141$	$y = 0.9775x - 0.0099$	$y = 0.9775x - 0.0099$
2	Smuggler Mtn	Loam	Yes	0.94, 0.98	$y = 0.9842x + 0.0017$	$y = 0.8273x - 0.0053$	$y = 0.8273x - 0.0053$
3	Glassier Ranch	Sandy Loam	No	0.983, 0.975	$y = 1.284x + 0.0613$	$y = 1.4725x - 0.0533$	$y = 1.4725x - 0.0533$
4	Brush Creek	Clay	Yes	0.994, 0.996	$y = 0.9829x - 0.0001$	$y = 0.8341x - 0.004$	$y = 0.8341x - 0.004$
5	Glenwood Springs	Clay Loam	no	0.949, 0.975	$y = 1.0575x + 0.0106$	$y = 0.8639x + 0.0214$	$y = 0.8639x + 0.0214$
6	Northstar Aspen Grove	Sandy Loam	Yes	0.96, 0.982	$y = 0.9599x - 0.0082$	$y = 0.8421x - 0.0198$	$y = 0.8421x - 0.0198$
7	Northstar Transition Zone	Sandy Loam	No	0.961, 0.909, 0.985	$y = 1.0582x + 0.0039$	$y = 0.9086x + 0.0616$	$y = 0.7748x + 0.0167$
8	Spring Valley	Clay	No	0.912, 0.933	$y = 1.1359x - 0.0326$	$y = 0.9577x - 0.0257$	$y = 0.9577x - 0.0257$
9	Independence Pass	Sandy Loam	Yes	0.998, 0.998	$y = 0.9934x + 0.00002$	$y = 0.8617x - 0.0079$	$y = 0.8617x - 0.0079$

Table 1. This table shows soil type and calibration equation results for each station in the iRON

4.0 Conclusion

In comparison to in-lab tests carried out by Campbell, Cobos and Chambers, and Kizito, the methods used to calibrate the iRON's soil moisture sensors appeared to yield comparable results. Adding back water at intervals of 5% soil volume tended to yield results with a better r^2 fit for relationships between actual moisture and sensor readings than did adding water in 10% intervals of total soil volume. Moving forward, it is intended that this approach will be applied to each soil type collected from all 9 iRON stations.

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References:

- Campbell, C. S. (n.d.). *Calibrating ECH2O Soil Moisture Probes*. Retrieved from www.onsetcomp.com
- Cobos, D. R., & Chambers, C. (2011). *Calibrating ECH2O Soil Moisture Sensors*.
- Kizito, F., Campbell, C. S., Campbell, G. S., Cobos, D. R., Teare, B. L., Carter, B., & Hopmans, J. W. (2008). Frequency, electrical conductivity and temperature analysis of a low-cost capacitance soil moisture sensor. *Journal of Hydrology*, 352(3–4), 367–378.
<https://doi.org/10.1016/j.jhydrol.2008.01.021>