The PRISMS Profiling Soil Moisture Sensor

A Stationary Sensor Reveals Soil Moisture Content in Continuous Profile

The ability to acquire time series measurements of *in situ* soil moisture content in continuous profile has long been sought by officials responsible for soil and groundwater remediation, dam and levee safety, landslide hazard warning, irrigation and water management, and monitoring land-atmosphere interactions that affect climate.

Transcend Engineering has developed a sensing technology called PRISMS ("Profile Resolving In-situ Soil Moisture Sensor") that provides long-term time series monitoring of soil moisture in profile in the vadose zone. Our proprietary approach extends the time domain reflectometry (TDR) technique for soil moisture determination previously used only with short, discrete monitoring probes that interrogate a limited local volume of soil.

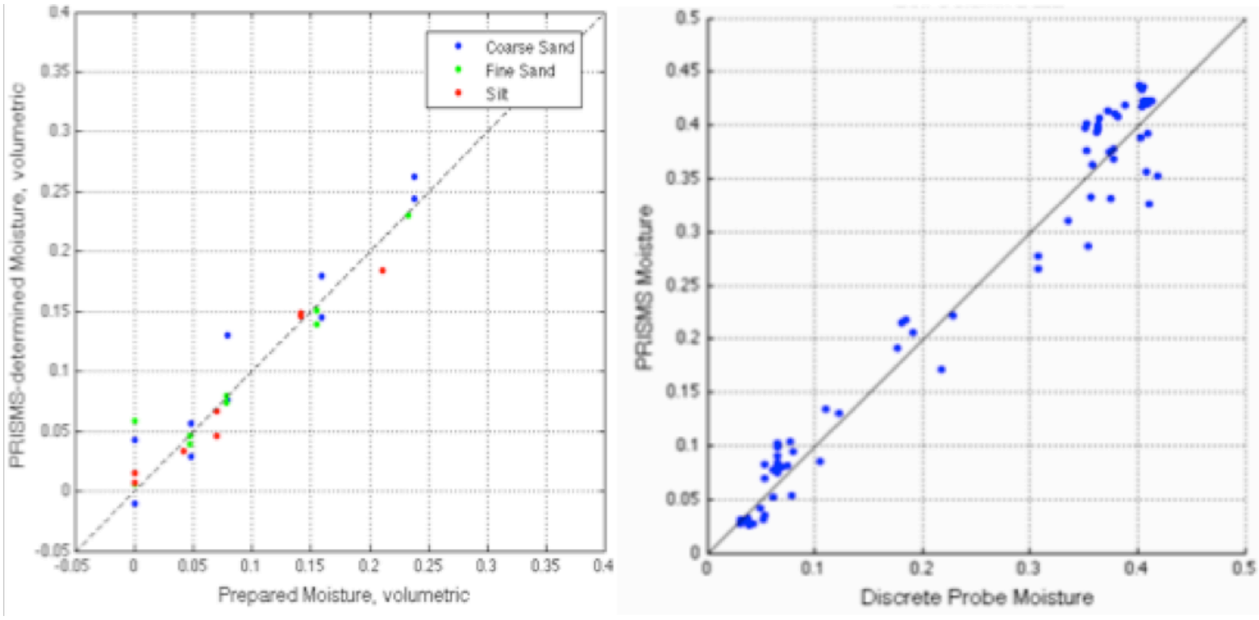
PRISMS combines advances in TDR data processing with innovations in the sensing element design to enable high spatial resolution of reflectance along the inner surface of borehole using a long, linear sensing element pressed against the adjacent soils by an inflatable borehole liner. TDR measures impedance differences along the element due to variation in soil moisture content. Using proprietary algorithms, PRISMS transforms the reverberant time domain reflectance signal into spatially resolved soil moisture everywhere along the borehole sensing element.

PRISMS sensor element on the outside of a rigid borehole liner.

Soil Moisture Determination from TDR

TDR was developed to locate faults in communication and power cables by sending an electrical impulse into the cable and monitoring the signal that returns due to reflection from changes in the cable impedance. Cable impedance is a function of the conductor electrical properties and geometry, as well as the dielectric permittivity and electrical conductivity of the material surrounding the conductors. Signal is reflected from any change in the cable's electrical impedance due to damage or water ingress. The ratio of reflected to transmitted voltage is known as the reflection coefficient, and its variation in time corresponds to locations along the cable where impedance varies. The travel time is converted to distance by knowing the propagation velocity in the cable. TDR was adapted to estimate soil water content by Hoekstra and Delaney (1974), Topp et al (1980), and others. Advances have since led to a number of commercial TDR probes.

In a typical soil moisture application, TDR measure the dielectric permittivity of the soil surrounding a short transmission line comprising bare metal rods inserted into the ground. Dielectric is closely related to the soil's water content. The real component of the dielectric is often referred to as the apparent dielectric, K_a, which can be estimated from the round trip travel time of a TDR pulse.



Plots above show the strong correlation of PRISMS to reference methods in laboratory soil column and soil trough tests.

Most commercial TDR equipment for measuring soil moisture employs a bulk measurement approach in which the moisture probe consists of two or three parallel conductive rods in contact with the soil. The time of arrival of the pulse reflected by the abrupt impedance contrast at the end of the waveguide are used to determine bulk apparent dielectric over the length of the rods. The most frequently cited equation relating soil volumetric moisture content, θ, to apparent dielectric, K_a, is a third order polynomial developed by Topp et al. (1980):

$$\theta = a + bK_a + cK_a^2 + dK_a^3$$

The conventional TDR method accounts for the cumulative effect of the soil-related impedance on the pulse over its roundtrip travel time, but does not resolve spatial variation in the soil. Previously available commercial TDR sensors have use relatively short conductors in electrical contact with the soil, and have reported a single moisture value for the soil volume around the conductors.

In contrast, PRISMS resolves soil moisture in fine spatial detail from analysis of the whole reflectance signal.

PRISMS Development Status

The U.S. Department of Energy is supporting development of PRISMS through a Small Business Innovation Research (SBIR) grant. Following laboratory assurance of feasibility in multiple soil types, we have manufactured PRISMS sensor elements and deployed them at the U.S. Department of Energy's Rifle, Colorado IFRC using mature borehole liner technology from Flexible Underground Liner Technologies, aka FLUTe (Santa Fe, NM) and other methods. Check http://transcendengineering.com/PRISMS.html for animated time series of *in situ* vertical soil moisture profiles at the Rifle site.

Transcend Engineering is seeking sites interested in hosting additional PRISMS field evaluations and demonstrations.

Contact Stephen Farrington via email at sfarrington@transcendengineering.com or by calling 802-431-3456, for more information.