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MONITORING TEMPORAL SOIL MOISTURE VARIABILITY WITH DEPTH USING CALIBRATED IN-SITU SENSORS

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I. INTRODUCTION

Studies have shown that soil moisture is the basic link between the hydrologic cycle and the energy budget of land surfaces (Houser, 1996). Therefore, soil moisture data is useful in many disciplines including agriculture, forest ecology, civil engineering, water resources, meteorology and soil science (Wetzel and Woodward, 1987). In semiarid rangelands, soil moisture is a major control of evapotranspiration and a significant factor in runoff generation. Consequently, soil moisture is one primary component of many hydrologic models. Unfortunately, long term soil moisture data sets are rare because conventional soil moisture techniques (e.g., gravimetric and Time-Domain-Reflectometry) have historically been procedurally and labor intensive. Electrical Resistance Sensors, however, are capable of collecting nearly continuous data with little maintenance using data-loggers. Like most soil moisture instruments, ERS require a calibration to convert a measured signal to a volumetric water content. In this experiment, we calibrated a network of *in situ* ERS sensors in the Walnut Gulch Experimental Watershed to create a long term, temporally continuous soil moisture data set.

Two primary goals of this research are:

1. To develop a 16 month, hourly soil moisture data set at 5, 15 and 30 cm depths under three bare and three shrub cover surfaces; and

2. To use these data to validate the Simultaneous Heat and Water (SHAW) model for use in storm and inter-storm hydrologic modeling.

2. APPROACH

Electrical Resistance Sensors (ERS) used in this study are similar to those described by Colman and Hendrix (1949) and identical to those of Amer et al. (1994). Original laboratory and site calibration procedures for ERS used in this experiment were described by Amer et al. (1994). Their research described the calibration of the ERS in representative soil samples extracted from the installation site. Measured resistance values from known volumetric water contents (θ_v) were used to identify calibration parameters. Furthermore, gravimetric samples taken during final sensor installation were used to test the laboratory calibrations. After installation, soil moisture values calculated from laboratory determined calibration coefficients were excessive, indicating an incompatibility between *in situ* and laboratory calibrations.

Time Domain Reflectometry (TDR) has been established as a nondestructive method for measuring θ_v (Young et al., 1997; Topp et al., 1980). Over the past decade, research has focused on the reliability of TDR θ_v measurements. Results proved that TDR readings are only slightly influenced by changing temperature and salinity conditions, and are independent of temperature in soil textures finer than sand (Halbertsma et al., 1994). Furthermore, soils with electrical conductivity values less than 8 dSm^{-1} will not have any effect on TDR measured θ_v values (Dalton, 1992).

During the initial installation, TDR probes were placed adjacent to ERS at each of the installation sites. One disadvantage of the TDR probes installed at these sites is that they require an on-site operator and post processing. Therefore, TDR measurements were sampled at intervals varying from daily to biweekly. Analysis revealed that the TDR measurements were accurate by ± 2% θ_v (L. Bach, personal comm.). To increase our confidence in the ERS measurements, we decided to use an *in situ* calibration that would integrate high frequency ERS data with reliable TDR data.

3. EXPERIMENT

In 1990, USDA - Agricultural Research Service (ARS) scientists installed ERS and TDR sensors in the Walnut Gulch Experimental Watershed

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(31.72 N°, 100.00 W°). Eighteen pairs of ERS and TDR probes were installed horizontally into trench faces under three bare and three shrub covered surfaces in the Lucky Hills sub-watershed at 5, 15 and 30 cm depths. Data loggers recorded hourly ERS values and ARS scientists collected TDR samples at varying time intervals. ERS readings were stored as a series of resistances (ohms) while TDR values were recorded as θ_v (m^3m^{-3}).

ERS and TDR measurements taken at identical times between August of 1990 and December of 1991 were extracted for individual trenches and depths. Calibration parameters for each ERS sensor were derived using the expression $TDR = a \cdot ERS^b$, where TDR represents θ_v (m^3m^{-3}), ERS equals raw resistance (ohms) and a and b are calibrated parameters. Seyfried (1993) found a non-linear relationship between TDR measured θ_v and ERS resistance values, as did Amer et al. (1994).

Parameters a and b were optimized with non-linear curve fitting techniques from a statistical software package. Once acceptable parameters were calculated for each sensor, the calibration expression was applied to the entire hourly ERS data set to produce 16 month, hourly θ_v.

4. RESULTS

Statistical tests indicated that our calibration expression worked well for each ERS data set. Table 1 provides parameter and coefficient of determination (r^2) values for all 18 sensors. Data presented in Figure 1 show a representative calibration curve with matched TDR and ERS values (r^2 = .88). Clearly, resistance values approach zero as θ_v increases.

Calibration parameters were applied to each individual ERS. A portion of the resultant data set for one individual trench with sensors at 5, 15 and 30 cm depths is shown graphically in Figure 2.

At the time of this writing, we have not completed the comparisons of these soil moisture measurements with the Simultaneous Heat and Water (SHAW) model. The SHAW model simulates heat and water movement through a plant-residue-soil system. A vertical, one dimensional profile extending from the vegetation canopy to a specified depth within the soil is represented in this model. As demonstrated in 1990, the SHAW model was capable of simulating heat and water fluxes at both grass and shrub dominated sites (Flerchinger, 1996).

Table 1. Optimized parameter (a and b) and coefficient of determination (r^2) values for individual ERS sensors

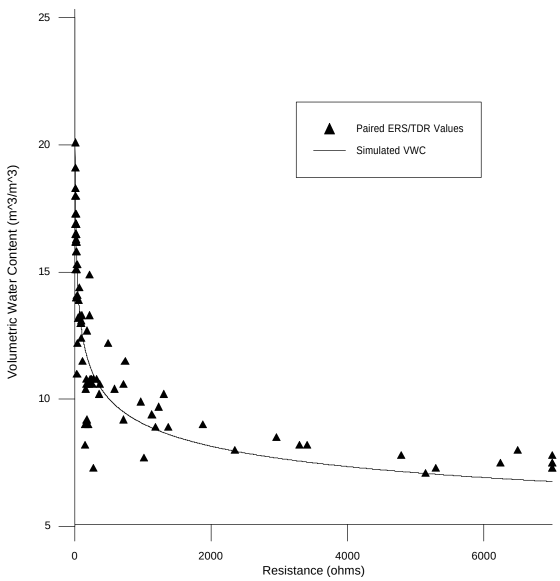
Sensor	a	b	r^2
1	15.62	-0.45	.58
2	27.88	-0.17	.66
3	27.59	-0.11	.61
4	26.32	-0.21	.65
5	19.88	-0.19	.80
6	15.67	-0.14	.81
7	29.43	-0.21	.72
8	23.63	-0.13	.84
9	20.35	-0.11	.33
10	18.99	-0.40	.71
11	22.15	-0.21	.82
12	15.27	-0.65	.58
13	17.87	-0.10	.74
14	16.97	-0.27	.70
15	15.07	-0.08	.62
16	27.89	-0.24	.67
17	25.34	-0.18	.73
18	25.34	-0.15	.88

5. CONCLUDING REMARKS

These findings indicate that an *in situ* calibration of ERS sensors that integrated high frequency ERS data with reliable TDR data worked well. An hourly soil moisture data set for a 16 month period was composed for 6 replicate sites at 3 different depths. This simple calibration procedure also demonstrates the utility of the ERS sensor for future soil moisture studies.

This calibrated soil moisture data set will be used to validate the SHAW model for use in storm and inter-storm modeling in Walnut Gulch. Additionally, we plan to apply this calibration technique to more recent ERS data sets.

Figure 1. Sample calibration curve for matched TDR and ERS values



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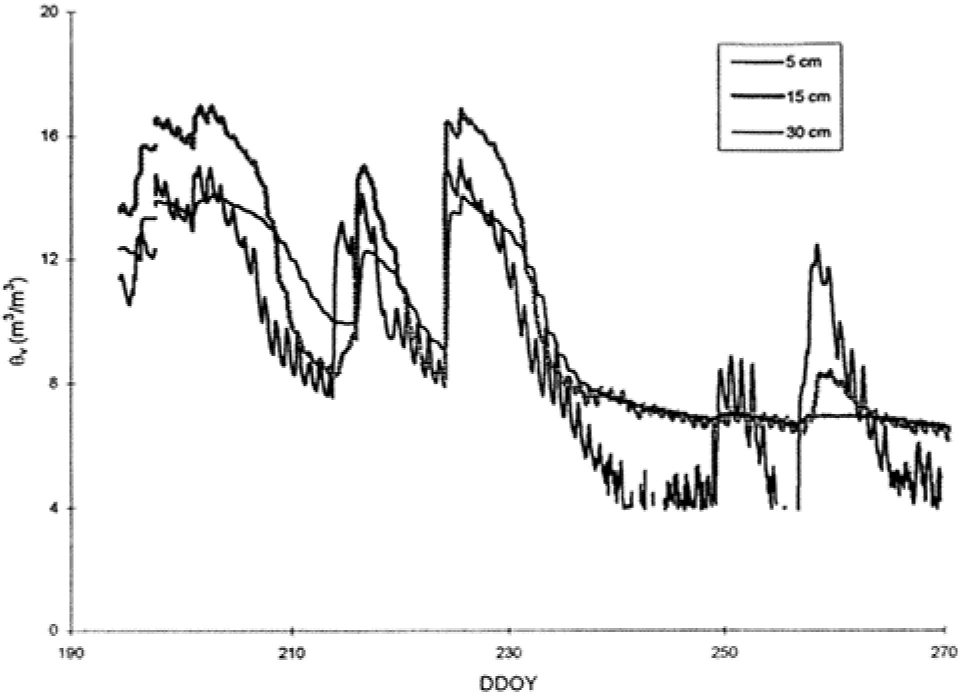

Figure 2. Calibrated θ_v (m^3m^{-3}) values at 5, 15 and 30 cm depths for 1990 (DOY 194-270)