Waveform Digitizing Time Domain Reflectometers

Technical Performance Data

TDR-315H Soil Moisture Sensor

Features

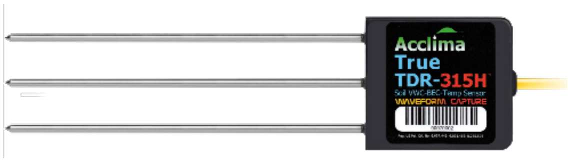
- True Waveform Digitizing TDR: 5ps Resolution Measures Water Content up to 1.00 m^3/m^3
- Reads Soil Bulk EC: 0 to 2000 μS/cm
- VWC Readings not affected by Bulk EC (under 1.8 dS/m for this low power model)
- VWC Readings not affected by Compaction
- Soil Specific Calibration not required
- Accurate Soil Temp Measurements: <±0.25°C
- Supports Time Domain Waveform Download
- Ultra-Fast Incident Wave Rise Time: 150ps
- Fast Measurement Response: typ. <0.25 sec
- Supports Long Battery Life: .09 J per Reading
- Low Sleep Current: < 10 μA
- SDI-12 Interface

Applications

- In-Situ Soil Water Monitoring for Agriculture
- High Credibility Data for Cloud-Based Analysis
- Gold Standard VWC Reference
- Replacement for Neutron Probes
- Portable Measurements using Acclima Reader
- Laboratory and Field Research Instrumentation

Description

The TDR315H is a true Time Domain Reflectometer designed to provide highly accurate Volumetric Water Content Measurements in soils and other porous media. It incorporates the same basic TDR components found in console-based TDR instruments costing 20 times more – housed inside the small enclosure that also supports the 15 cm waveguide. The patented TDR function is coupled directly to the waveguide, thus



eliminating the coax cable associated with conventional TDR devices. The absence of the coax cable provides the

TDR315H with higher bandwidth waveform data thus improving its resolution and sensitivity over expensive conventional TDRs.

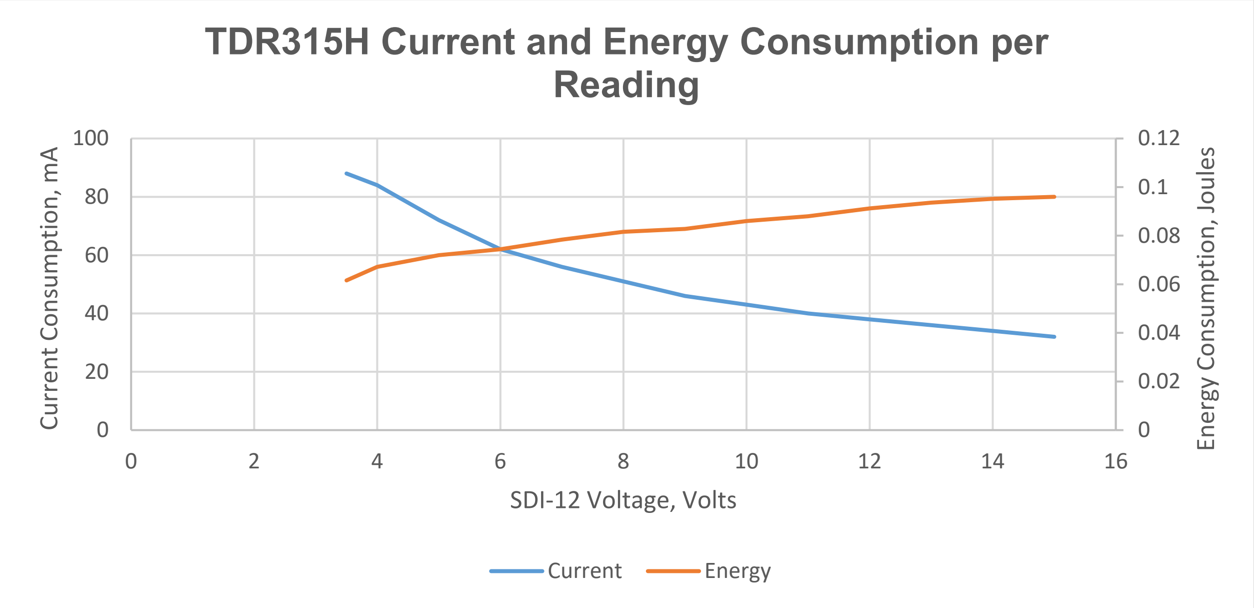
Time Domain technology – implemented properly – provides superior water content sensing over other electronic sensors because of its insensitivity to soil electrical conductivity. This insensitivity occurs because only the temporal events of the waveform are analyzed. Waveform amplitude, which is highly affected by soil EC, is effectively eliminated in the determination water content and permittivity.

Table of Contents

Electrical Characteristics and Limits

SDI-12 Voltage		**Minimum**	**Maximum**	**Units**
Red to White Wires	Warranty Limits	-15	+15	Volts
Red to White Wires	Operating Limits	5	+15	Volts
Data Line Voltage				
Blue to White Wires	Warranty Limits	-12	+12	Volts
Blue to White Wires	Operating Limits	5 volt logic SDI-12 spec Ver. 1.4	5 volt logic SDI-12 spec. Ver. 1.4	
Miss-Wiring Tolerance				
Blue to Red Wires	Warranty Limits	-12	+12	Volts
Sleep Current			10	µA
1 Year Sleep Energy	SDI Bus = 12v		3784	Joules
Read Time Duration		0.1	0.4	sec

Current and Energy Consumption



A good quality 18650 Li-Ion cell stores about 40,000 Joules. Allowing for sleep current it could power a TDR315H for more than 200,000 readings. At 100 readings per day that is about 5 years. This does not take into consideration the energy consumed by the data recorder and other devices drawing current from the SDI-12 bus.

Theory of Operation

Two remarkable physical occurrences lay the foundation for accurate determination of water content in various porous materials.

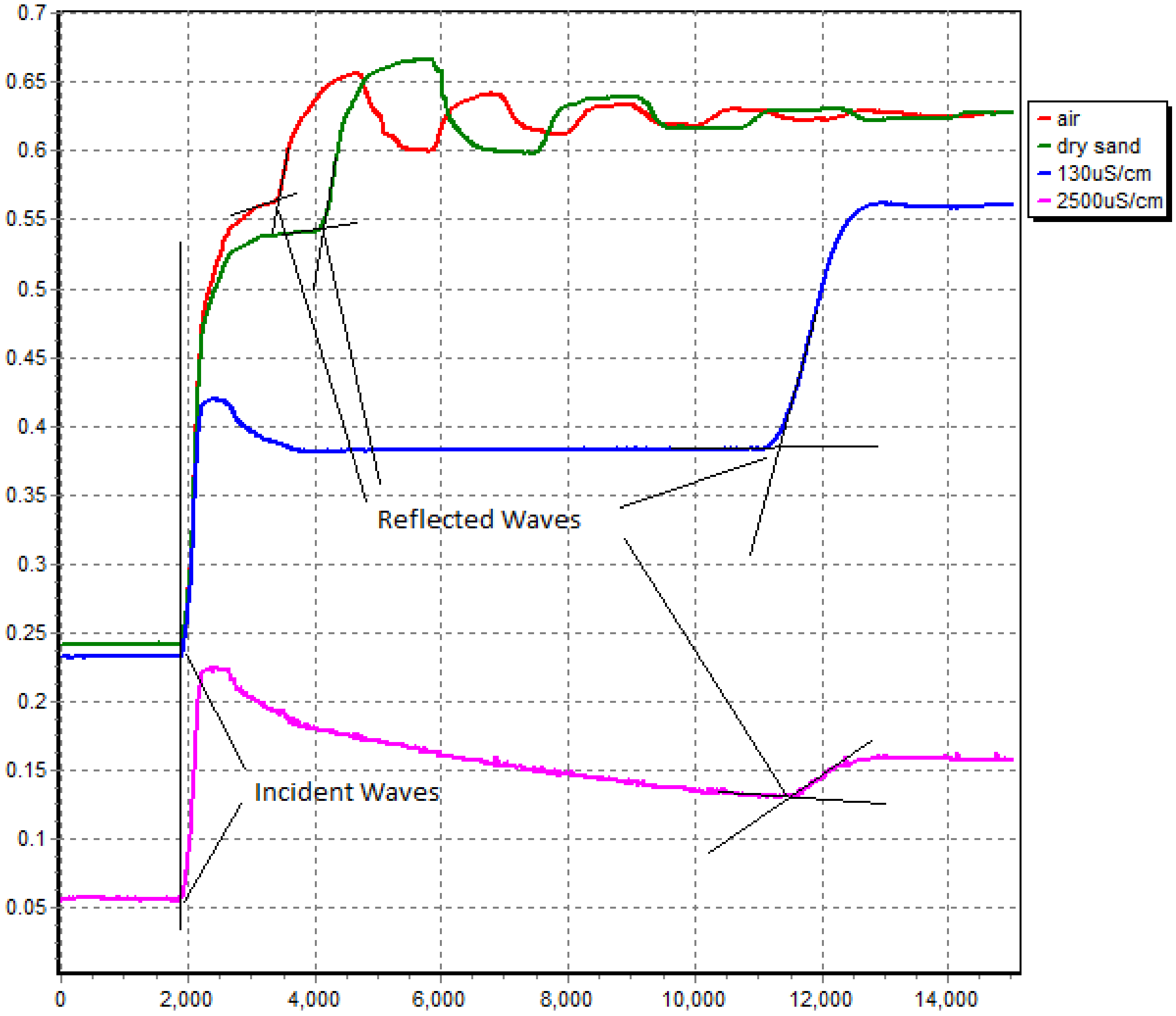
Permittivity – formerly dielectric constant – is a property of all matter and of free space itself. Permittivity is the ratio of stored charge to electric field in any geometry where an electric potential difference is present. Its value is a function of whatever material co-occupies the space where an electric gradient exists. Most natural materials have permittivity values in the range of 1 to about 4 times the permittivity value of free space. A remarkable exception is water which at room temperature has 80 times the permittivity of free space. The permittivity of any porous medium containing water is dominated by the contribution of the permittivity of the water. If the material permittivity can be measured accurately then the water content can be accurately derived.

One method of measuring the permittivity of a medium is based on using Gauss' Law. Two electrodes apply an electric field – either fixed or alternating – to the medium and the resultant movement of charge is measured. This is done through a capacitance measurement, a frequency measurement or an impedance measurement. Water content sensors based on one of these methods are called 'capacitive sensors' or 'Gaussian sensors'. Any ions in the medium disrupt the accurate relationship between fields and charge movement and cause significant errors in the measurement of permittivity. Capacitive sensors thus are error prone in electrically conductive media.

The other remarkable physical occurrence is that permittivity governs the rate at which an electromagnetic wave is propagated. The propagation equation,

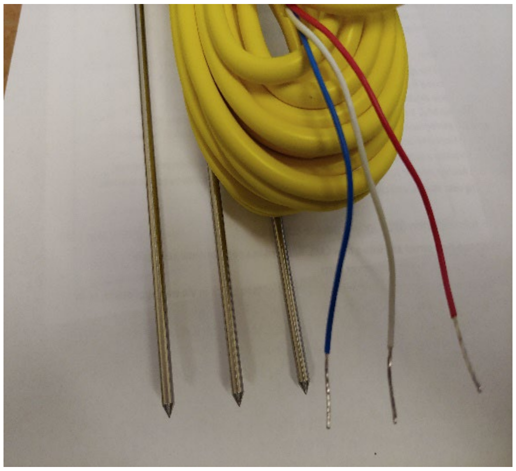
$$c^2 = 1/\mu\boldsymbol{\varepsilon}$$

states that the speed of propagation c of an electromagnetic wave is determined by two physical constants – permittivity ($\boldsymbol{\varepsilon}$) and permeability (μ). If the propagation speed can be measured accurately then permittivity can be calculated with no errors caused by medium electrical conductivity. This method of measuring permittivity is based in the time domain and requires accurate temporal measurements of waveform features with measurement accuracies in the pico-second range.



The waveforms above represent readings in air, dry sand, tap water and salted water. On the left at 1900 ps a fast-rising incident wave is launched. This propagates through the medium to the distal end of the 15 cm waveguide where it is reflected back to the point of origin. For air the reported round trip propagation time is 1000ps. The reading in dry sand it is 1495 ps. For distilled water it is 8945 ps and for the salted water it is 8965 ps. Note the small 20ps difference between the distilled water reading and the salted water reading. The Electrical Conductivity of the salted water is 2500 uS/cm. Even though the waveform in the salted solution is severely attenuated to 20% of tap water value it yields a propagation time that is only 2 tenths of a percent in error. This shows the dramatic advantage of time-domain-based sensing over Gaussian-based sensing, which is influenced by waveform amplitude.

Wiring Description



RED = SDI-12 POWER 5 to 15 volts
WHITE = COMMON
BLUE = SDI-12 DATA 5-volt logic

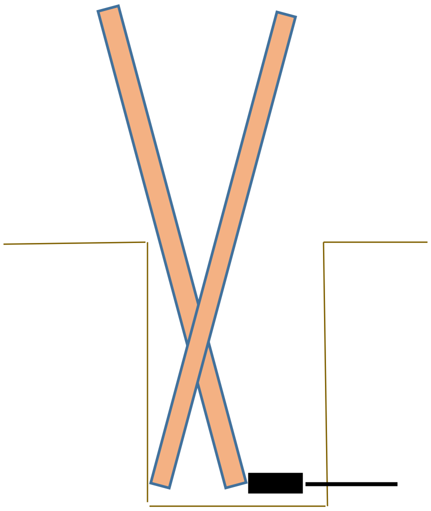
Installation Tips

The TDR315H can be installed either in a horizontal alignment or a vertical alignment with the waveguide pointing downward. In either case it is important to ensure that the soil is compacted well around the waveguide so that no air pockets exist near the rods. It is also important to use the supplied waveguide spacing tool when starting the insertion of the waveguide into the soil. If the rods are not parallel at the beginning of the installation, they will splay outward or inward as they are inserted and cause errors in the conductivity measurements.

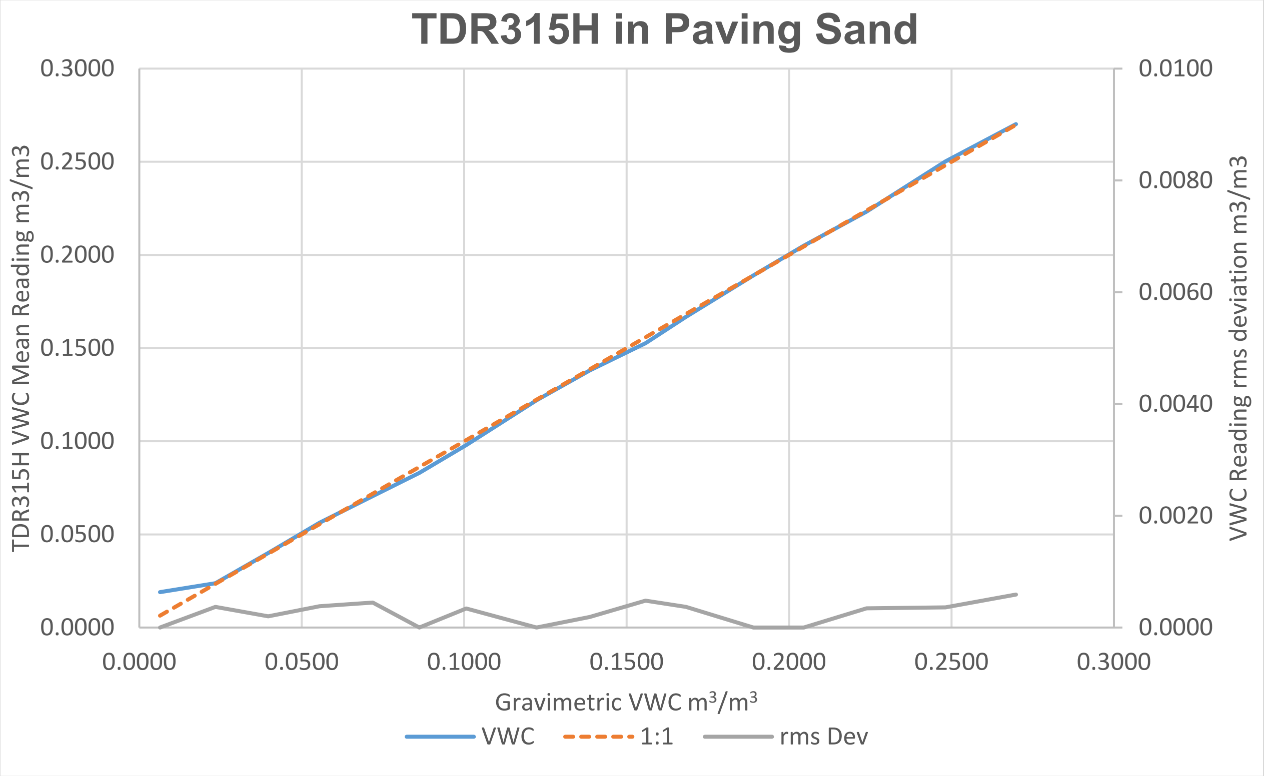
In vertical installations a hole can be dug that is large enough in diameter to allow getting an arm down the hole to use the alignment tool during the start of the insertion. After the insertion the hole must be filled and compacted in layers so as to avoid creating a preferential percolation location for surface water.

For horizontal installations a trench can be dug and the sensor can be laid in the bottom of the trench where soil can be compacted around it. Be sure to compact the soil between the waveguide electrodes. Refill and compact the trench in layers so as to avoid the creation of a preferential percolation site for surface water.

Horizontal installation into undisturbed soil can be achieved by inserting the waveguide into the sidewall of the trench as shown below. A wooden scissor can be fabricated to assist pushing the waveguide into the sidewall after assuring that the rods are parallel.



Vwc Reporting in Paving Sand



In the chart above and following the TDR315H-reported volumetric water content is displayed vs. the gravimetrically measured readings. 30 readings were taken at each point with the points separated at intervals of about 2 percentage points in water content. The mean of the 30 readings is displayed. Also the standard deviation of the readings around the mean is displayed. Note that for this soil the standard deviation never exceeded 0.1%. The absolute error of all of the readings was less than ±1% except for the first reading where the permittivity of the sand appears to overwhelm the small contribution from the water.

VWC Reporting in Norfolk Soil (South Carolina fine sand and silt soil)

Figure NF1 shows the reported vs measured VWC for Norfolk Soil contributed by Dr. Ken Stone. This graph also shows the standard deviation and the maximum and minimum values reported in the 30 readings at each point. The error in the readings is shown in Figure NF2 and is below 1% except for the first (dry) reading which is about 1.4% in error. Associated TDR waveforms are shown in Figure NF3. Figure NF4 shows the reported electrical conductivity of the soil vs water content.

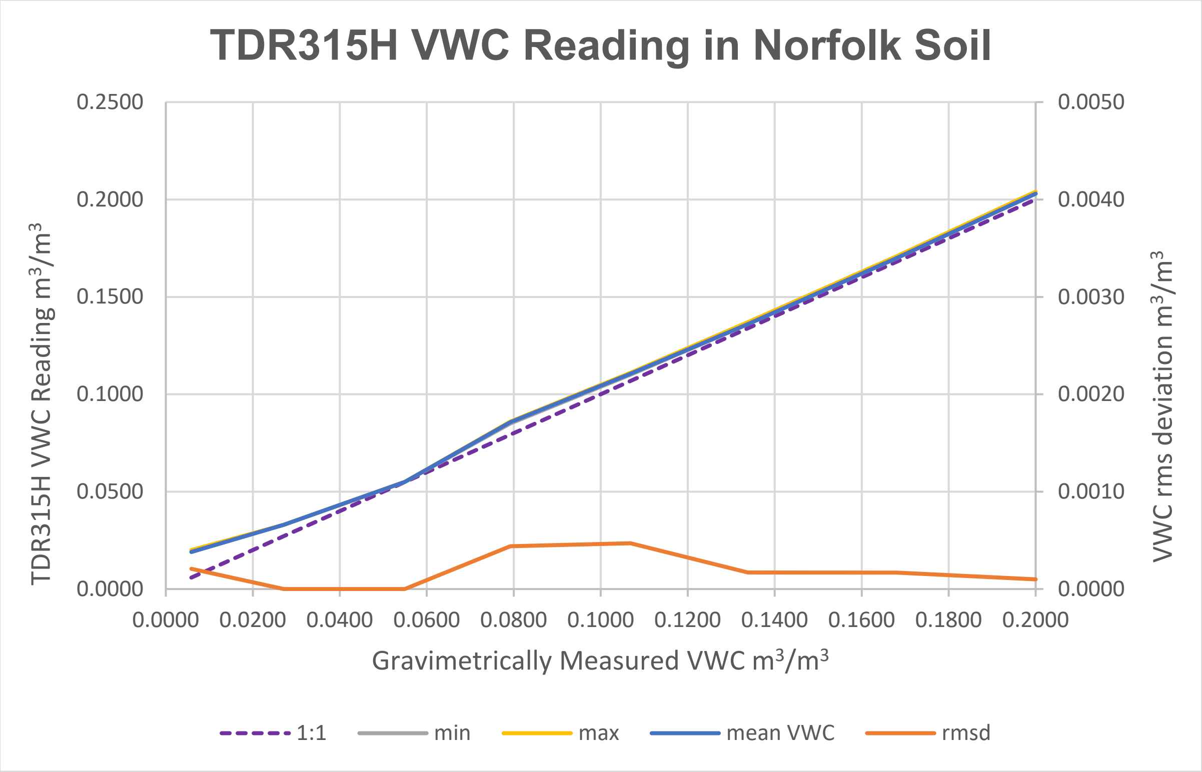


Figure NF1

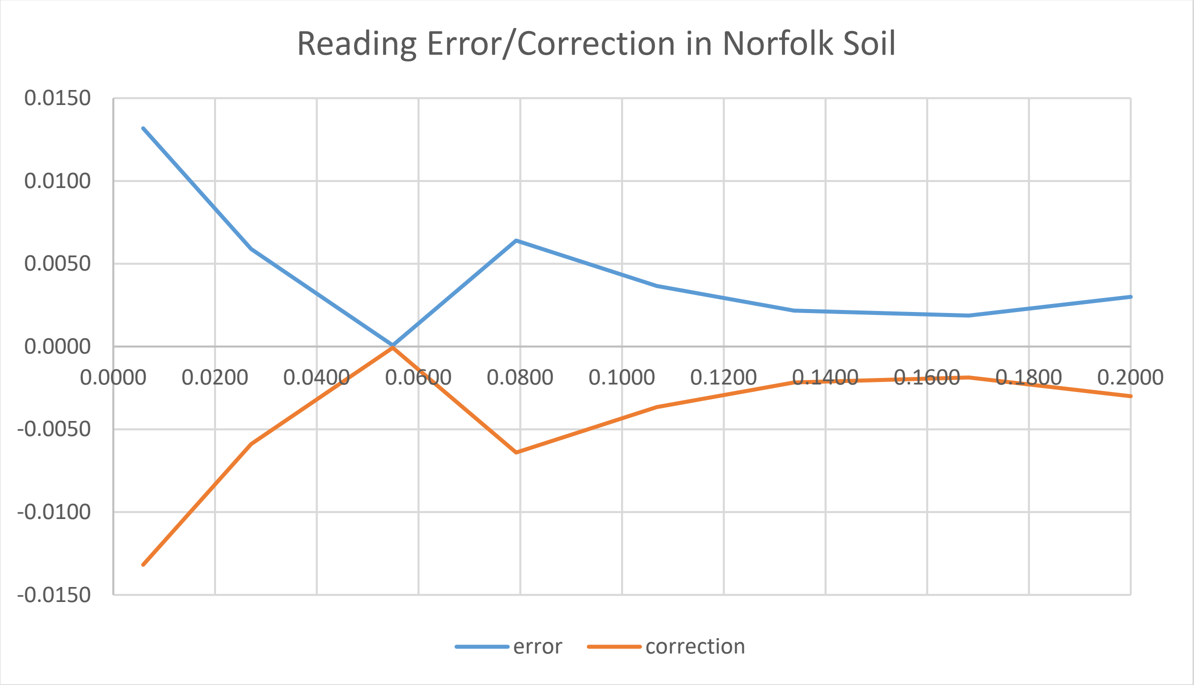


Figure NF2

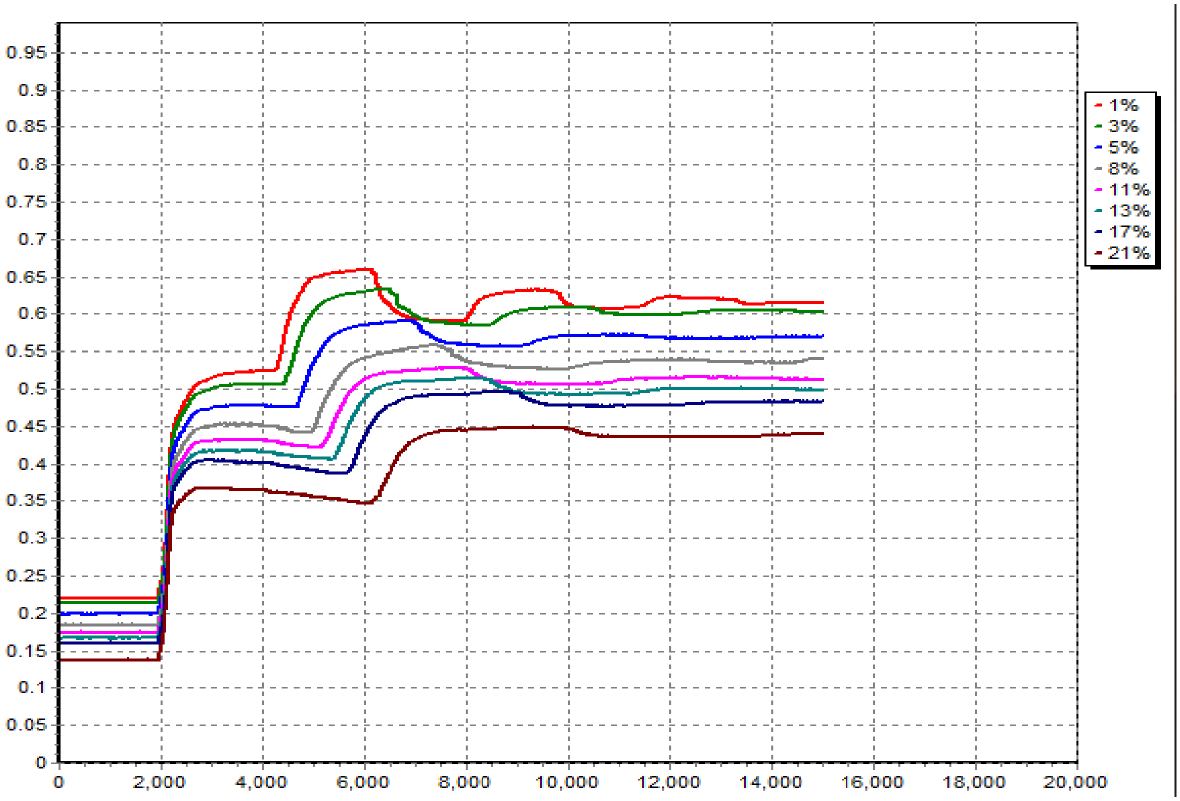


Figure NF3

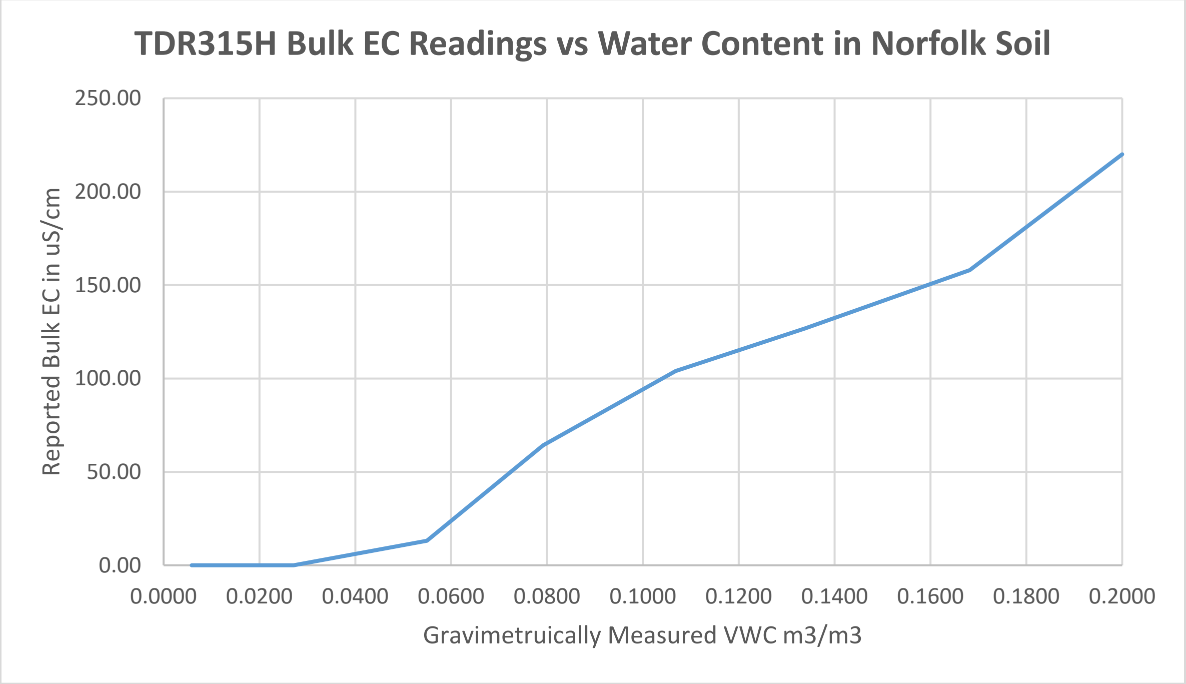


Figure NF4

VWC Reporting in Portneuf Soil (Idaho potato loam)

Figures PN1 through PN3 show the response of the TDR315H in Portneuf soil from Kimberly, Idaho. As shown in Figure PN2 the reading error gets up to little over 1% in the mid-range. The rms deviation in the readings is below 0.1% everywhere.

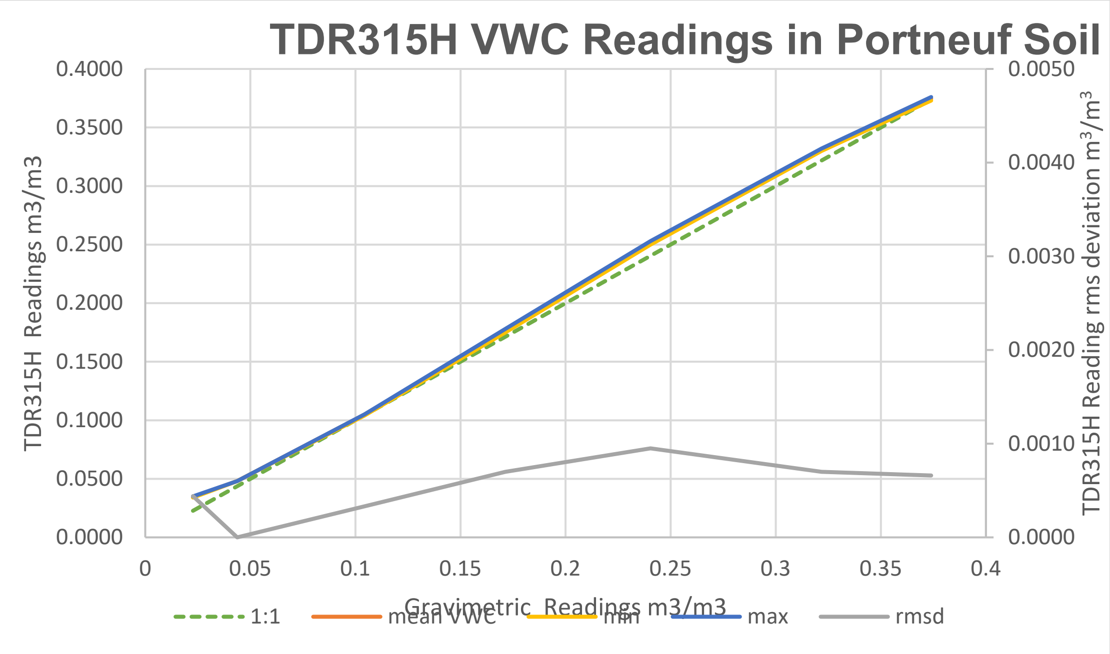


Figure PN1

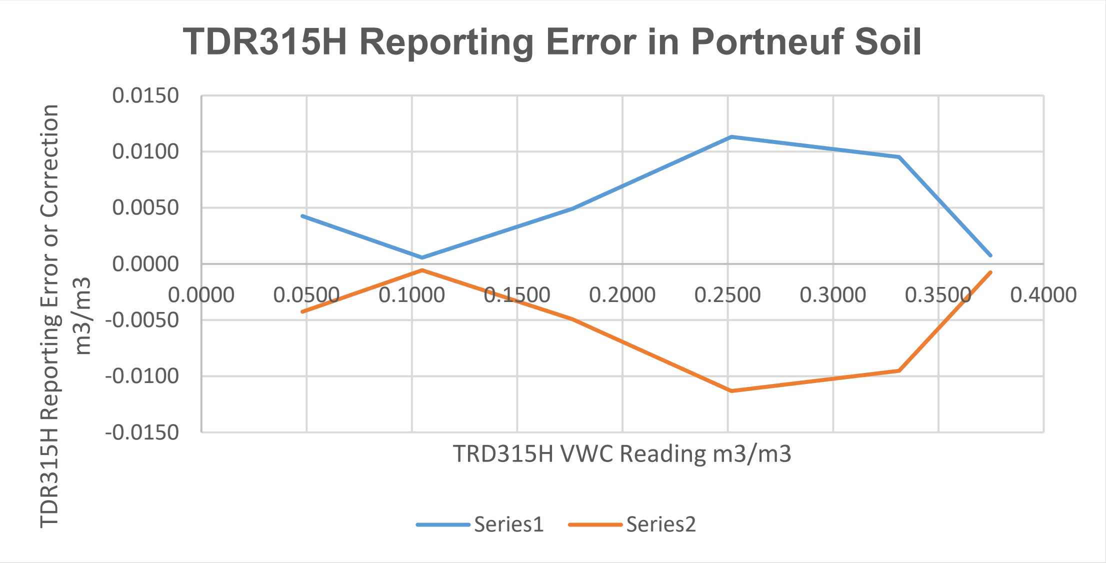


Figure PN2

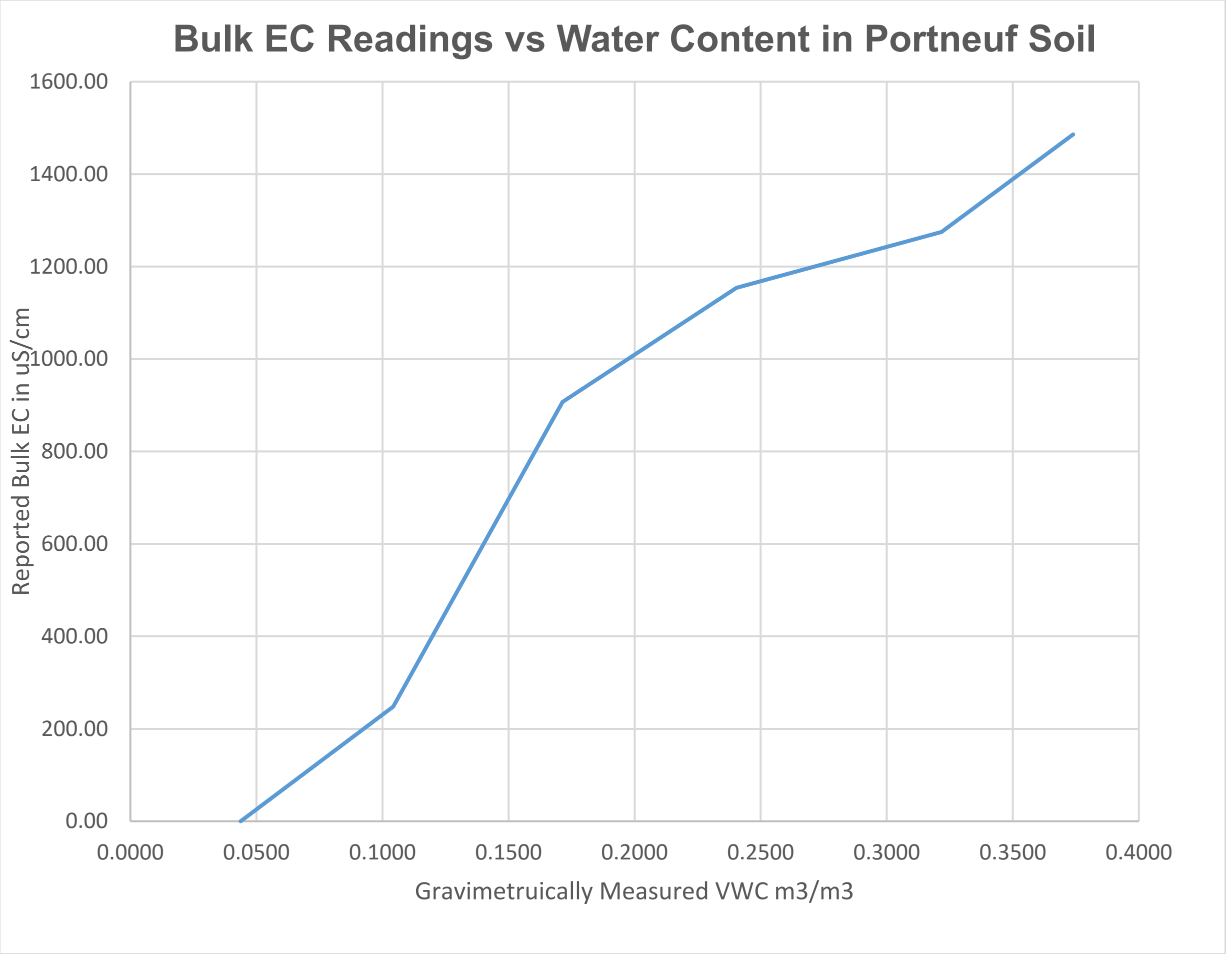


Figure PN3

VWC Reporting in Pullman Soil (Texas Panhandle 80% Clay and 20% Silt)

Pullman Soil was contributed by Dr. Robert Schwartz from Bushland, TX. Measurements in this soil were accurate to within about 1.4% out to 0.42 m3/m3 water content. Note that the rms error increases with water content due to the increasing EC with water content. Measurements were not taken beyond 0.42 m3.m3 because of the stickiness of the soil and the inability to homogenously mix test samples that did not contain large inclusions of air.

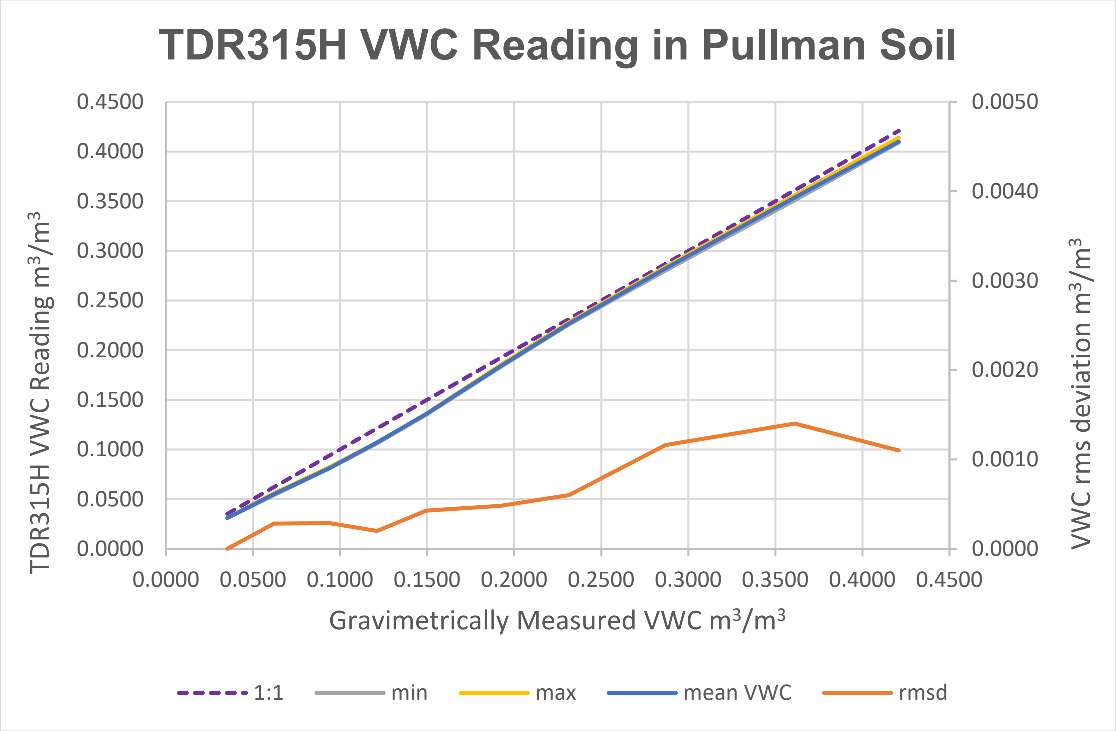


Figure PL1 - Pullman Soil Sensor Readings vs Gravimetric

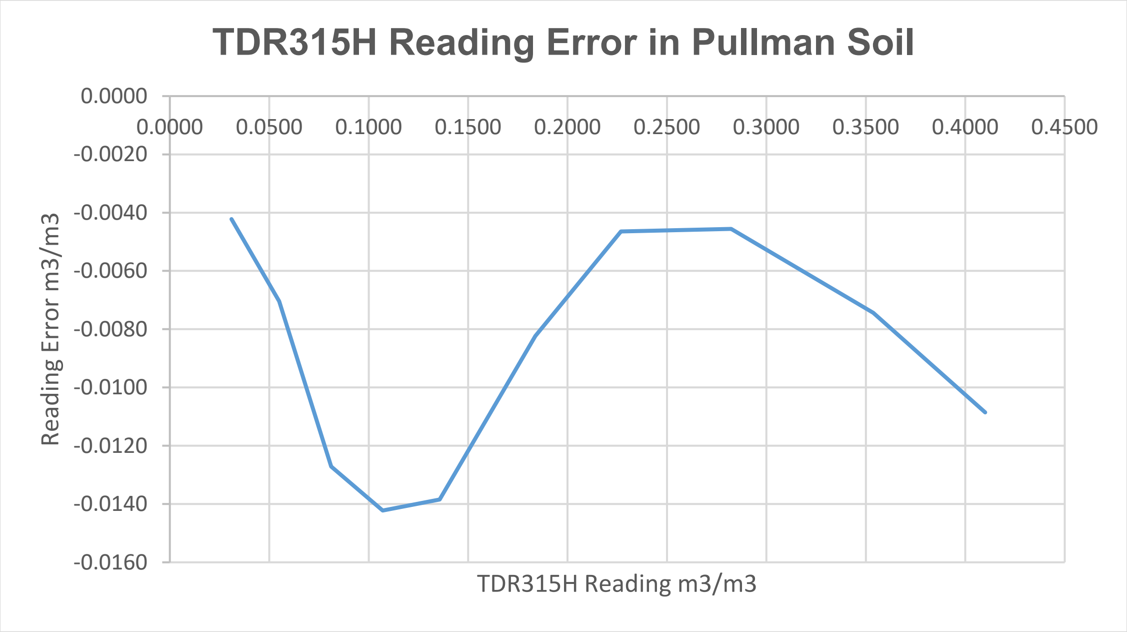


Figure PL2 - Error in TDR315H readings in Pullman Soil

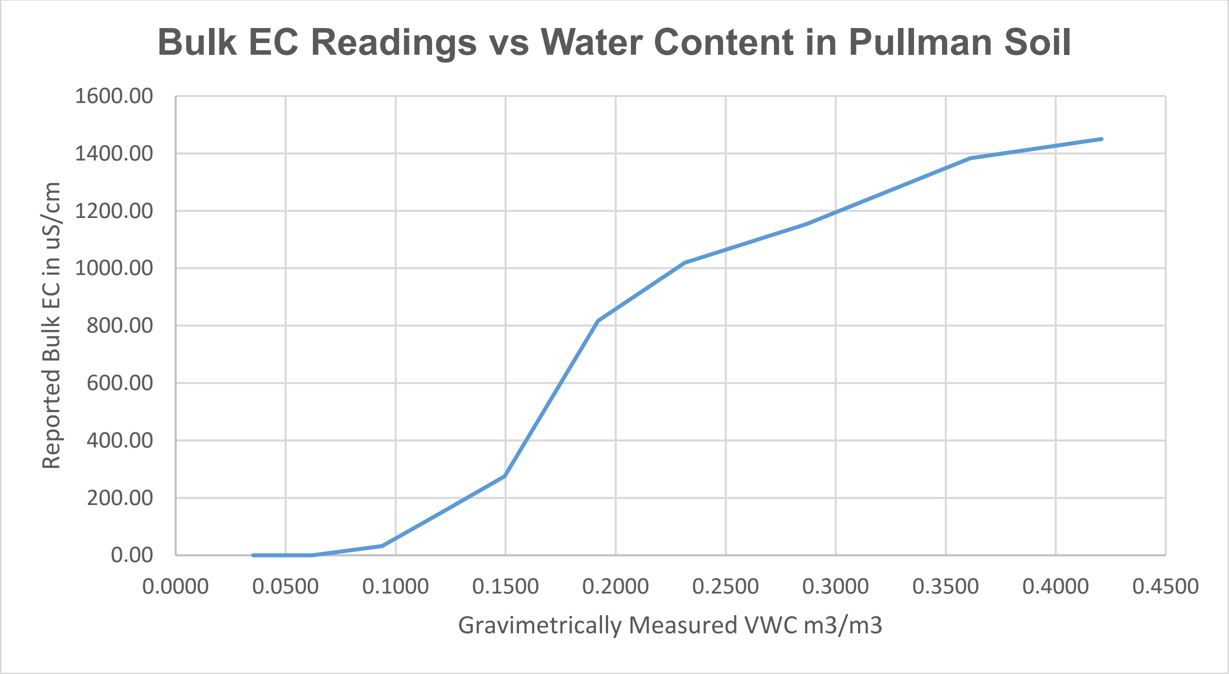


Figure PL3 - Reported EC in Pullman Soil vs Water Content

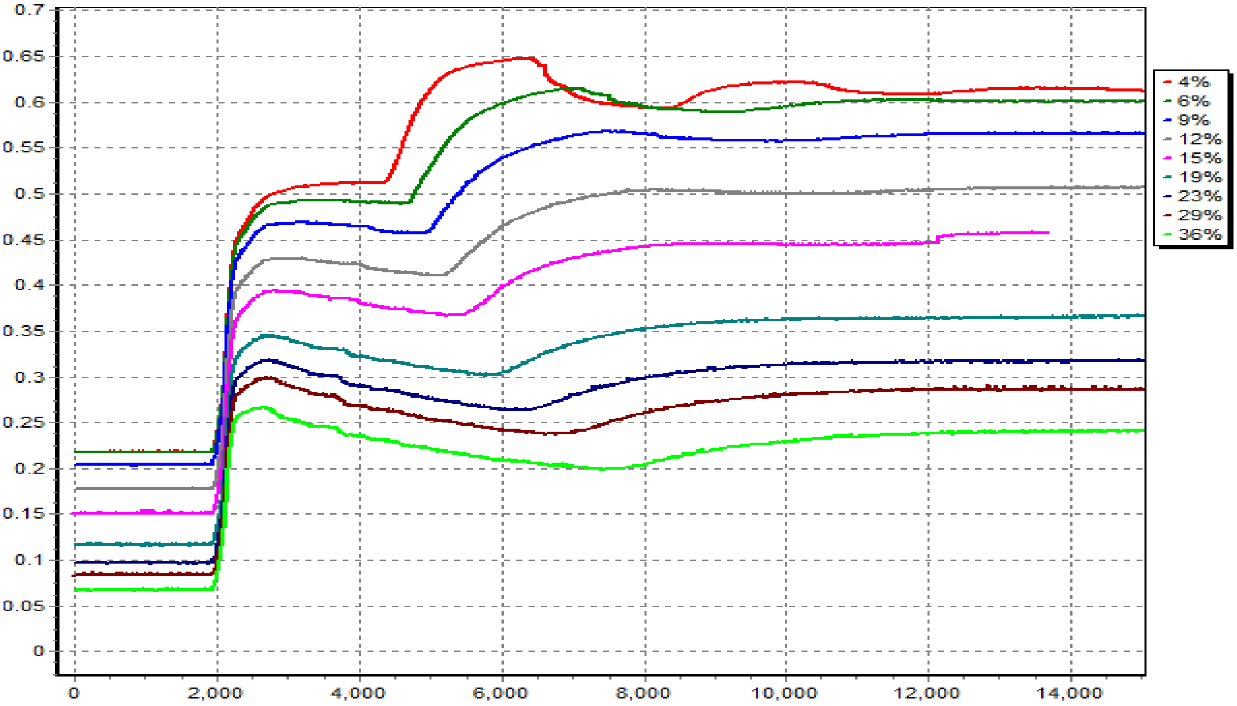


Figure PL3 - Waveforms in Pullman Soil

VWC Reporting in Coconut Coir

Figures CC1 through CC4 show responses from Coconut Coir. As can be seen in Figure CC1 the VWC reporting was underestimated by about 2 percent FS for most of the range of water content. The dry material also showed an underestimation of 2%. This is expected since the material has no mineral content and its relative permittivity when dry is close to 1. The reading error is shown in Figure CC2 and can be accurately corrected using the correction equation shown on the graph.

This material has a relatively high salt content, likely from the environment where is was processed and packaged. Hence the rms error in the readings increase with increasing water content. Also the waveforms show severe attenuation at higher VWC levels. The EC vs water content is displayed in Figure CC3. Waveform attenuation with increasing water content can be seen in Figure CC4.

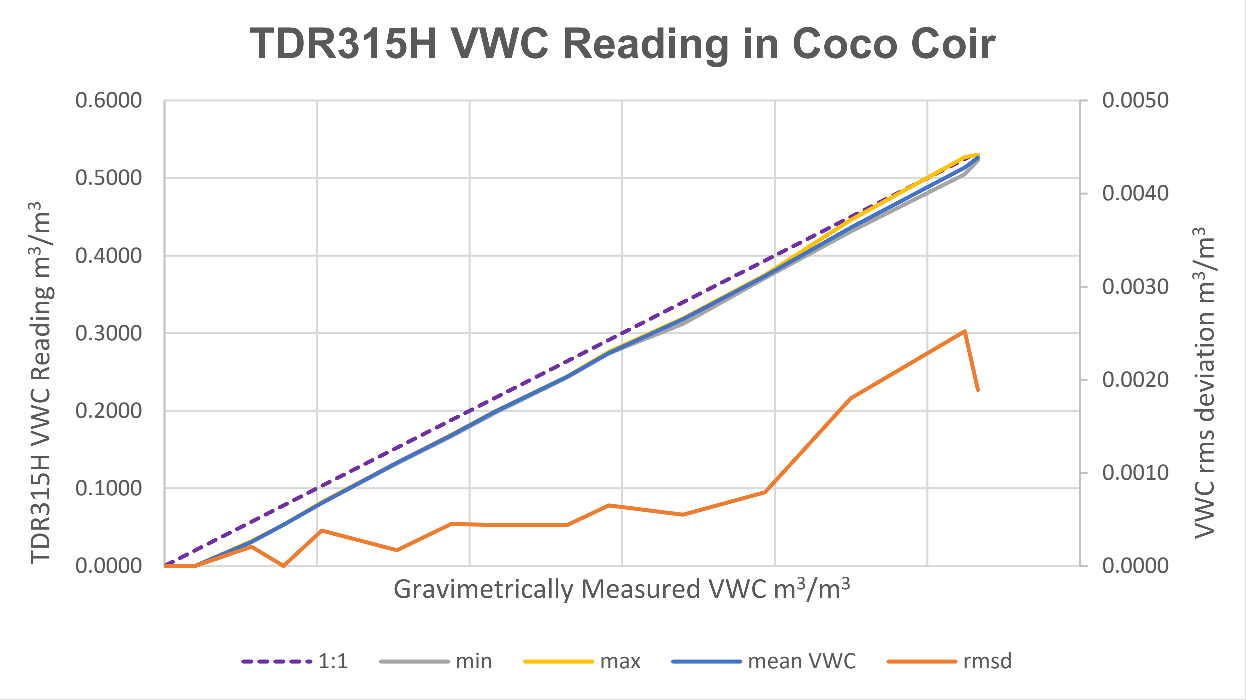


Figure CC1

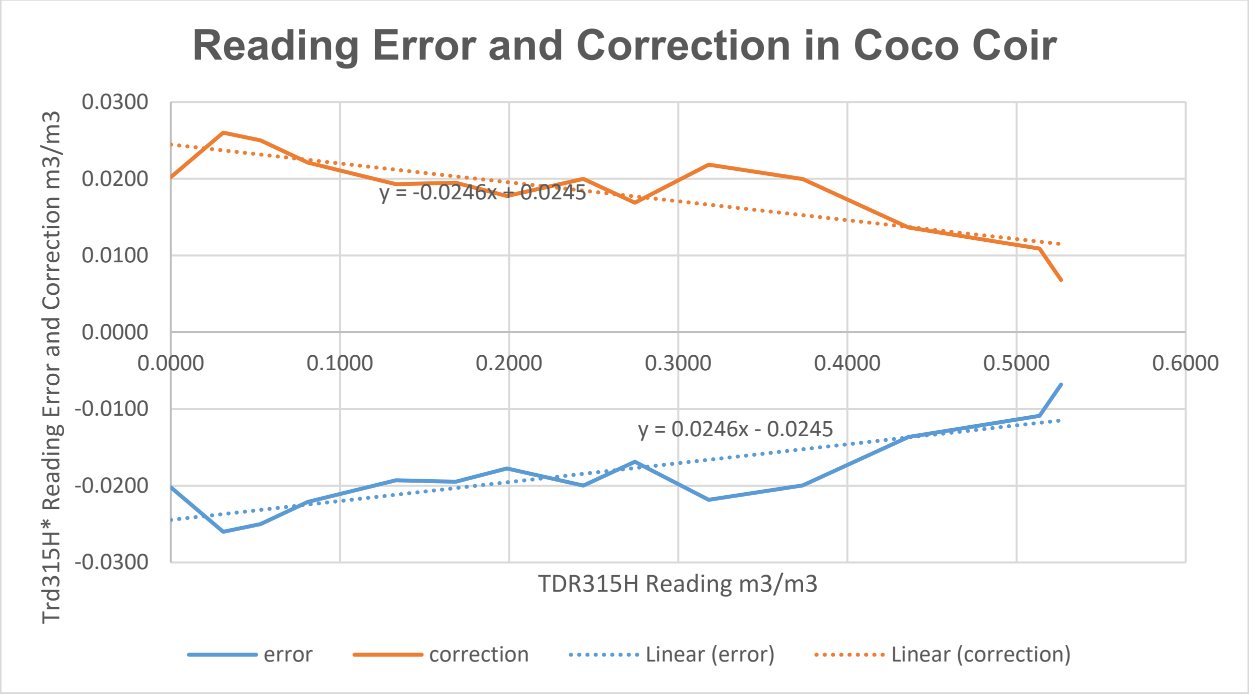


Figure CC2

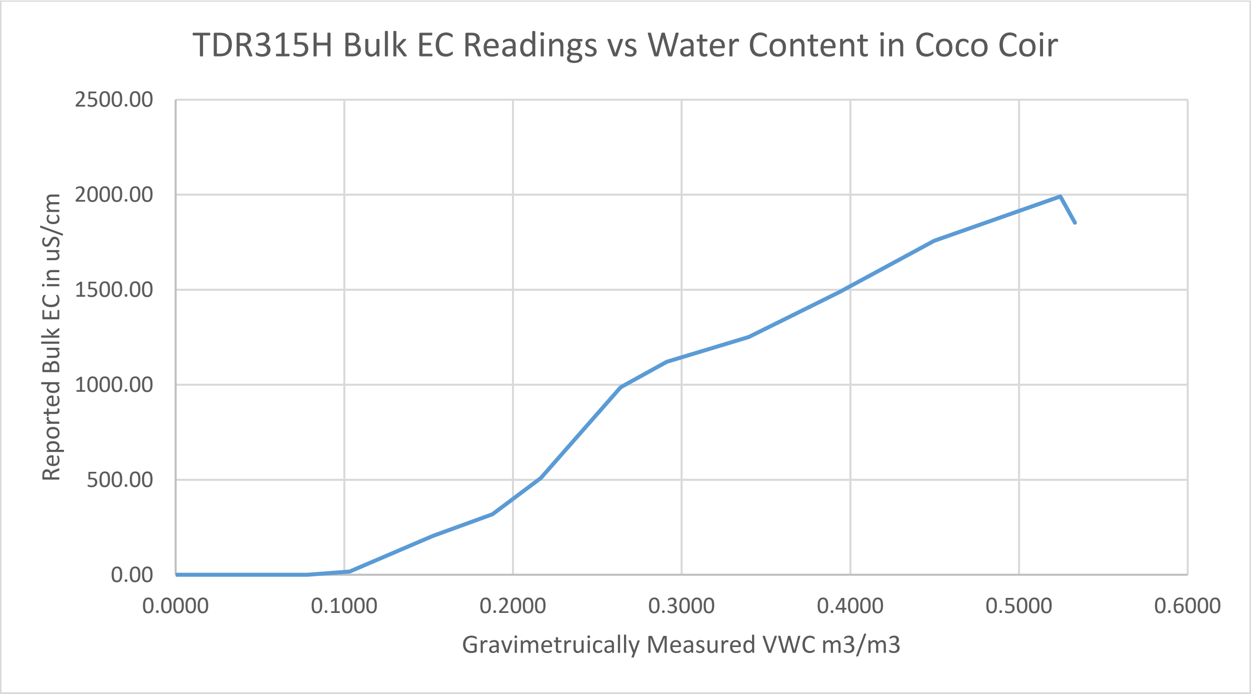


Figure CC3

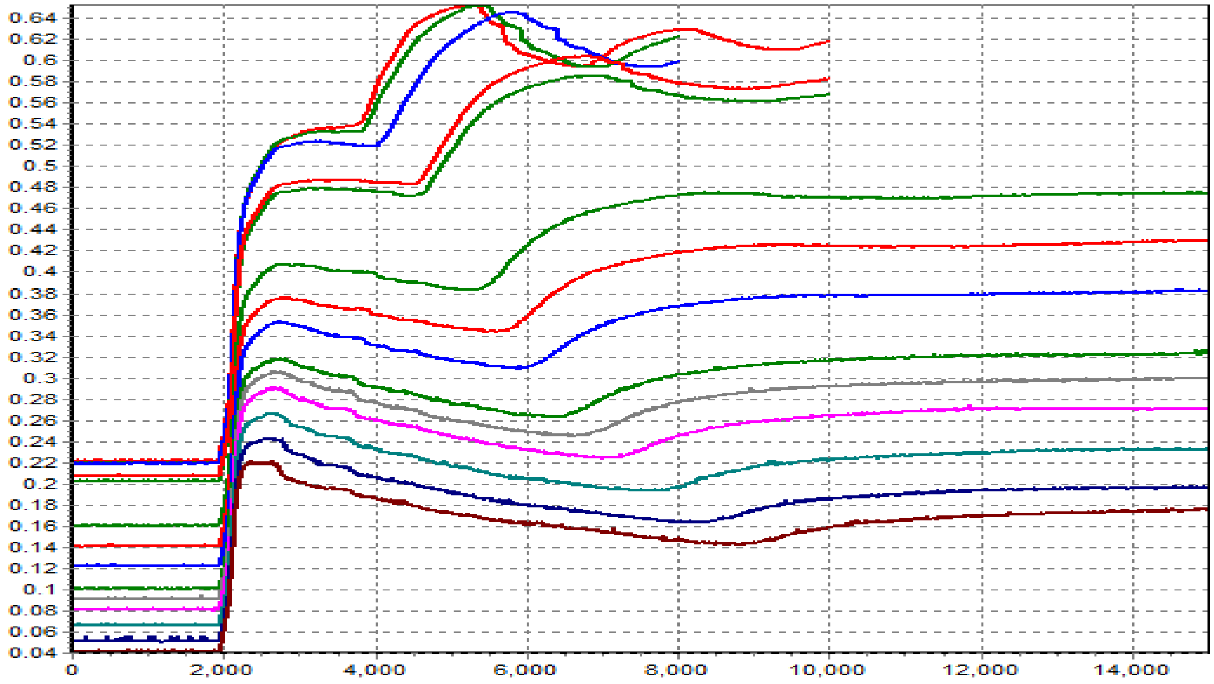

0.64
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Figure CC4