STUDY AREA

The Noland Divide Watershed (NDW) covers a 17 ha area from an elevation of 1500 m to 2000 m in the Great Smoky Mountains National Park of North Carolina and Tennessee. The catchment is considered to be in the latter stages of nitrogen saturation, having high N deposition loads (~27 kg N/ha/yr) and high nitrate-N concentrations in the soil and stream water (~ 40 kg N/ha/yr).

Purposes

- **Understand hillslope response as it pertains to Nitrogen Export**
- **Examine topographic control on soil moisture**

Measurements

Continuous

- **Streamflow at two outlet wiers**
- **Precipitation**
- **Soil moisture at three locations with CS-615 reflectance probes**

Soil characteristics

- **Soil depth to refusal of penetration probe**
- **Hydraulic conductivity using Guelph permeameter**
- **Porosity from dry density and organic content**

Periodic at biweekly interval

- **Capacitance (Theta) probe soil moisture map (SSM)**

Abstract

As part of an effort to understand the effects of hydrology on the nitrogen cycling and biogeochemistry of the Noland Divide Watershed, we conducted detailed soil moisture and hydrologic process measurements during the summer of 1999 in the Noland Divide Experimental Watershed in the Great Smoky Mountains National Park. Our objectives were to calculate a water budget, based on measured input, output, continuous and synoptic measurements of soil moisture and on estimated evapotranspiration within the watershed. Soil Moisture was mapped spatially using a hand held theta probe on nine occasions ranging from wet to dry. Access tubes facilitated repeat sampling of the same locations and profiling of the soil moisture with depth. Reflectance probes monitored the soil moisture profile continuously at three locations. Precipitation and discharge were recorded. Soil depth to the shallow bedrock was mapped based upon refusal of penetration by a probe, hydraulic conductivities were measured using a Guelph permeameter and porosity was estimated using measurements of dry density and soil organic content. Slope, specific catchment area and wetness index were calculated from a high resolution (5 m grid spacing) digital elevation model. This paper discusses the analysis of this data. We found a linear relationship between basin averages of the synoptic moisture measurements and each of the continuous monitoring sites, consistent with the idea that point measurements can represent basin average topography. The slope of the regression relationship is related to topographic location. There was little evidence of association between soil moisture and topographic wetness index. There was some evidence of association with aspect (slope direction) with the more southerly slope being drier. Vertical soil moisture profiles were almost always saturated at the base and pivoted from almost uniform during wet conditions to an increase with depth during to dry conditions, consistent with preferential pathway infiltration processes.

NDW Stream Gages, SW and NE Weirs, respectively.

Hydraulic conductivity (K_{sat}) was estimated using a Guelph permeameter. Hydraulic conductivity tests were conducted at 51 sites in the NDW. A graduated metal rod was used to measure the **soil depth**. Soils consisted of non-compacted sandy loams, underlain by sandstone and were easily penetrated by the rod. Due to the high spatial variability a total of 16 measurements were taken at each site and the values averaged to produce a soil depth estimate. **Porosity** was estimated using a bulk density soil sampler. The soil particle density used in the porosity estimate was based upon laboratory analysis of organic content.

Capacitance (Theta) Probe

50 mm PVC Access Tubes

37 mm PVC Insert Filled with Soil, Removed Prior to Probe Insertion

The spatial distribution of soil moisture across the watershed was characterized with biweekly mappings of volumetric water content readings at 66 soil moisture mapping (SSM) sites across the watershed. Access tubes were made by boring a hole sufficient to admit a 50 mm Schedule 40 PVC pipe. A screen across the bottom of the tube prevented material from entering from the bottom, and a 37 mm section of PVC, slightly shorter than the outer tube, was filled with excavated soil and inserted into the larger tube to maintain a more natural condition. When measurements were made, the inner tube was removed and the probe inserted, penetrating the 5 cm soil layer below the access tube. Five shallow access tubes, 5 cm in depth, were installed at each site. Further tubes were added in 5-cm increments to a maximum depth of 35 cm. Bedrock depth at the majority of sites prevented installation of access tubes deeper than 25 cm. Each site thus maintained anywhere from five to ten access tubes.

Probe Depth – 15 cm

Probe Depth – 35 cm

Probe Depth – 57 cm

Soil moisture content was sampled continuously at three locations using CS-615 reflectance probes, at three (four in one case) depths.

Calibration of theta capacitance probes

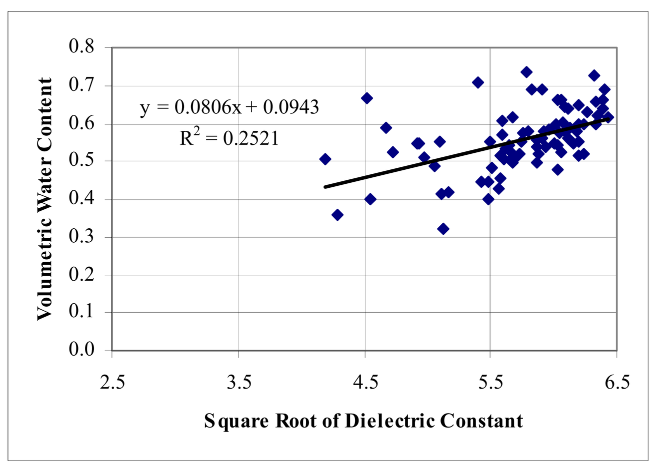
Dielectric constant, ε - Voltage, V relationship provided by the manufacturer.

$$\sqrt{\varepsilon} = 1.07 + 6.4V - 6.4V^2 + 4.7V^3$$

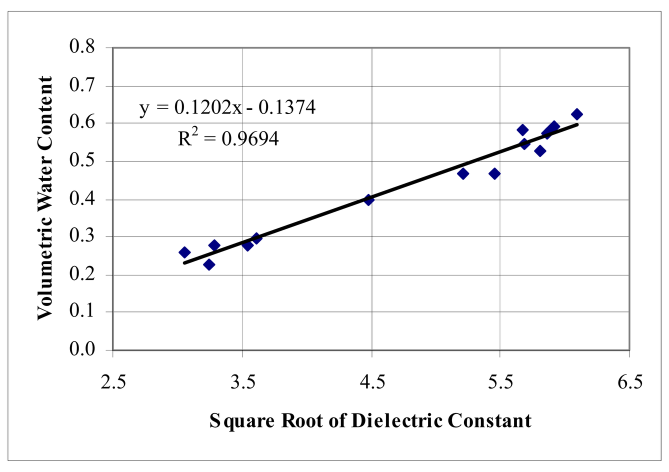
Dielectric constant, ε – volumetric water content, θ relationship suggested by the manufacturer. Parameters a_0 and a_1 are soil dependent.

$$\theta = \frac{\sqrt{\varepsilon} - a_0}{a_1}$$

During the measurement of bulk density, moisture content was obtained gravimetrically. The theta probe was used to record voltage (and hence dielectric constant) inserting the probe into the soil just below where the bulk density sample was taken. We attempted to obtain a field calibration using this data. The result was unacceptable scatter indicating uncertainty in the field soil moisture measurements. Fifteen lab samples of NDW soil were then prepared at different moisture contents and the probe inserted into each to perform a lab calibration. Based upon the linear fit between $\sqrt{\varepsilon}$ and θ we estimated the parameters a_0 and a_1 for NDW soil. These fell between the range of manufacturer suggested parameters for mineral and organic soils. The NDW soil lab calibration parameters were used in the soil moisture mapping (SSM) results shown.



Field Calibration

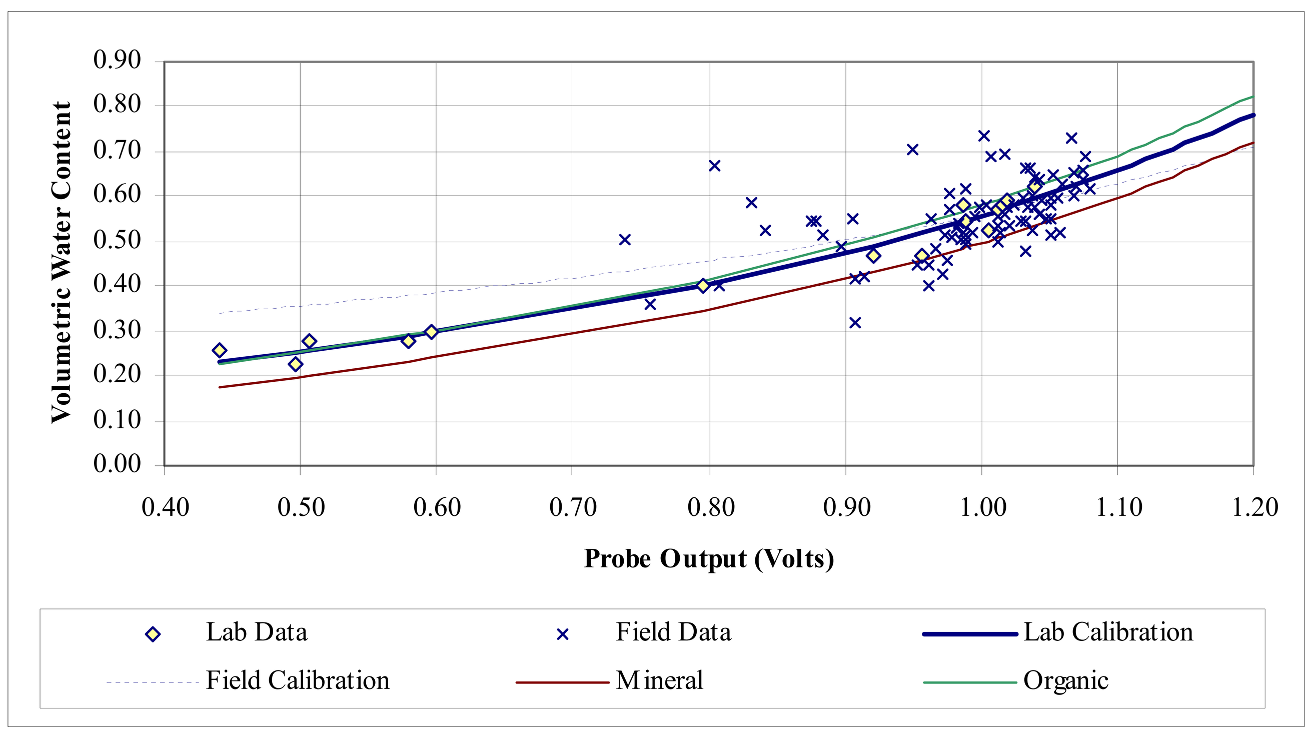


Laboratory Calibration

Theta probe parameters

	Mineral	Organic	**Lab fit**
a_o	1.6	1.3	**1.143**
a_1	8.4	7.7	**8.319**

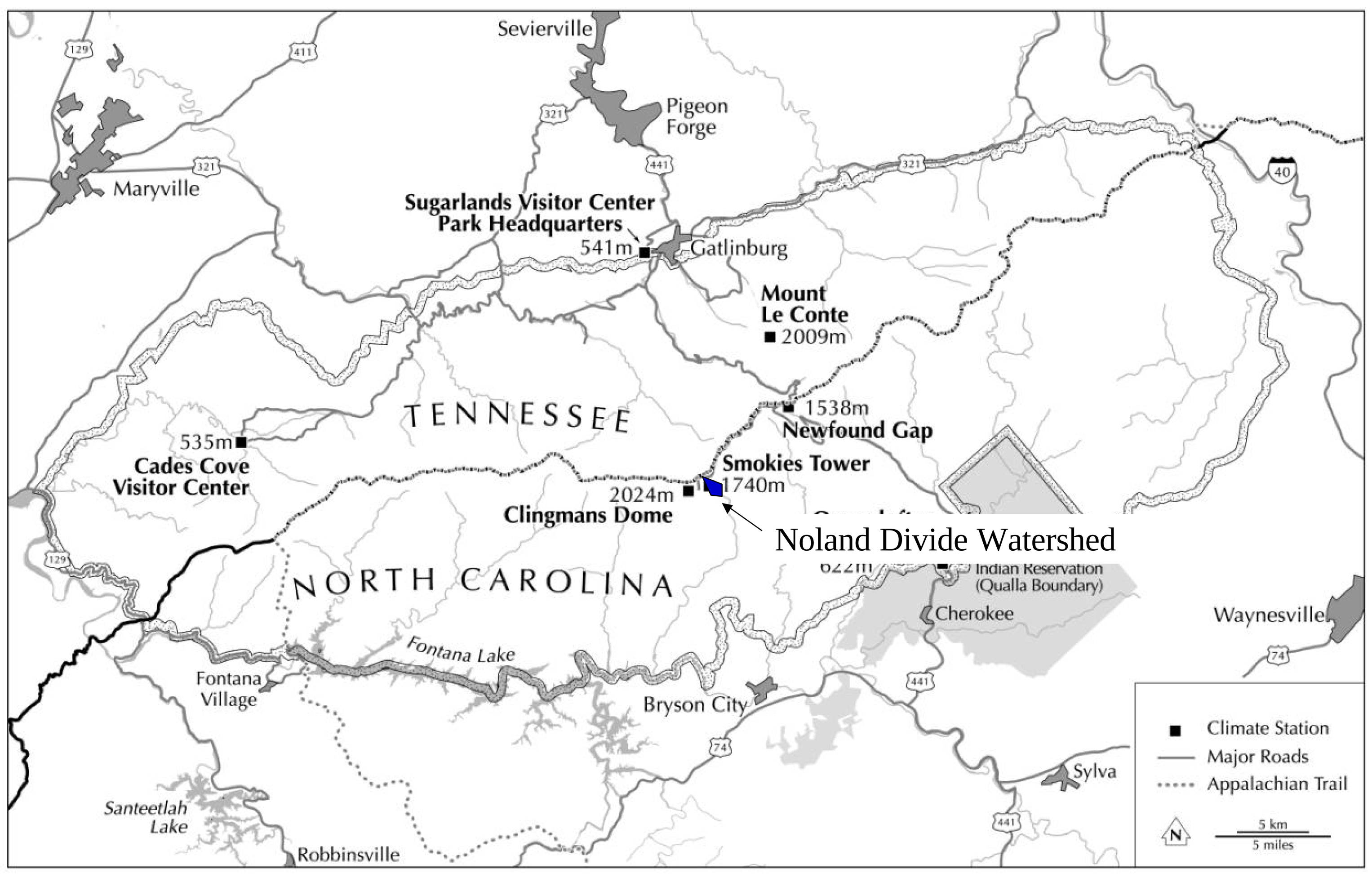
The lab calibration spanned a greater moisture content range and is therefore more reliable. The scatter in the volumetric water content below, we interpret as indicative of the uncertainty due to small scale variability in moisture content.



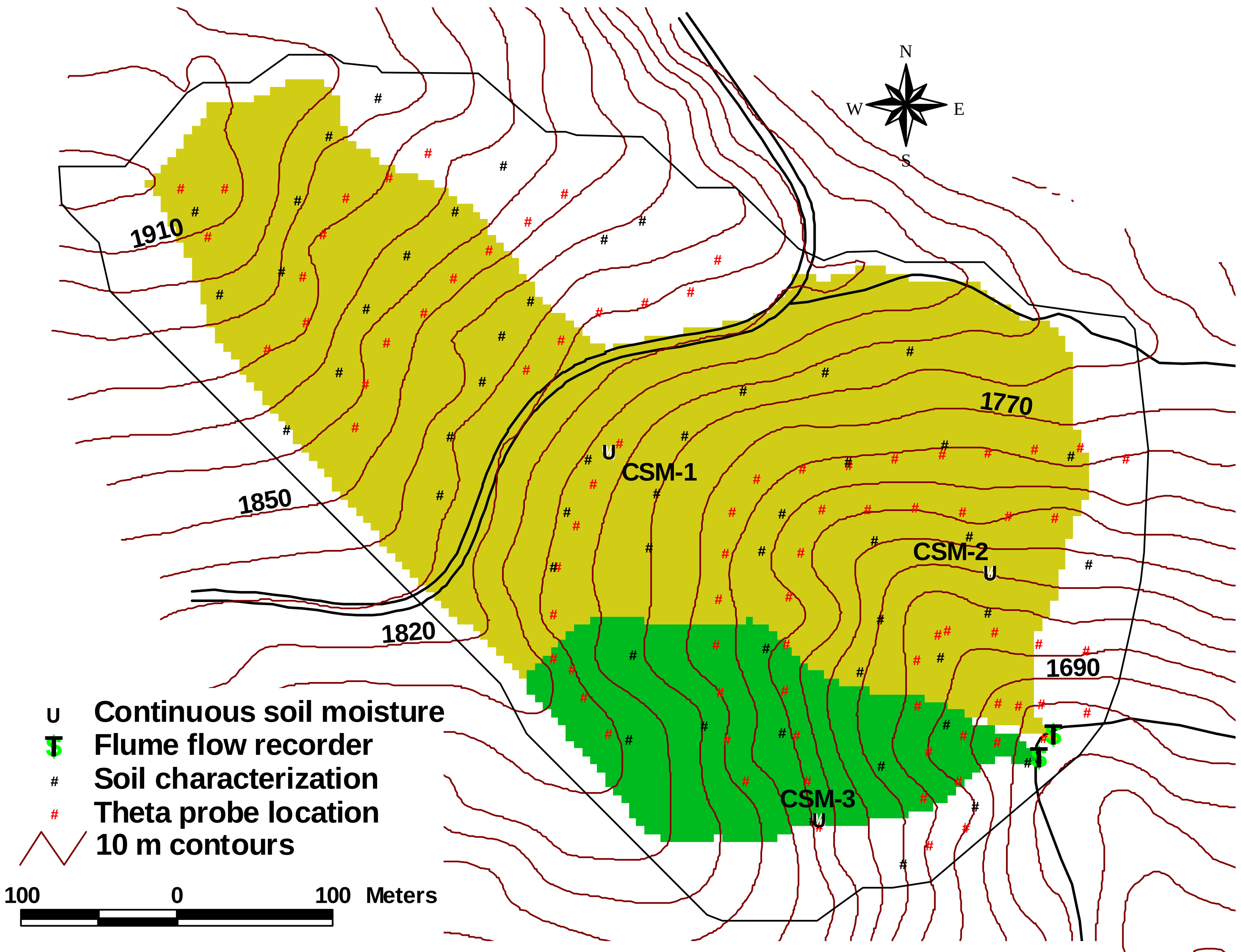
Soil Moisture Variability in a Small Steep Forested Watershed

G Loscher[1] (gloscher@psomas.com); D G Tarboton[2] (dtarb@cc.usu.edu); I Creed[3] (icreed@uwo.ca); K Webster[3] (klwebste@uwo.ca)

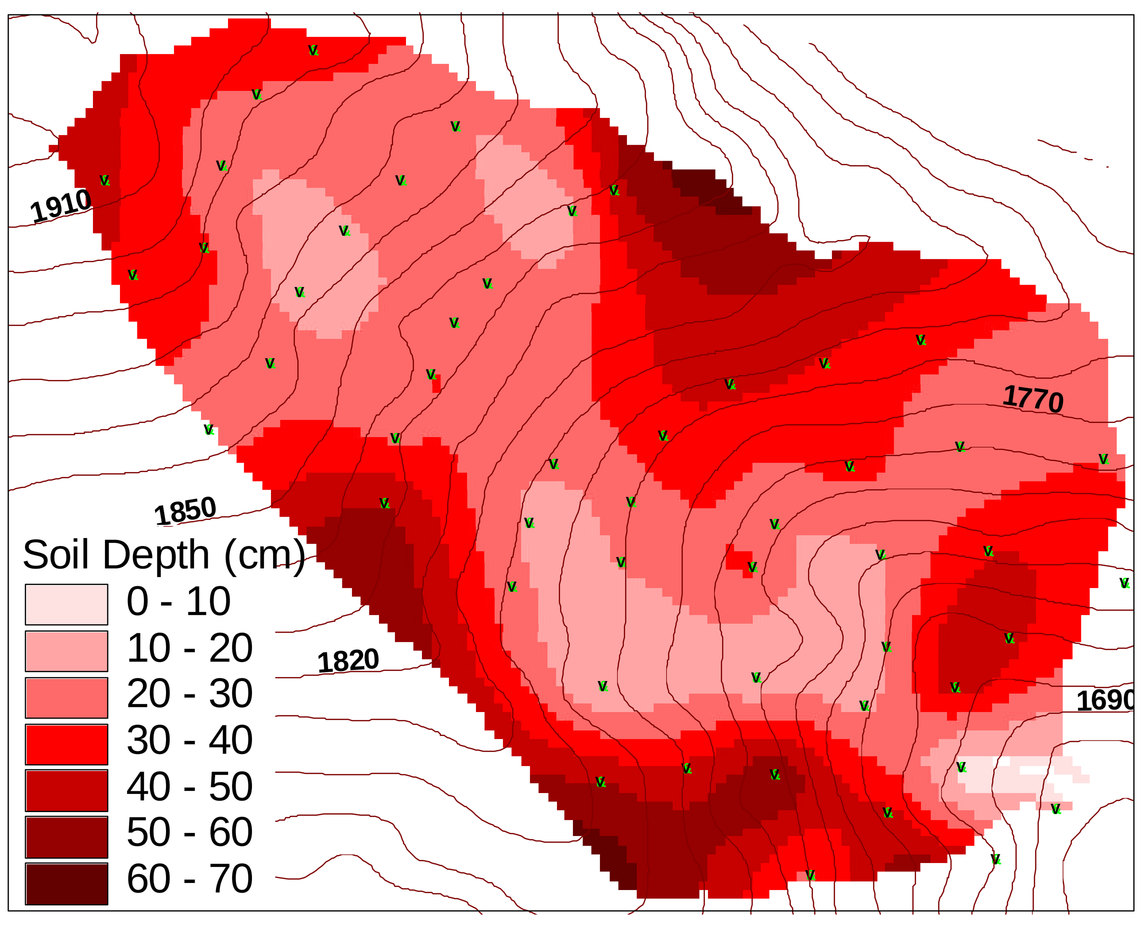
1. Psomas Engineering, 2825 E. Cottonwood Parkway Suite 120, Salt Lake City, UT 84121
2. Civil and Environmental Engineering, Utah State University, Logan, UT 84322-8200
3. University of Western Ontario, London, ON, Canada



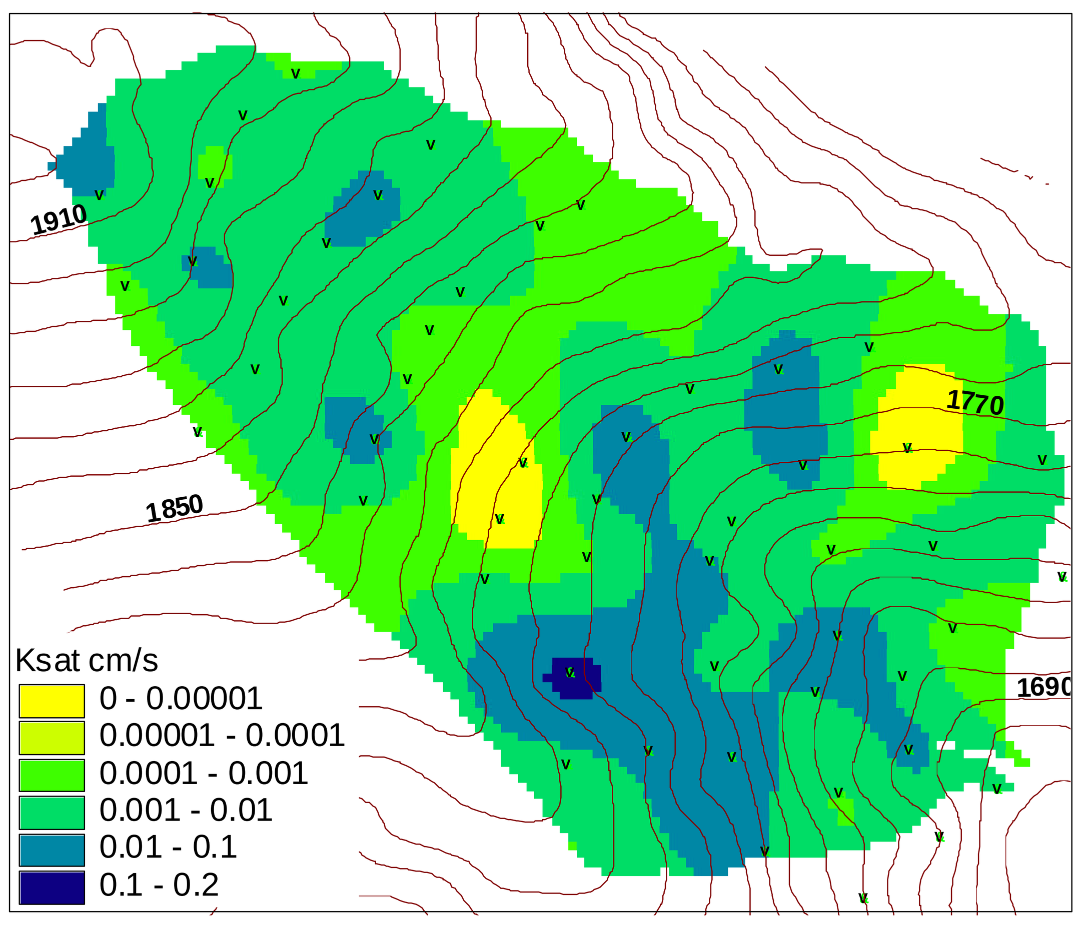
Noland Divide Watershed is located within the Great Smokey Mountains National Park on the Tennessee and North Carolina Border



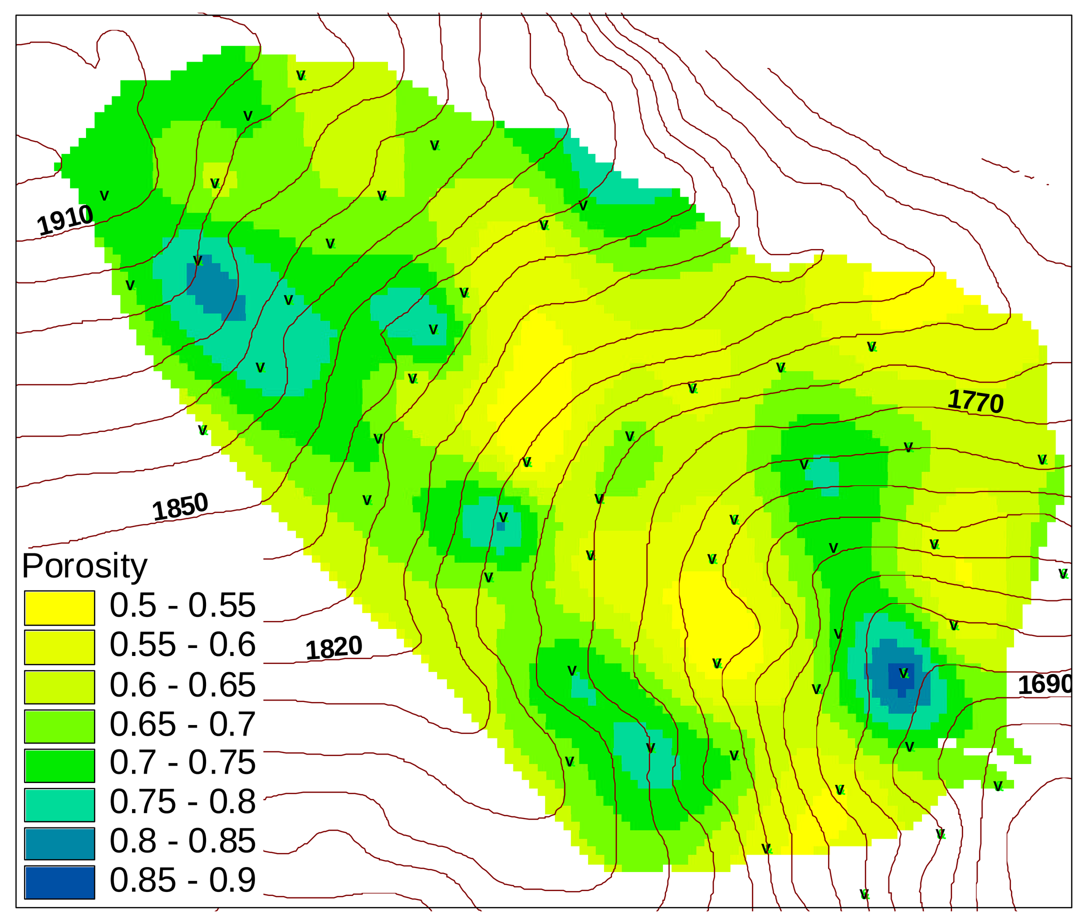
Noland Divide Watershed Instrumentation Map



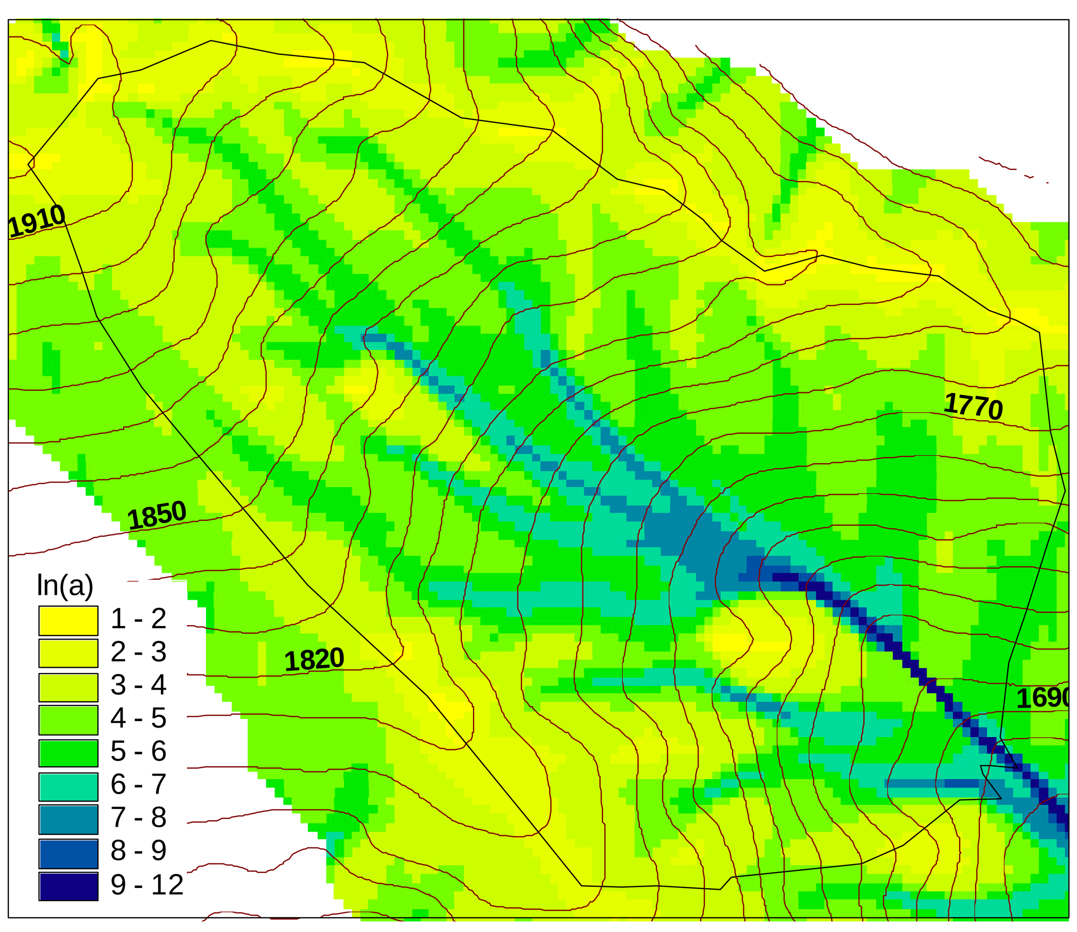
Soil depth on 5 m grid by tension spline interpolation



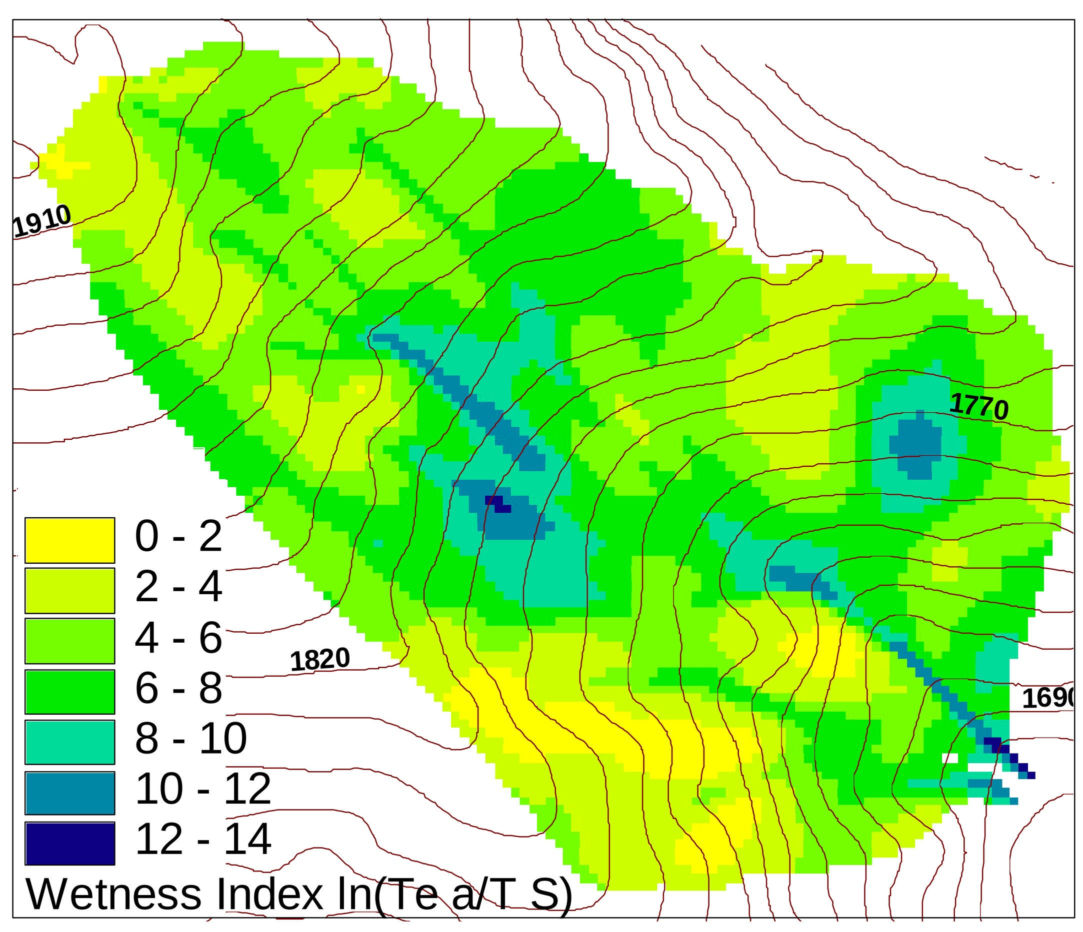
Saturated hydraulic conductivity on 5 m grid by tension spline interpolation of Guelph Permeameter measurements



Porosity on 5 m grid by tension spline interpolation of bulk density measurements



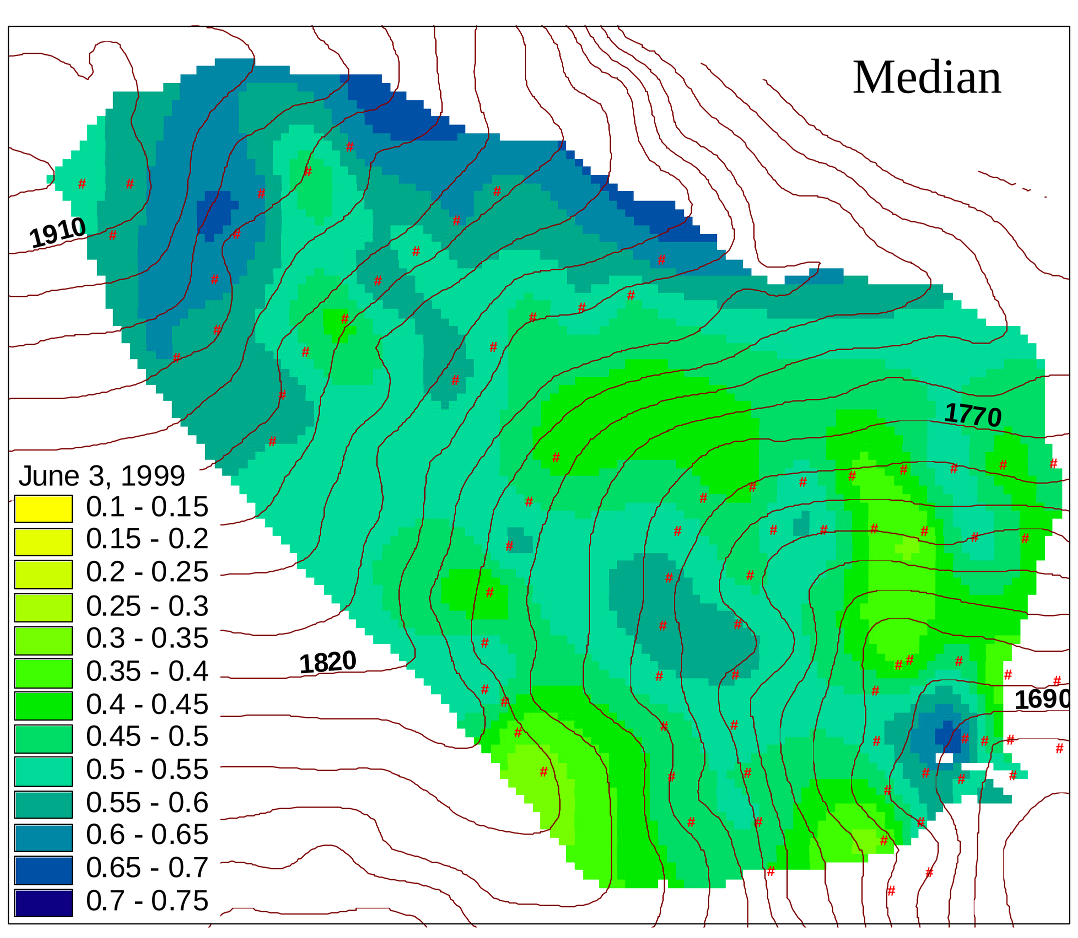
Specific Catchment area

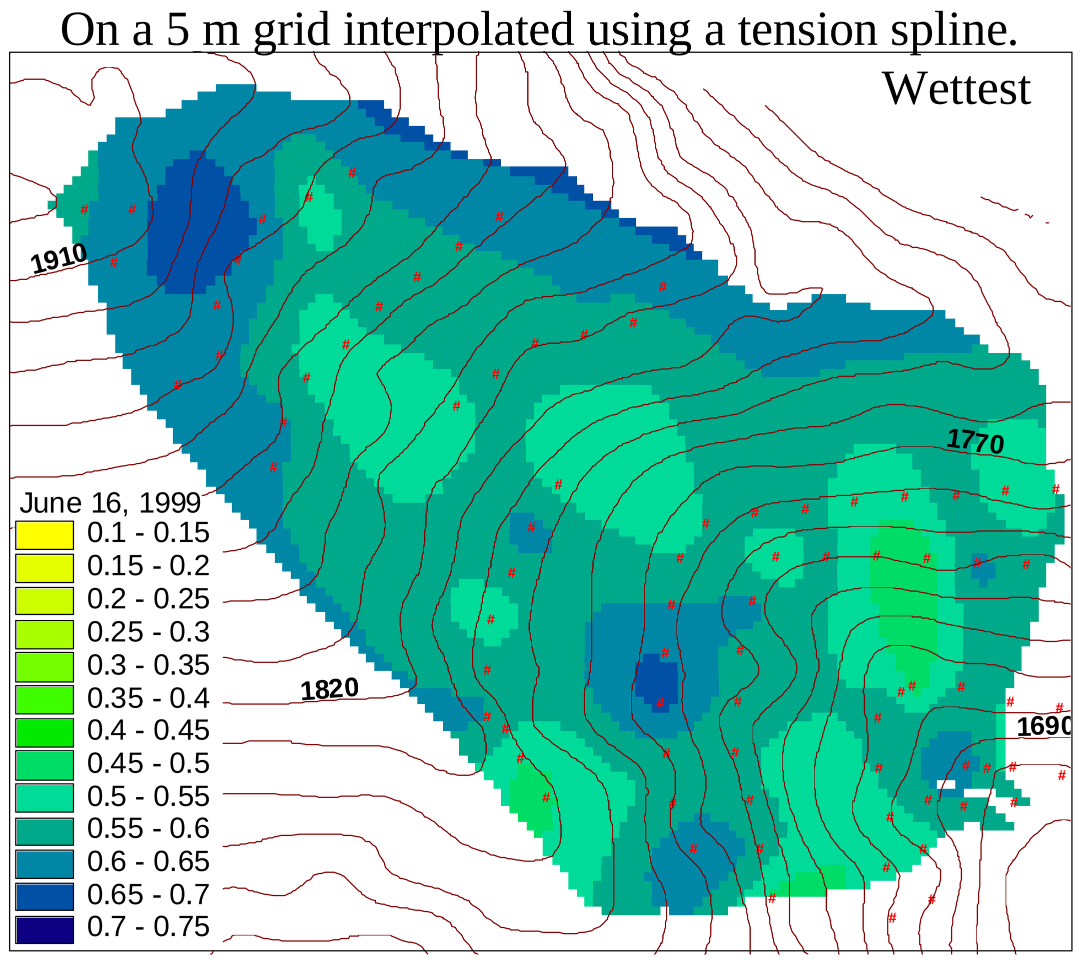


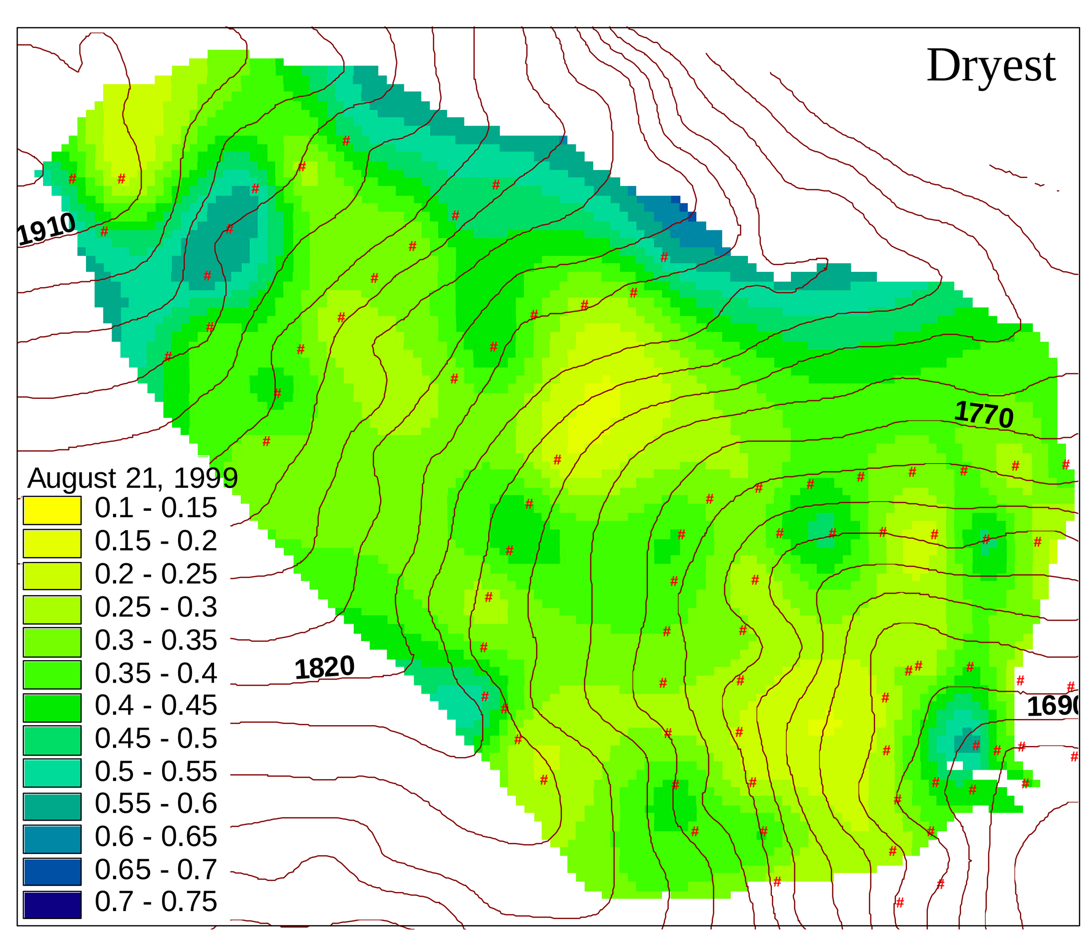
Topographic wetness index

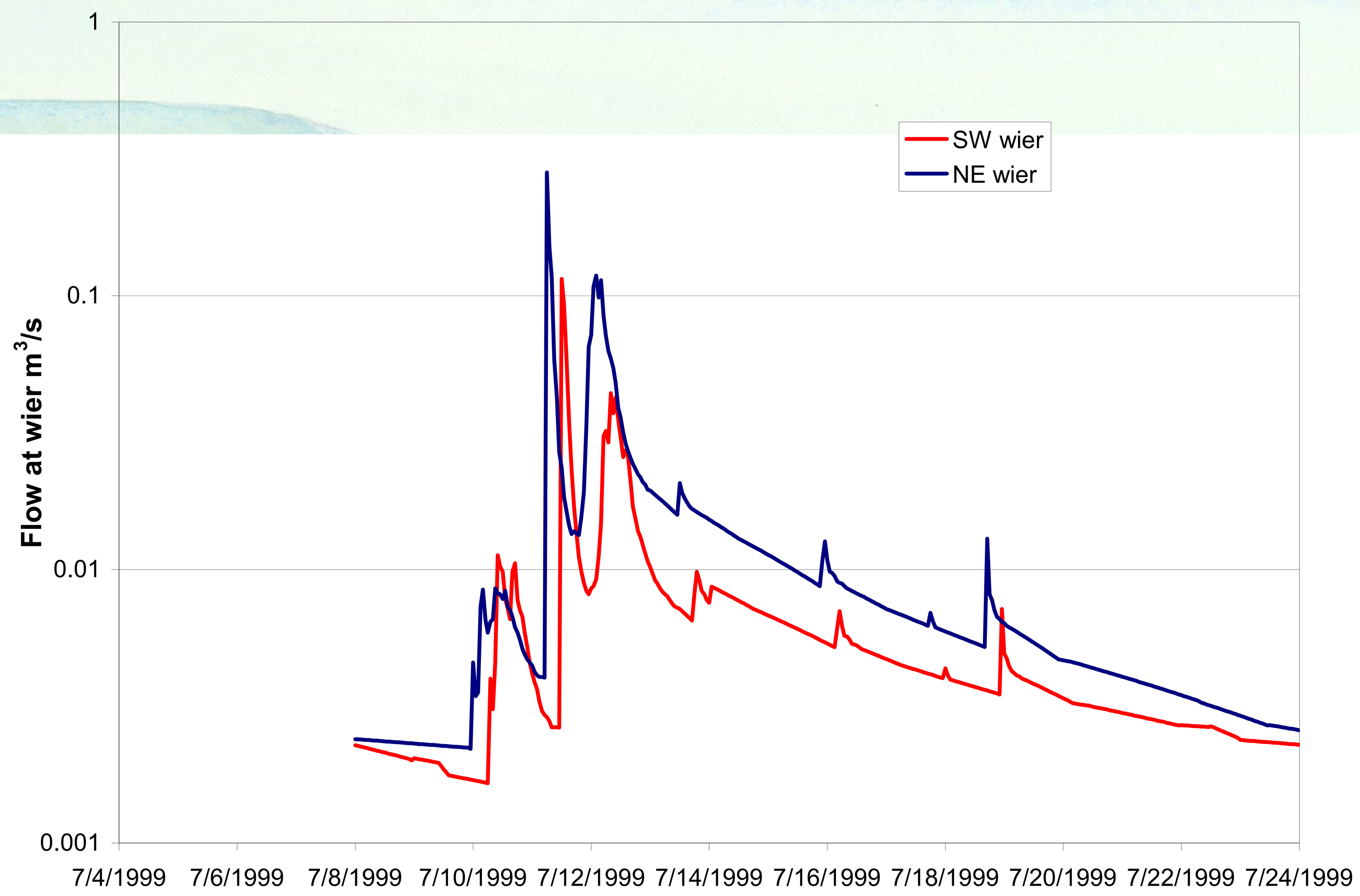
Representative Soil Moisture Maps

On a 5 m grid interpolated using a tension spline.

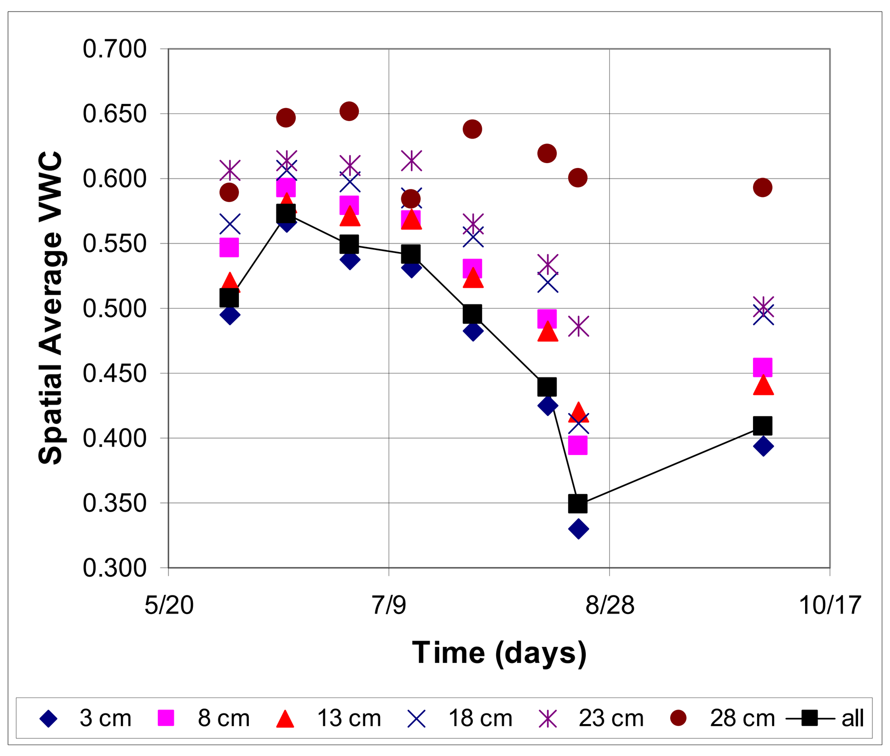


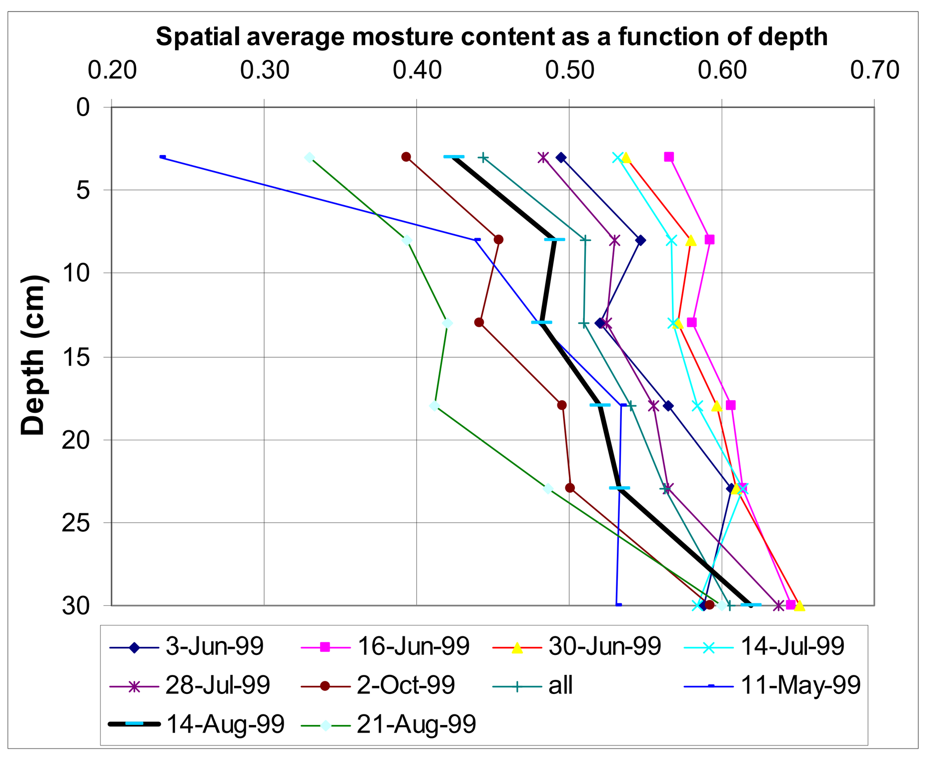




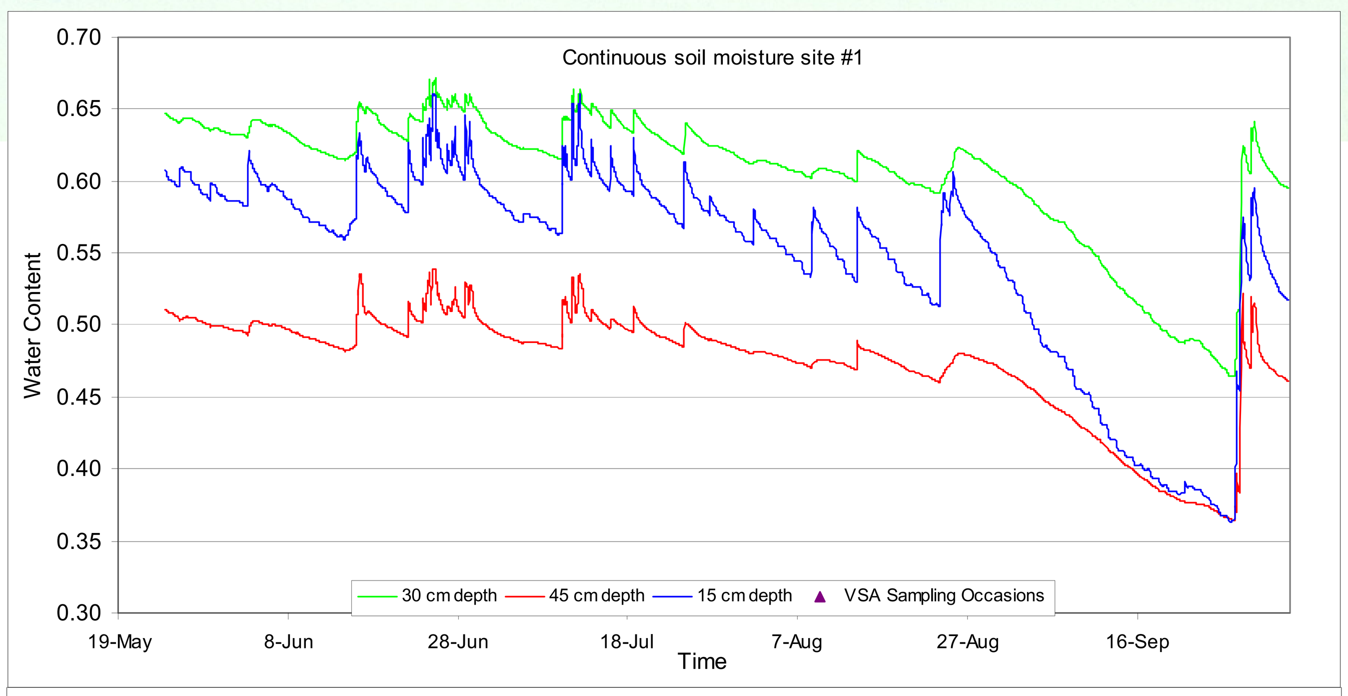


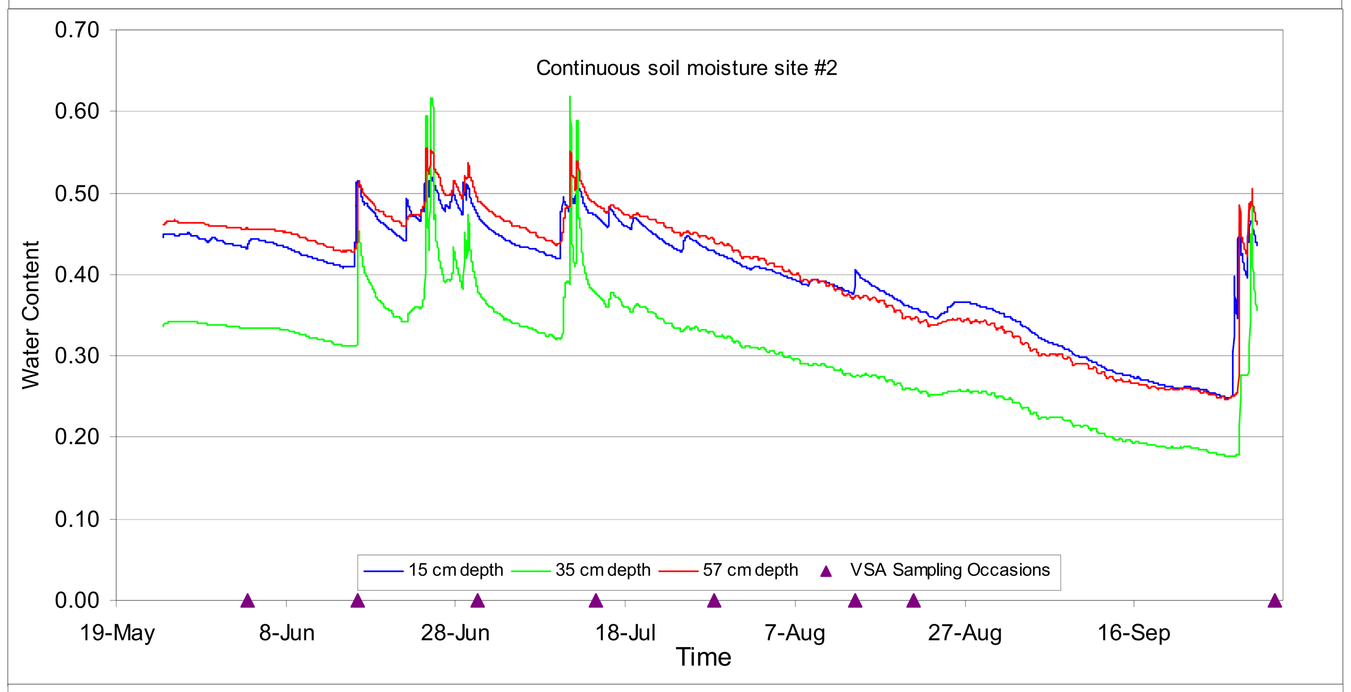
Streamflow, summer of 1999.

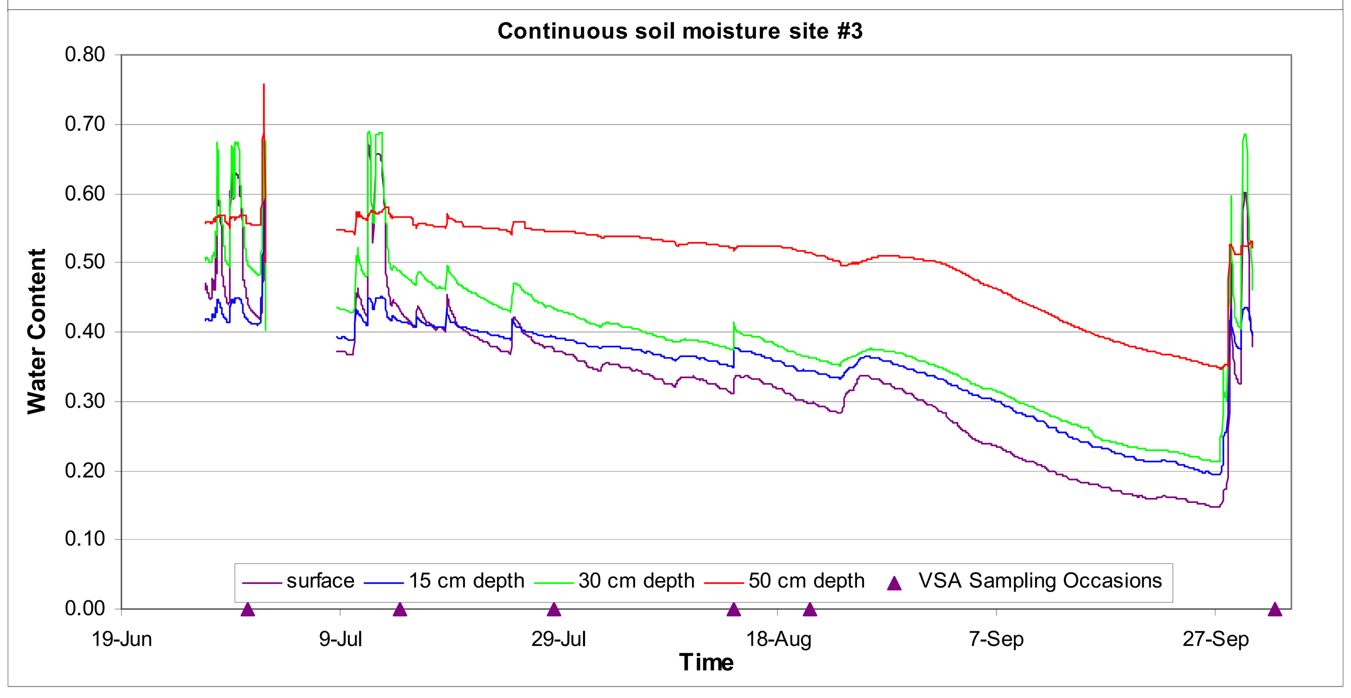




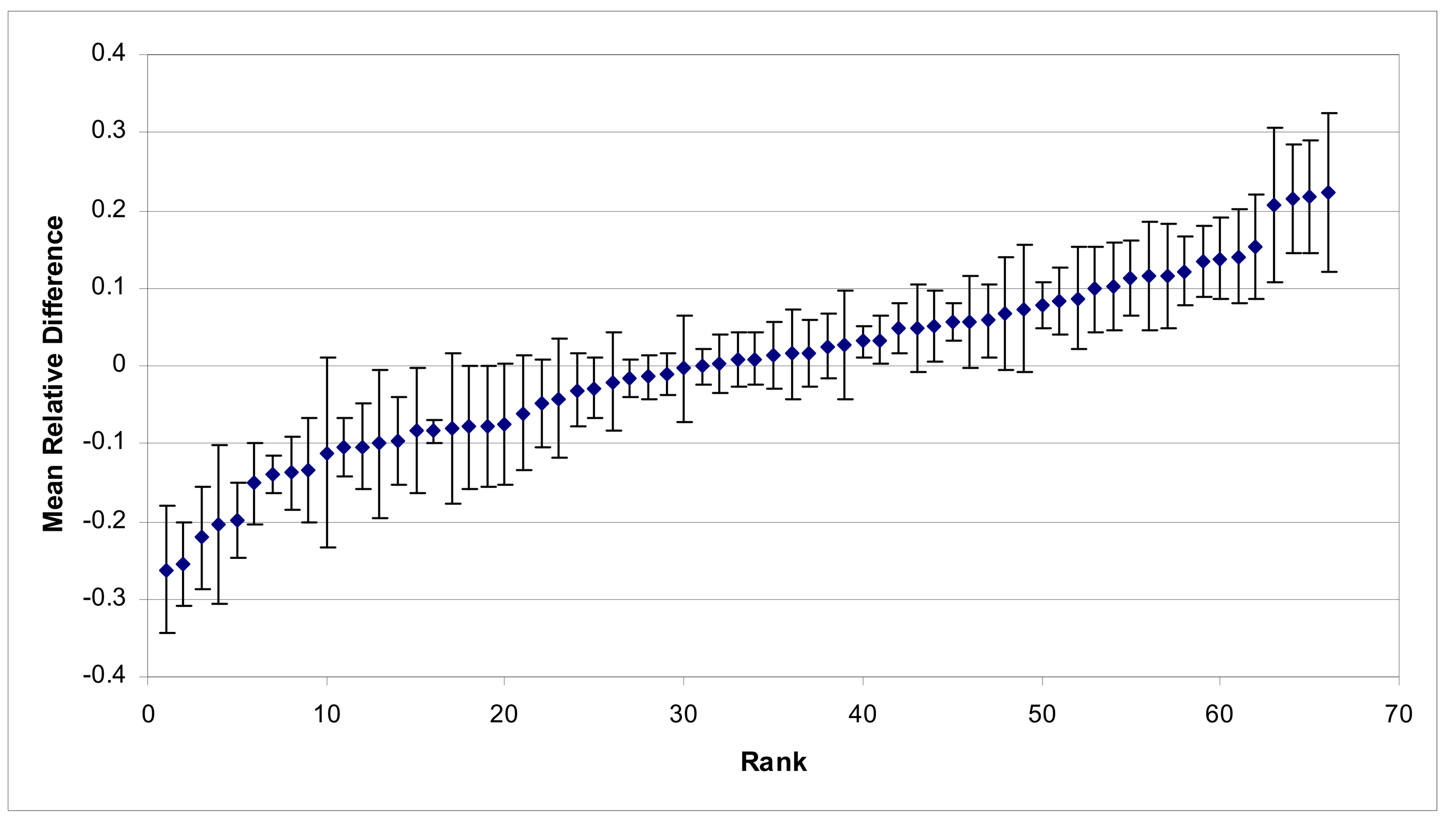
These figures show the watershed average moisture content at each depth from the capacitance probe mapping. Note the relative constant moisture content lower in the soil with wetting and drying fluctuations at the surface.





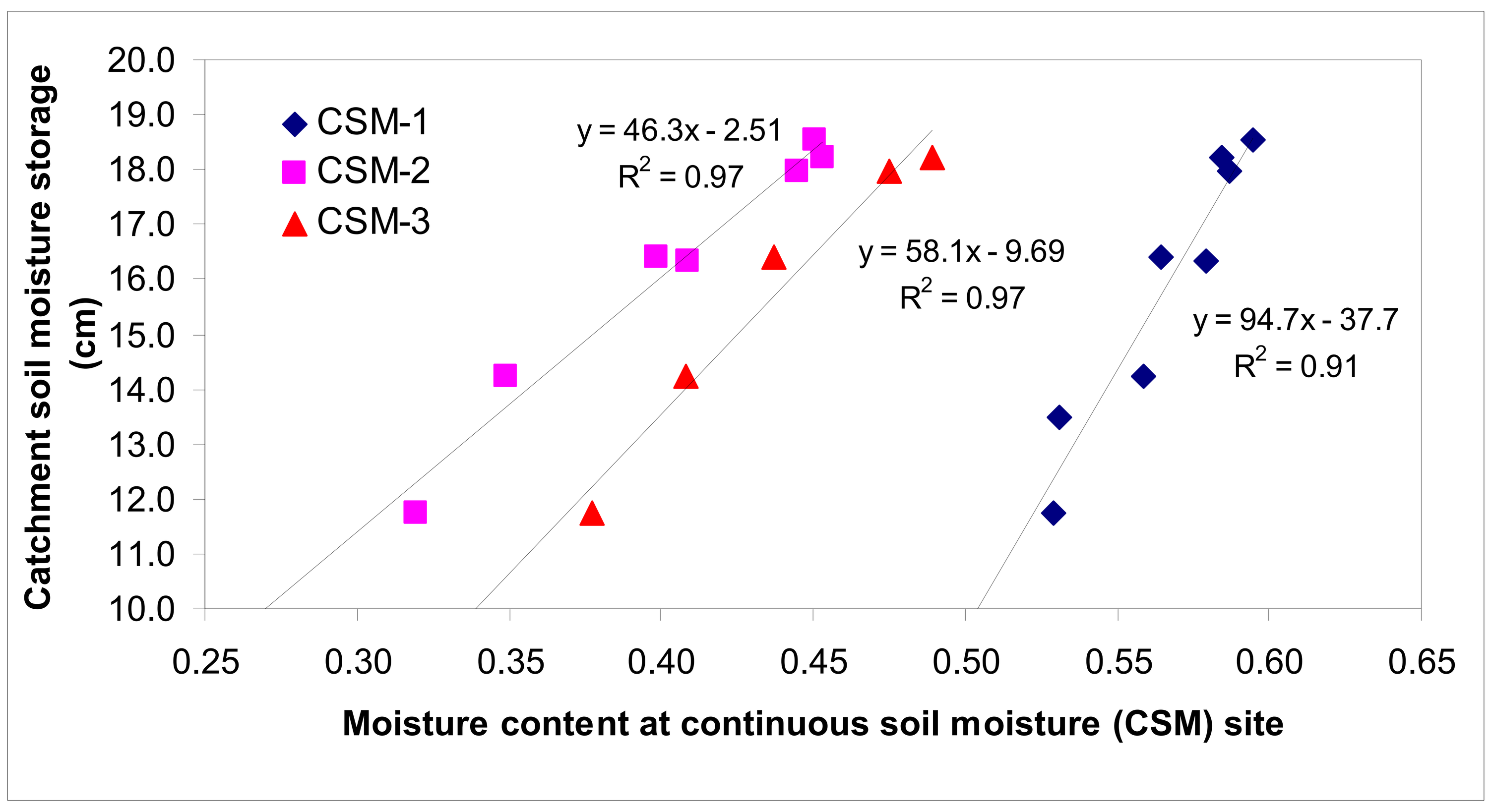


Can point soil moisture measurements serve as a surrogate for catchment averages?



This graph shows the difference between soil moisture (depth averaged) at each capacitance probe location from the mean of all measurements on a given sampling occasion. The dot represents the mean of all differences (over the six sampling occasions used) and the error bars give the standard deviation of the differences at each location. Standard deviations are only based on six sampling occasions. Sites that plot near zero are likely to be representative of the mean catchment soil moisture at any given time. Sites with small standard deviations are relatively "time stable“ (Grayson and Western, 1998). This figure is based on SMM data from 6/3, 6/16, 6/30, 7/14, 7/28, 10/2.

Catchment soil moisture storage at each SSM sampling occasion is estimated on the 5 m grid of interpolated moisture content and soil depths by multiplying soil depth by moisture content and averaging over the grid. This graph shows catchment soil moisture storage versus soil moisture at the continuously monitored sites. The fit suggests that relationships can be established between catchment average soil moisture storage and point soil moisture measurements.



Conclusions

- Relationships do exist between point and catchment average soil moisture.
- Soil moisture profiles exhibit a pivoting behaviour remaining wet near the base and drying above. The base wetness may be sustained by lateral flow near the bedrock, or along preferential paths.
- There was little evidence of strong association between soil moisture and topographic quantities.

Future work

- Reconcile changes in soil moisture that have been observed in soil moisture maps and continuous measurements with the water balance involving precipitation, streamflow and evaporation.
- Look for a discharge versus soil moisture basin response function.

Reference

Grayson, R. B. and A. W. Western, "Towards Areal Estimation of Soil Water Content from Point Measurements: Time and Space Stability of Mean Response," Journal of Hydrology, 207(1-2): 68-82. 1998.

Acknowledgements

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