TDR310N and TDR315N Sensor characterization in different soil types

The following pages show the test results of both the TDR310N and the TDR315N in six soil types ranging from coarser sand to very fine clay. The same sensors were used for each soil with no adjustments to their response between the testing of the different soil types. The tests clearly illustrate that the TDR310N and TDR315N sensors can provide highly accurate VWC measurements across a broad range of soil types and electrical conductivity levels without soil-specific calibration.

Testing started with oven dried soils that had been milled to break up clods where necessary. The soil was packed into a test cylinder which facilitated the measurement of the soil volume. Water content was determined by weighing the soil-water mixture in the cylinder. The initial water content and dry soil weight were determined by baking out residual water from a small sample in a microwave oven and measuring the lost water gravimetrically.

Between each test an incremental amount of water was added to the samples and was thoroughly mixed to insure a homogenous medium. The wetted mixture was then re-packed into the cylinder for volume and weight measurements. Great care was taken in the mixing and packing processes to avoid the loss of any of the soil. When the soil reached saturation the process was ended, since at saturation the test cylinder began leaking water.

Appreciation is given to several researchers who provided buckets of various soils for this work.

Figures 1 & 2: **Paving Sand** is a mixture of coarse and fine sand particles that was purchased at Home Depot.

Figures 3 & 4: **Norfolk Soil** was contributed by Dr. Ken Stone at the USDA ARS station in South Carolina. This is a silt soil with a lesser amount of fine sand.

Figures 5 & 6: **Portneuf Soil** was provided by David Bjomeberg at the USDA ARS station in Kimberly, Idaho. This is a loam soil containing about 20% clay – the original Idaho Potato Soil.

Figures 7 & 8: **Pullman Soil** was contributed by Dr. Robert Schwartz at the USDA ARS station in Bushland, Texas. This is a clay-loam soil with a larger portion of clay than Portneuf.

Figures 9 & 10: **Potters Clay** is a commercial ‘pure clay’ product used by hobbyists. It was purchased from Amazon.

Figures 11 & 12: **Australian Clay** was contributed by Dr. Foley at the University of Southern Queensland in Australia. This is a very fine clay soil – rock hard when dry and slimy when wet. The sample that we received has a high salt content making it a real challenge for measuring water content. The Acclima sensors met the challenge.

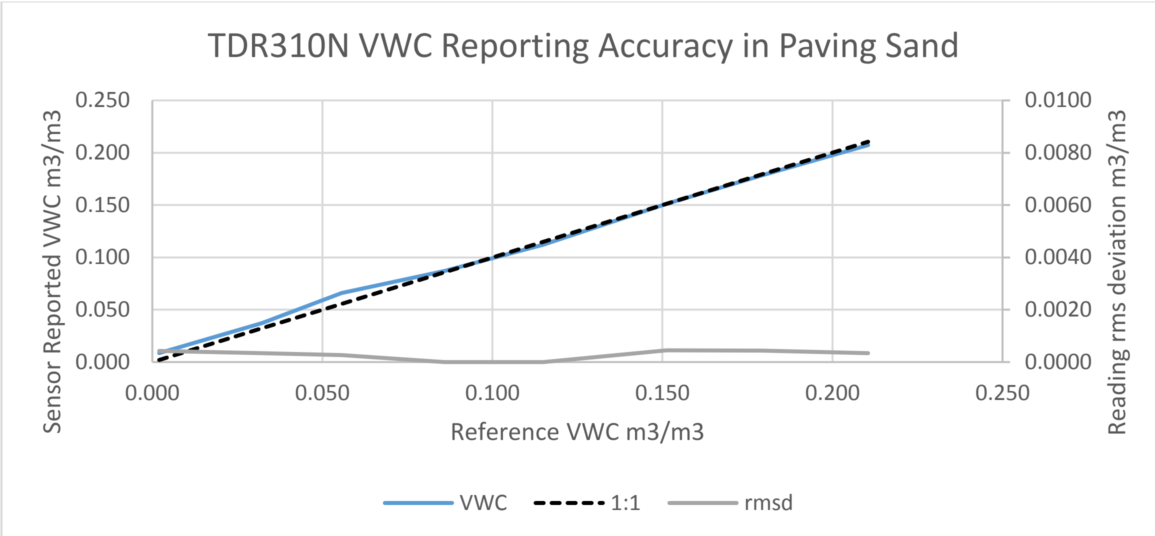


Figure 1. TDR310N Sensor readings in carefully prepared samples of Pavers Sand of known water content. Ten readings were taken at each moisture level. The VWC line shows the average water content reading vs the known water content of the sand sample. The rmsd line shows the deviation of the 10 readings around the average reading. Errors in the VWC reading were never more than 1%. The rms deviation in readings was never above 0.05%. The reported Bulk Electrical Conductivity of this sample was 116 uS/cm measured with a water content reading of 0.207 m3/m3.

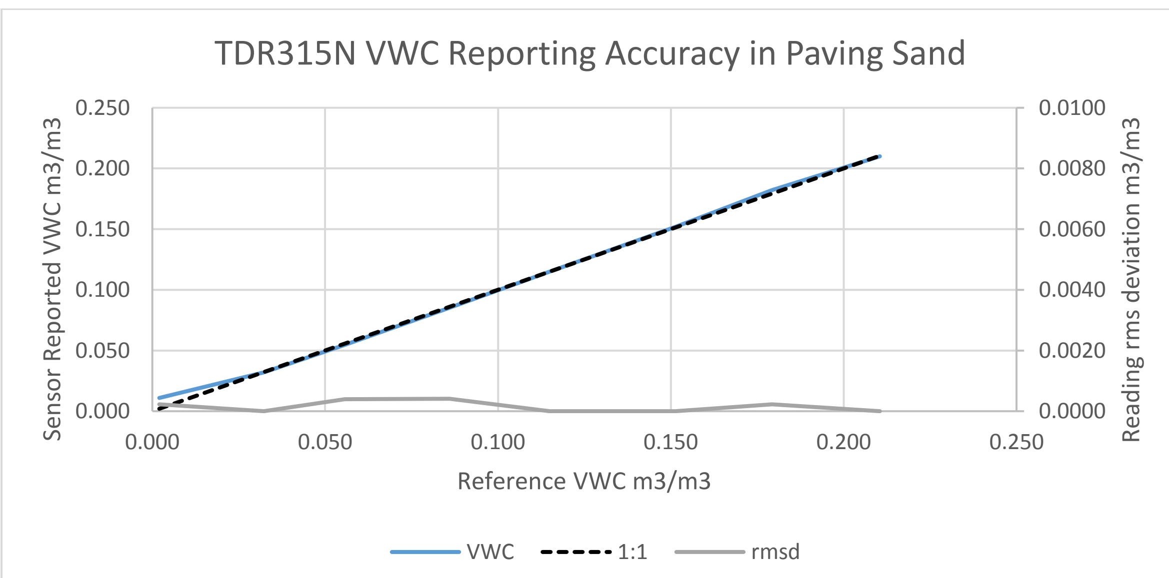


Figure 2. TDR315N Sensor readings in carefully prepared samples of Pavers Sand of known water content. Ten readings were taken at each moisture level. The VWC line shows the average water content reading vs the known water content of the sand sample. The rmsd line shows the deviation of the 10 readings around the average reading. Errors in the VWC reading were never more than 1%. The rms deviation in readings was never above 0.05%. The reported Bulk Electrical Conductivity of this sample was 120 uS/cm measured with a water content reading of 0.210 m3/m3.

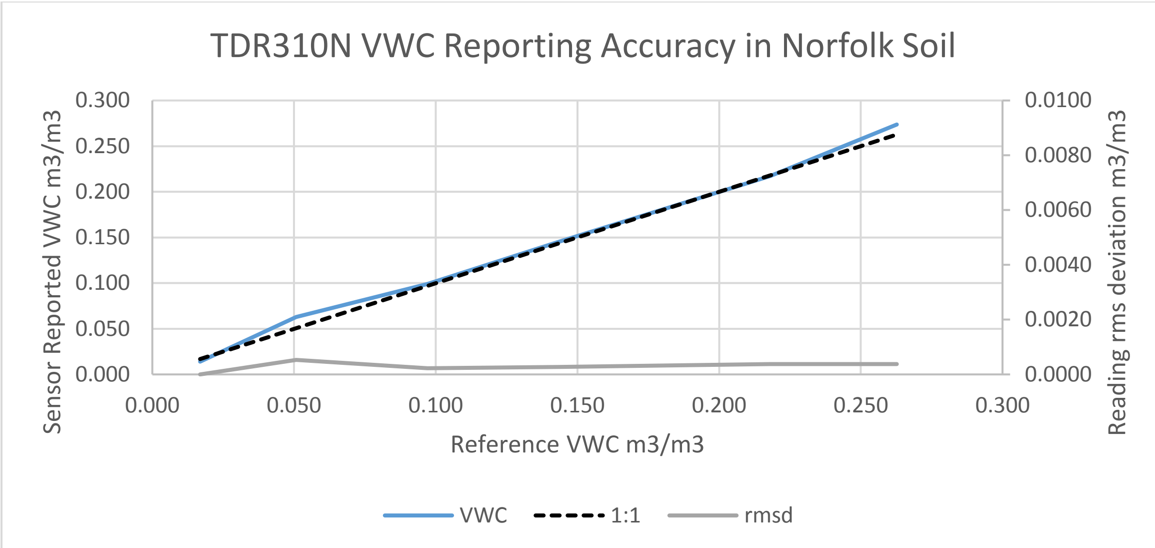


Figure 3. TDR310N Sensor readings in carefully prepared samples of Norfolk Silt of known water content. Ten readings were taken at each moisture level. The VWC line shows the average water content reading vs the known water content of the silt sample. The rmsd line shows the deviation of the 10 readings around the average reading. Errors in the VWC reading were never more than 1.5%. The rms deviation in readings was never above 0.05%. The reported Bulk Electrical Conductivity of this sample was 508 uS/cm measured with a water content reading of 0.274 m3/m3.

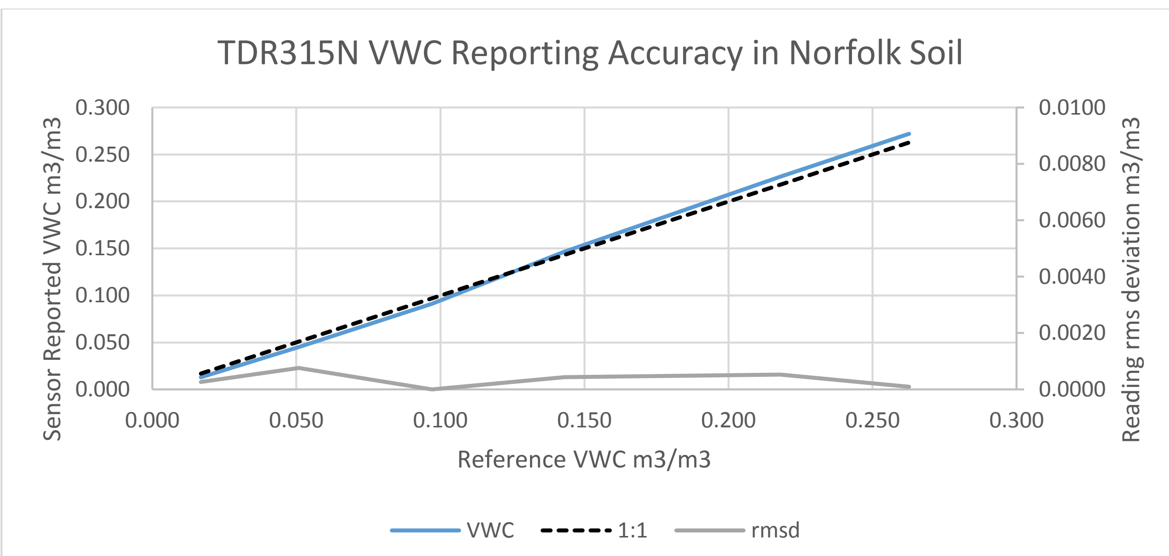


Figure 4. TDR315N Sensor readings in carefully prepared samples of Norfolk Silt of known water content. Ten readings were taken at each moisture level. The VWC line shows the average water content reading vs the known water content of the silt sample. The rmsd line shows the deviation of the 10 readings around the average reading. Errors in the VWC reading were never more than 1%. The rms deviation in readings was never above 0.1%. The reported Bulk Electrical Conductivity of this sample was 485 uS/cm measured with a water content reading of 0.272 m3/m3.

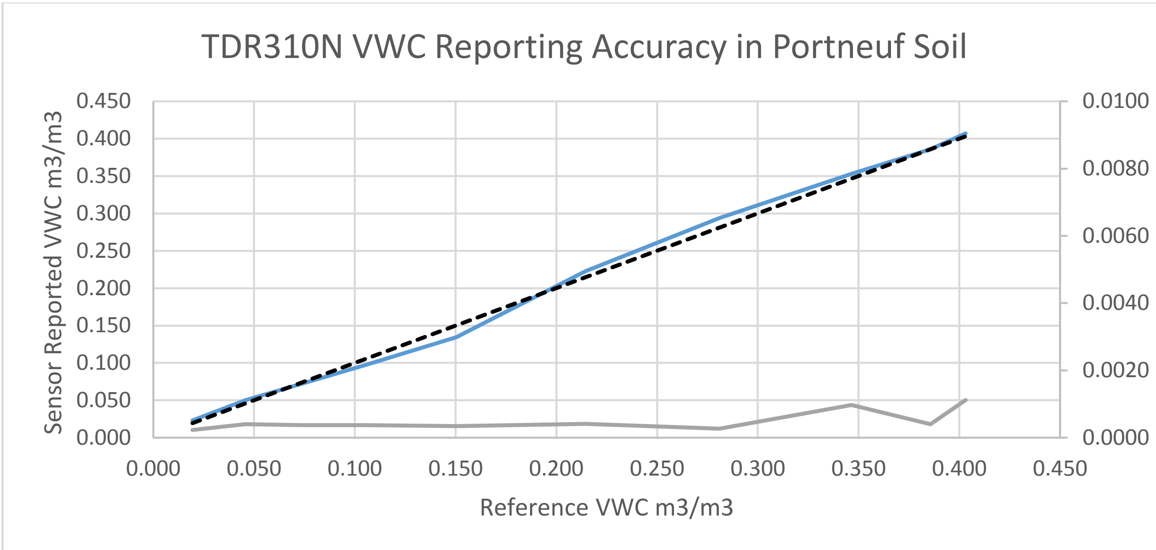


Figure 5. TDR310N Sensor readings in carefully prepared samples of Portneuf Soil of known water content. Ten readings were taken at each moisture level. The VWC line shows the average water content reading vs the known water content of the soil sample. The rmsd line shows the deviation of the 10 readings around the average reading. Errors in the VWC reading were never more than 1.6%. The rms deviation in readings was never above 0.1%. The reported Bulk Electrical Conductivity of this sample was 1100 uS/cm measured with a water content reading of 0.407 m3/m3.

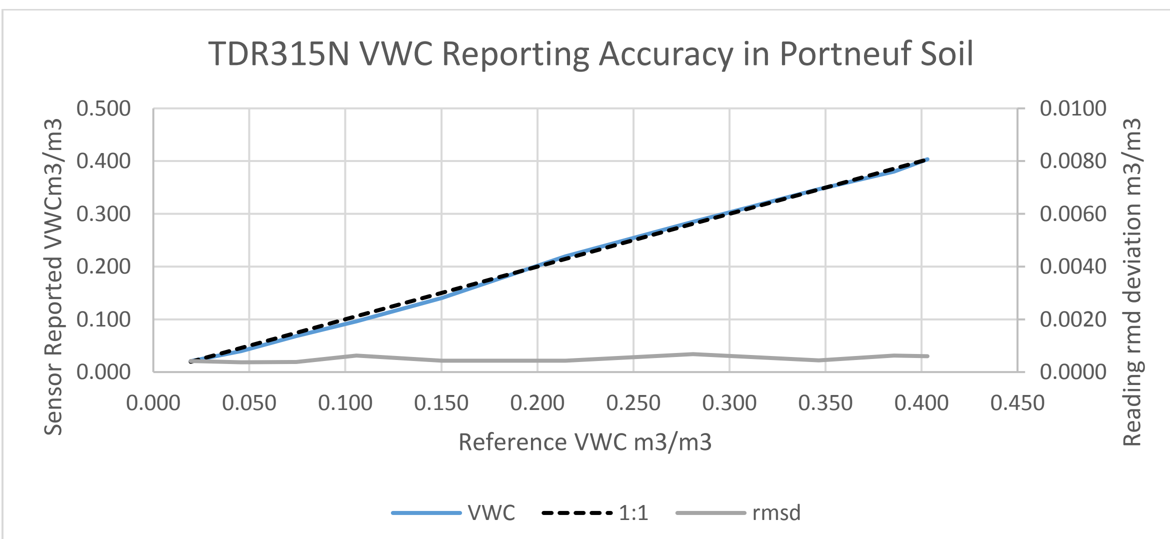


Figure 6. TDR315N Sensor readings in carefully prepared samples of Portneuf Soil of known water content. Ten readings were taken at each moisture level. The VWC line shows the average water content reading vs the known water content of the soil sample. The rmsd line shows the deviation of the 10 readings around the average reading. Errors in the VWC reading were never more than 1%. The rms deviation in readings was never above 0.1%. The reported Bulk Electrical Conductivity of this sample was 1085 uS/cm measured with a water content reading of 0.404 m3/m3.

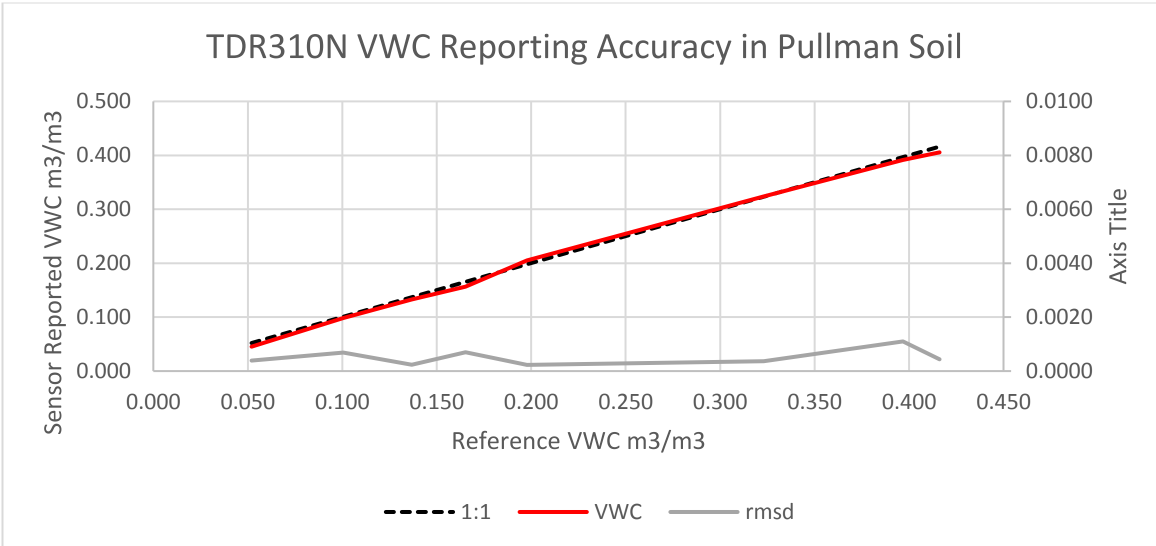


Figure 7. TDR310N Sensor readings in carefully prepared samples of Pullman Soil of known water content. Ten readings were taken at each moisture level. The VWC line shows the average water content reading vs the known water content of the soil sample. The rmsd line shows the deviation of the 10 readings around the average reading. The worst case error in the VWC reading was 1%. The rms deviation in readings was never above 0.11%. The reported Bulk Electrical Conductivity of this sample was 1049 uS/cm measured with a water content reading of 0.397 m3/m3.

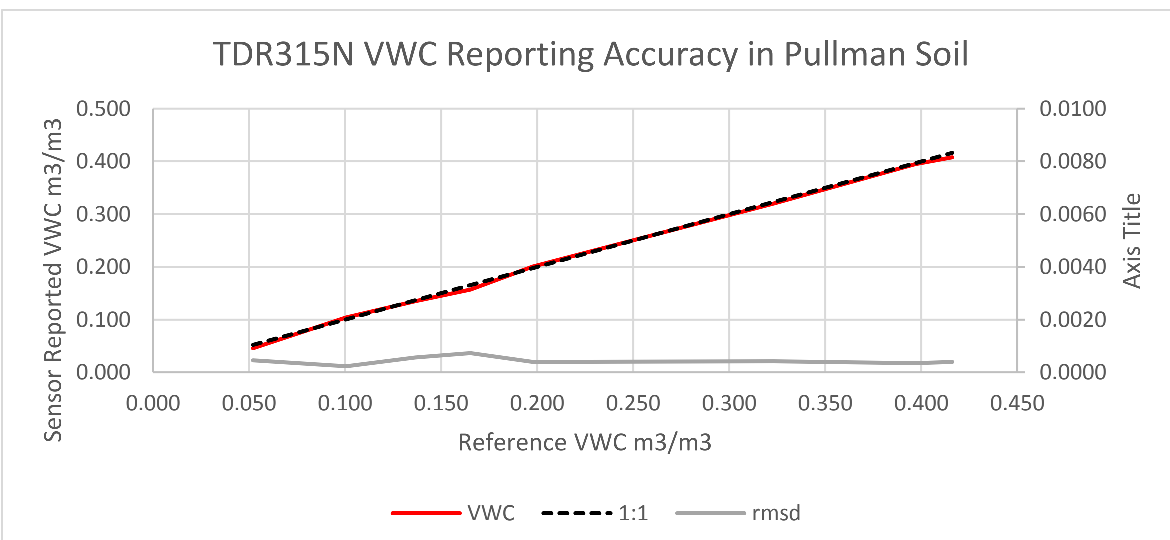


Figure 8. TDR315N Sensor readings in carefully prepared samples of Pullman soil of known water content. Ten readings were taken at each moisture level. The VWC line shows the average water content reading vs the known water content of the soil sample. The rmsd line shows the deviation of the 10 readings around the average reading. The worst casel error in the VWC reading was less than 1%. The rms deviation in readings was never above 0.1%. The reported Bulk Electrical Conductivity of this sample was 1048 uS/cm measured with a water content reading of 0.395 m3/m3.

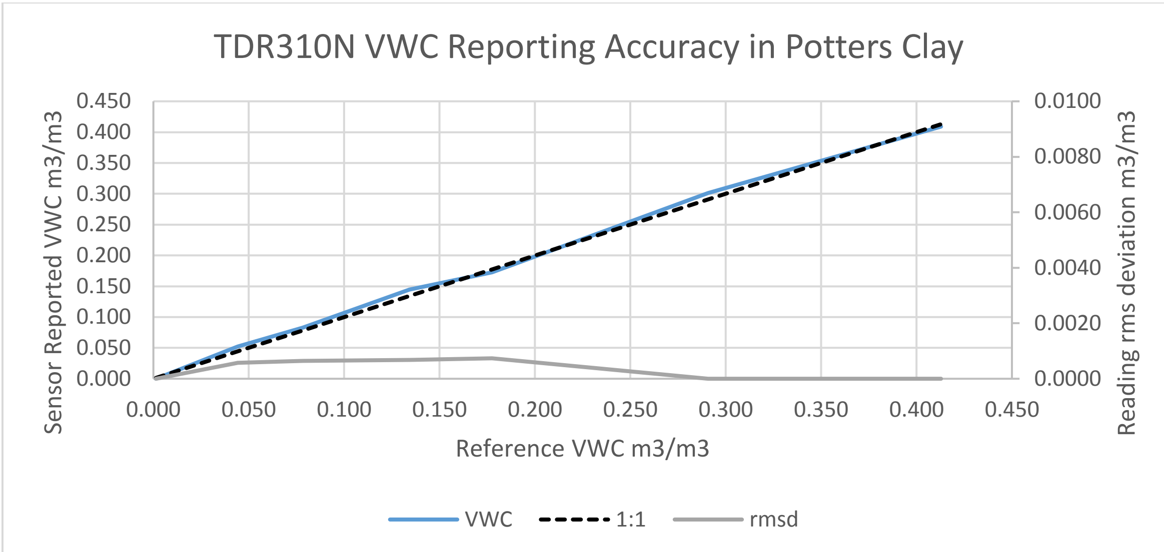


Figure 9. TDR310N Sensor readings in carefully prepared samples of Potters Clay of known water content. Ten readings were taken at each moisture level. The VWC line shows the average water content reading vs the known water content of the clay sample. The rmsd line shows the deviation of the 10 readings around the average reading. A typical error in the VWC reading is less than 1% and never more than 2%. The rms deviation in readings is never above 0.1%. The reported Bulk Electrical Conductivity of this sample was 844 uS/cm measured with a water content reading of 0.409 m3/m3.

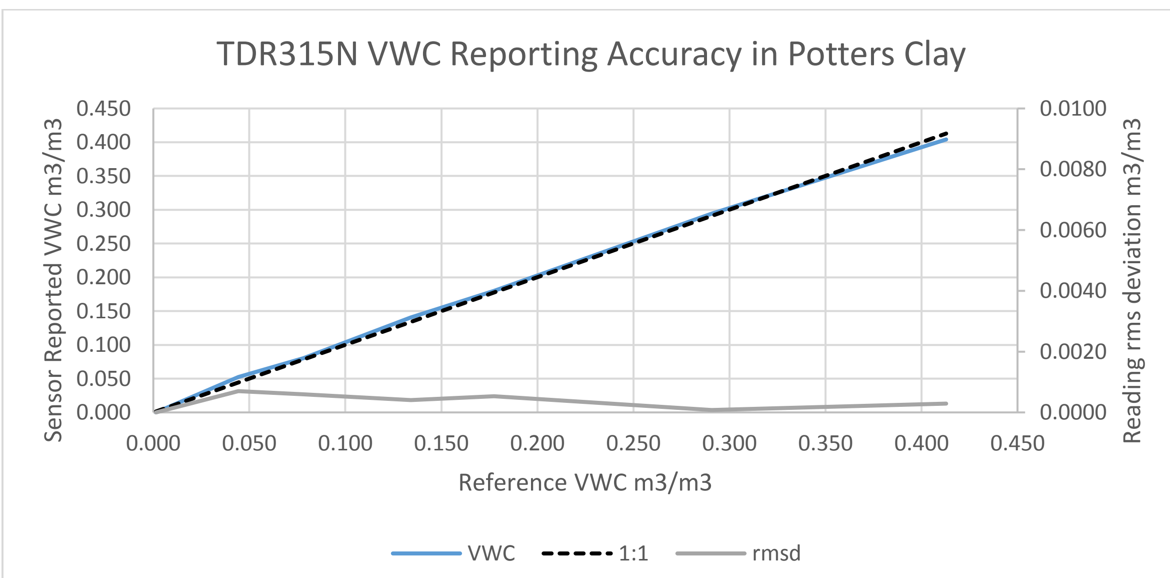


Figure 10. TDR315N Sensor readings in carefully prepared samples of Potters Clay of known water content. Ten readings were taken at each moisture level. The VWC line shows the average water content reading vs the known water content of the clay sample. The rmsd line shows the deviation of the 10 readings around the average reading. A typical error in the VWC reading is less than 1% and never more than 2%. The rms deviation in readings is never above 0.1%. The reported Bulk Electrical Conductivity of this sample was 875 uS/cm measured with a water content reading of 0.404 m3/m3.

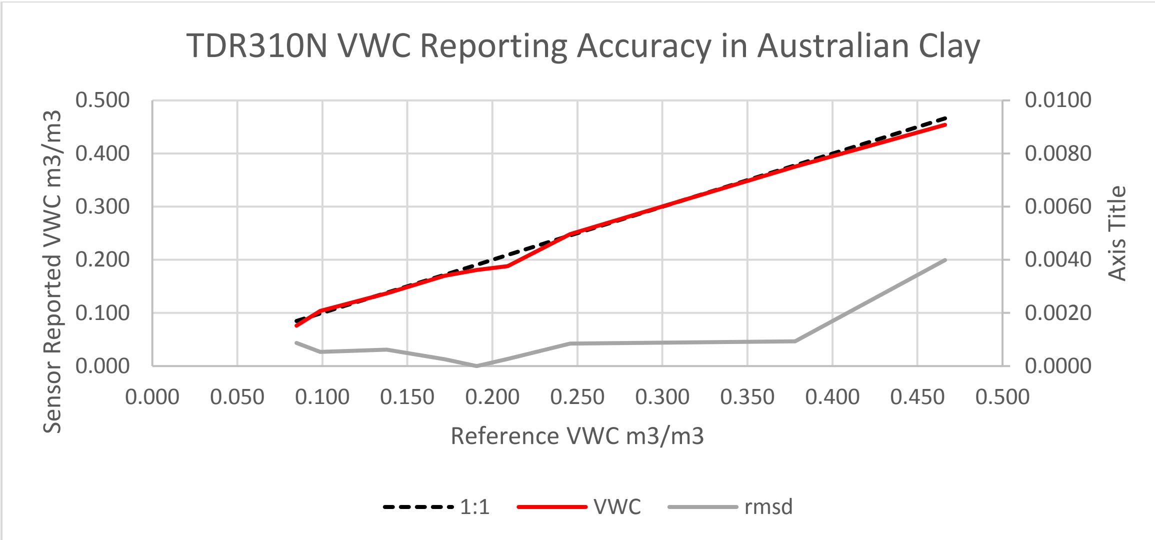


Figure 11. TDR310N Sensor readings in carefully prepared samples of highly saline clay of known water content. Ten readings were taken at each moisture level. The VWC line shows the average water content reading vs the known water content of the clay sample. The rmsd line shows the deviation of the 10 readings around the average reading. The worst case VWC reading error was 2.5%. The rms deviation in readings was never above 0.4%. The reported Bulk Electrical Conductivity of this sample was 2151 uS/cm measured with a water content reading of 0.454 m3/m3.

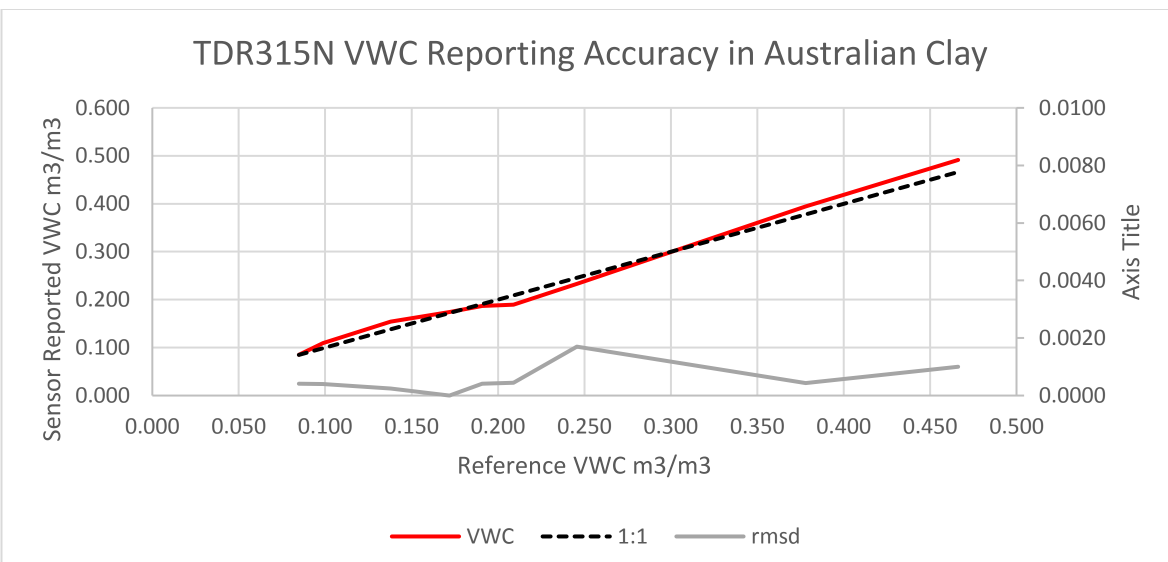


Figure 12. TDR315N Sensor readings in carefully prepared samples of highly saline clay of known water content. Ten readings were taken at each moisture level. The VWC line shows the average water content reading vs the known water content of the clay sample. The rmsd line shows the deviation of the 10 readings around the average reading. The worst case VWC reading error was 2.1 %. The rms deviation in readings was never above 0.2%. The reported Bulk Electrical Conductivity of this sample was 2184 uS/cm measured with a water content reading of 0.491 m3/m3.

TDR310N and TDR315N Product Specifications

The following specifications assume that the sensor has been installed with care taken to assure that the waveguide rods have not been bent and that no air pockets exist around them. The sensor is assumed to be installed in reasonably homogenous soil – meaning that there are no abrupt discontinuities in permittivity along the length of the waveguide such as exposure to the air or a very abrupt transition from very wet to very dry soil. The sensor must be supplied with at least 6 volts from a supply with an output impedance of less than 0.1 ohms.

Volumetric Water Content:

Reading Range:	0 to 1.050 m3/m3 or 0 to 105% volumetric water content	
Reading Resolution	0.001 m3/m3 or 0.1%	
Water Reading Accuracy:	Water @ 0 to 3000 uS/cm @ 23C	.99 to 1.01 m3/m3
Soils VWC Reading Accuracy over the range dry to saturation:		
	Sand @ 0 to 3000 uS/cm BEC	±1.5% of full scale
	Loam @ 0 to 3000 uS/cm BEC	±1.5% of full scale
	Clay @ 0 to 2000 uS/cm BEC	±2.0% of full scale
Reading Repeatability:		
	Sand @ 0 to 3000 uS/cm BEC	±1.5% of full scale
	Loam @ 0 to 3000 uS/cm BEC	±1.5% of full scale
	Clay @ 0 to 2000 uS/cm BEC	±2.0% of full scale

Permittivity:

Reading Range:	0 to 100 relative permittivity units	
Reading Resolution:	.1 relative permittivity units	
Reading Accuracy:	Water @ 0 to 3000 uS/cm @ 23C	79.0 to 79.7
	Sand @ 0 to 3000 uS/cm	±1.5% of full scale
	Loam @ 0 to 3000 uS/cm	±1.5% of full scale
	Clay @ 0 to 2000 uS/cm	±2.0% of full scale
	Permittivity reading in air	1.0 to 1.1

Temperature with standard thermistor:

Reading Range:	-40C to +70C
Reading Resolution:	0.1 degrees C
Reading Accuracy:	± 0.25 C from +17 to +28 C
	±0.50 C from -12 to +50 C
	±0.75 C from -33 to +65 C
	±1.00 C from -40 to +70 C

Temperature with optional precision thermistor:

Reading Range:	-40C to +70C
Reading Resolution:	0.1 degrees C
Reading Accuracy:	±0.10 C from -12 to +55 C
	± 0.20 C from -30 to +70 C
	± 0.30 C from -40 to +70 C

Bulk Electrical Conductivity:

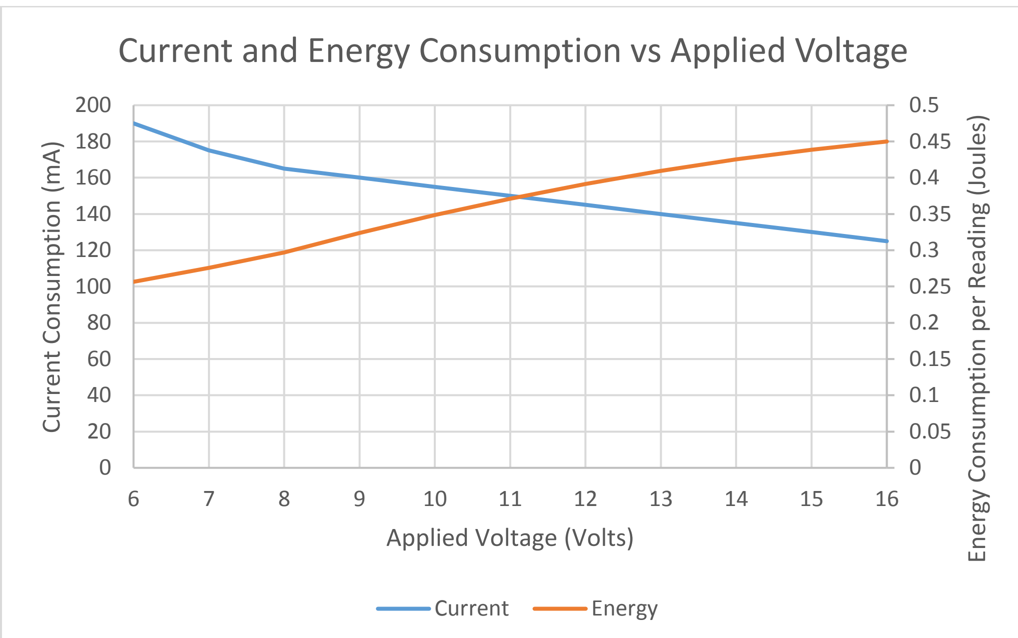
Reading Range:	0 to 10,000 uS/cm	
Reading Resolution:	1 uS/cm	
Reading Accuracy:	0 to 500 uS/cm	±10 uS/cm
	500 to 3000 uS/cm	±2%
	3000 to 6,000 uS/cm	±3%
	6,000 to 10,000 uS/cm	±5%

Power Requirements/Characteristics of the Acclima Soil Smart Series TDR Soil Water Content Sensors

The TDR-315N, TDR-310N, TDR-305N and TDR-310W are identical in their power requirements. They operate between 6.0 volts and 16.0 volts. Below 6 volts they will not provide stable readings. Above 16 volts damage can occur to the overvoltage protection devices within the sensor. It is strongly recommended to limit the lower voltage to 7 volts due to voltage drops in the cable and in the Data Recorder power supply. The chart below shows the current required by the sensor vs applied voltage. The duration of the current flow is 225 milliseconds. The energy consumption per reading is also shown in the graph below. As a reference, a typical 18650 Li-Ion battery stores about 40,000 joules of energy.

When choosing or designing a power supply to operate the sensors a few pointers should be heeded:

1. Battery operation using rechargeable batteries with 7 volts or less output will require a boost regulator with 0.5 A minimum output capability and an output impedance of less than 0.5 ohms. The ideal design output voltage is 12 volts, but voltages down to 7 volts are acceptable.
2. The transient load response of the power supply should limit negative output spikes to less than 0.25 volts below the design voltage when the sensor turns on. The sensor inrush current can be as high as 0.3 amperes for a few microseconds when the TDR circuitry turns on.



The sensors are compliant with the version 1.4 specifications available at SDI-12.org.

The data retrieval command aD0! returns the following string of values in the order shown below:

1. Volumetric Water Content expressed as a percent with one decimal point resolution
2. Temperature in degrees C with 0.1 degree resolution
3. Permittivity with 1 decimal point resolution
4. Bulk Electrical Conductivity expressed in µS/cm
5. Pore Water EC expressed in µS/cm

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