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Controls on the temporal and spatial variability of soil moisture in a mountainous landscape: the signatures of snow and complex terrain

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Abstract

The controls on the spatial distribution of soil moisture include static and dynamic variables. The superposition of static and dynamic controls can lead to different soil moisture patterns for a given catchment during wetting, draining, and drying periods. These relationships can be further complicated in snow-dominated mountain regions where soil water input by precipitation is largely dictated by the spatial variability of snow accumulation and melt. In this study, we assess controls on spatial and temporal soil moisture variability in a small ($0.02\,\mathrm{km}^2$), snow-dominated, semi-arid catchment by evaluating spatial correlations between soil moisture and site characteristics through different hydrologic seasons. We assess the relative importance of snow with respect to other catchment properties on the spatial variability of soil moisture and track the temporal persistence of those controls. Spatial distribution of snow, distance from divide, soil texture, and soil depth exerted significant control on the spatial variability of moisture content throughout most of the hydrologic year. These relationships were strongest during the wettest period and degraded during the dry period. As the catchment cycled through wet and dry periods, the relative spatial variability of soil moisture tended to remain unchanged. We suggest that the static properties in complex terrain (slope, aspect, soils) impose first order controls on the spatial variability of snow and consequent soil moisture, and that the interaction of dynamic (timing of water input) and static properties propagate that relative constant spatial variability through the hydrologic year. The results demonstrate snow exerts significant influence on how water is retained within mid-elevation semi-arid catchments throughout the year and infer that reductions in annual snowpacks associated with changing climate regimes may strongly influence spatial and temporal soil moisture patterns and catchment physical and biological processes.

1 Introduction

Soil moisture exists at a critical nexus between atmospheric and terrestrial hydrologic processes. It occurs as a balance between the competing demands of the atmosphere, vegetation, and gravitational drainage while also is a controlling factor on numerous catchment processes including runoff generation, groundwater recharge, evapotranspiration, soil respiration, and biological productivity. Understanding the controls on the spatial and temporal variability of soil moisture is an essential step towards developing improved predictive models of catchment processes. A challenge is that the controls on the spatial distribution of soil moisture can be combinations of static (e.g. topography, soil properties) and dynamic (e.g. precipitation, antecedent moisture) variables (Reynolds, 1970). The superposition of static and dynamic controls can lead to different soil moisture patterns for a given catchment or field during wetting, draining, and drying periods (Grayson et al., 1997; Grayson and Western, 1998; Western et al., 1999; Western et al., 2004). For example, Famiglietti et al. (2008) summarized numerous studies and data sets illustrating how the spatial variability of soil moisture content can increase or decrease with the spatial mean moisture content depending on relationships between soils, vegetation, topography, antecedent moisture content, and scale. These relationships can be further complicated in snow-dominated mountain regions where precipitation does not necessarily enter the soil where it falls, but where it melts.

Historical approaches to explain the catchment-scale spatial variability of soil moisture have primarily been motivated by the need to understand runoff generation or other "wet" hydrologic processes and invoke the concept that soil moisture moves laterally according to topography (e.g. Anderson and Burt, 1977; Beven and Kirkby, 1979; O'Loughlin, 1981; Burt and Butcher, 1985; Moore et al., 1988; Barling et al., 1994; Brocca et al., 2007). This concept works well when there is excess moisture that is able to drain freely. In semi-arid environments where moisture is limiting, however, lateral movement of soil moisture may be possible only during brief windows of time (Grayson et al., 1997; Western et al., 1999; McNamara et al., 2005). Grayson et al. (1997) defined two preferred states for soil water dynamics along a hillslope:

1. a wet state, where precipitation exceeds evapotranspiration, hillslopes are hydraulically connected, and lateral flow occurs, and
2. a dry regime, where evapotranspiration exceeds precipitation, hillslopes are hydraulically unconnected, vertical fluxes dominate, and upslope topography does not affect the spatial distribution of soil water.

Grayson et al. (1997) and Western et al. (1999) investigated seasonal soil moisture patterns in the Wagga Wagga and Tarrawarra experimental catchments, Australia. Soil moisture patterns during wet periods of the year exhibited a high degree of spatial organization along drainage lines due to surface and sub-surface lateral flow (dictated by topography) while patterns during the dry period of the year showed low spatial organization associated with variable evapotranspiration demands. Grayson et al. (1997) and Western et al. (1999) described transition periods from the dry to wet conditions in which higher soil water contents were measured in areas of topographic convergence. McNamara et al. (2005) reported similar wet and dry period hydrologic responses for a snow-dominated semi-arid catchment in the Dry Creek Experimental Watershed, Idaho, USA, and suggested the transitional time from the dry to wet period was dependent on snowpack accumulation and persistence.

The influences of soil, vegetation, topography, and precipitation patterns on soil moisture have been extensively investigated (Hawley et al., 1983; Moore et al., 1988; Grayson et al., 1997; Famiglietti et al., 1998; Grayson and Western, 1998; Seyfried, 1998; Western et al., 1999; Gómez-Plaza et al., 2001; Ridolfi et al., 2003; Western et al., 2004; Tromp-van Meerveld and McDonnell, 2006; Brocca et al., 2007), but few studies have documented how snow interacts with other variables to control soil moisture patterns. Literature is particularly limited with respect to these relationships in mid-elevation ephemeral catchments with shallow soils. Understanding catchment processes in these water limited environments requires understanding of how and where water is retained in a catchment, as well as how it leaves a catchment. Redistribution of snow by wind and differential melt patterns controlled by elevation, aspect, and vegetation create spatially heterogeneous snow cover that leads to spatially variable soil moisture patterns (Litaor et al., 2008). The western United States is experiencing decreased snowpack, shifts in timing and volume of snowmelt runoff, and increased evapotranspiration (IPCC, 2007). Twentieth century increases in temperature (e.g. Jones et al., 1999; Brohan et al., 2006) have been accompanied by a shift towards earlier spring snowmelt-driven streamflow (Cayan et al., 2000, Stewart et al., 2005), and substantial declines on 1 April snowpack (Mote, 2003). These changes in snowpack dynamics necessitate understanding how snow impacts the distribution of soil moisture in a catchment in relation to other controlling variables, especially at mid-elevations where annual snow-dominated precipitation regimes are expected to change to rain-dominated.

In this study we assess the controls on spatial and temporal soil moisture variability in a small (0.02 km^2) semi-arid mountainous catchment by evaluating the spatial correlations between soil moisture and numerous site characteristics throughout the water year. The aim of this research is to understand what catchment properties best explain the spatial variability of soil moisture during the semi-arid hydrologic seasons. We assess the relative importance of snow with respect to other catchment properties on the spatial variability of soil moisture and how that variability scales with mean moisture content, and we track the persistence of those controls through a water year. Spatial variability is assessed by correlation analysis, and the temporal persistence of the patterns of variability is assessed by stability analysis.

2 Study site and hydrologic setting

The study was conducted in the Treeline site (0.02 km^2, Fig. 1) within the Dry Creek Experimental Watershed (DCEW) near Boise, Idaho. The Treeline site is located at a mean elevation of 1620 m and has 70 m total relief. The site trends northwest to southeast, with slopes averaging 30° over mostly concave and convex angles. The catchment has one main ephemeral channel with five connecting seep channels (Fig. 1). Soils are coarse-textured and shallow (~ 0.2 to 1.3 m), derived from weathering of the Idaho Batholith, a biotite granodiorite intrusion 75 to 85 million years in age. Soils are classified as coarse-loamy, mixed mesic Ultic Haploxeroll (Harkness, 1977). Treeline is located in a vegetation transition zone between grass and shrub-lands and the forested regions of the DCEW. The primary vegetation includes sagebrush (*Artemisia* spp.), forbs, and grasses. Approximately eight mature trees (*Pinus ponderosa*; *Pseudotsuga menziesii*) are present as isolated individuals.

Precipitation (annual average 57 cm) falls mostly during the cold season, with approximately half the annual precipitation falling as snow (McNamara et al., 2005). Rain-on-snow events are common during the late autumn and early spring seasons. Summer months are hot and dry with infrequent thunderstorm events. Streamflow typically begins in early autumn with the onset of autumn rains, but remains low or episodic with the development of the snowpack. Late autumn and early winter rain-on-snow events and/or complete melt on southerly aspects generate small hydrograph peaks. Snowpack on the northeast facing slope is usually maintained from the onset of snowfall. The annual hydrograph peak usually occurs in March or April depending on the duration of snowmelt (McNamara et al., 2005).

McNamara et al. (2005) described five preferred soil moisture states/periods for the Treeline site based on observations and simulations: (1) dry, (2) wet-up, (3) wet-low flux, (4) wet-high flux, and (5) drydown. The dry period occurs when evapotranspiration exceeds precipitation and soil moisture is greater in deeper portions of the soil profile. The wet-up period begins as autumn rains wet-up the near-surface environment and precipitation exceeds evapotranspiration. The wet-up period is marked by a rapid rise in soil moisture at soil depths from the surface to 45 cm at most points in the catchment. As the autumn season progresses to winter, precipitation shifts from rainfall to snowfall. Precipitation water is stored in the snowpack and water input to the soil is reduced (wet-low flux period). If the onset of a snowpack occurs before the wetting front reaches the soil bedrock interface dry soil at depth can persist through the winter until the snowpack melts. The wet-high flux period begins as the snowpack ripens and continues through the snowmelt period. Soil moisture during the wet-high flux period increases to maximum annual levels throughout the soil profile. The drydown period begins after complete melt of the snowpack and water input is reduced below evapotranspiration. Soil moisture during the drydown period declines first near the surface and more gradually and delayed at depth.

3 Methods

3.1 Site characterization

A 10×20 meter study grid (57 sampling points) was established to characterize catchment physical (topography and soils) and biological characteristics (vegetation) (Fig. 1). Site topography (aspect, elevation, and slope), soil texture, soil depth, and percent live canopy cover were measured at each grid point. Topographic details from each grid point were used in conjunction with 156 additional survey points to generate a digital elevation model (DEM). The percent of coarse (>2.00 mm), sand (<2.00 mm and >0.05 mm), and fine (<0.05 mm) soil fractions were determined by sieving soil samples from each point. Soil depth was determined by pounding a steel rod through the soil profile to refusal. Percent live canopy cover was measured during the spring, summer, and autumn seasons using the Daubenmire method (1959) within 100×70 cm rectangular plots at each study grid point. The autumn season vegetation survey occurred near the beginning of the winter season. Therefore, vegetation measured during the autumn survey was assumed equivalent to that of the winter season. Land surface convexity, concavity, and plan, mean, longitudinal, and cross-section curvature were determined by digital terrain analyses of the survey DEM using Landserf 2.1 (Wood, 1996). Upslope contributing areas for each study grid point were calculated using the D-infinity method within TauDEM (Tarboton, 2003). Snow density and snow water equivalent (SWE) at the time of maximum snow depth were determined by snow survey with Mt. Rose snow samplers.

Meteorological data (precipitation, snow depth, air temperature, relative humidity, wind speed, wind direction, and incoming solar radiation) are collected at a meteorological station located near a ridgeline on the north-facing slope between the middle and lower weirs (Fig. 1). Rainfall and snowfall are measured in a weighing-bucket gauge shielded on a post 1.5 m above the ground surface. Hourly snow depth is monitored near the meteorological station using a Judd sonic depth sensor. Soil moisture near grid location 9 is monitored in 15 min intervals with a Campbell Scientific TDR100 (time domain reflectometry) system at depths of 5, 15, 45, 75, and 105 cm. Data from the meteorological station and TDR100 system are collected with Campbell Scientific CR10X dataloggers. Streamflow at three v-notch weirs is determined from stage-discharge relationships established for each weir by timing the period required for discharge to fill a cylinder of known volume. Stage in the ponds behind each weir is monitored hourly by capacitance rods.

Spatial soil moisture measurements were obtained using a portable TDR unit along the study grid. The portable TDR unit consisted of a TDR100 wave generator, laptop computer, PC-TDR software (cable tester), RG-58 TDR connection cable, and TDR probe. The PC-TDR software calculates the soil dielectric constant from wave travel time, and determines the respective soil moisture content ($m^3 m^{-3}$) using a specified calibration equation (Ledieu et al., 1986). Laboratory testing with ten soil samples from Treeline found volumetric soil moisture content from the portable TDR unit was very strongly correlated (r^2=0.99) with known soil moisture over a range 0.05 to 0.40 $m^3 m^{-3}$, as is expected for soils with low salinity, clay and organic matter content (Jones et al., 2002). Point near-surface soil moisture measurements along the study grid were taken by vertically inserting the TDR probe through the upper 30 cm of the soil profile. Near-surface soil moisture was measured at each point on the study grid on 38 occasions between April 2003 and June 2004. Sampling occurred approximately twice monthly during summer 2003, bi-weekly during autumn 2003, and twice weekly during winter and spring 2004. Near-surface measurements recorded from January through February of 2004 were removed from the data set due to instrument error.

3.2 Temporal stability analysis

Temporal stability analysis (Vachaud et al., 1985; Grayson and Western, 1998; Grant et al., 2004) was used to assess how individual measurement locations deviated from site mean soil moisture conditions. The temporal stability analysis required, for each sample location on each sampling date, calculation of soil water storage (S_{ij}) at the greatest common depth (30 cm) and the relative difference (δ_{ij}) in soil water storage and site mean near-surface soil water storage ($\bar{S}_{ij}$). Soil water storage at each sample location i, at time j, was calculated as:

$$S_{ij}=\theta_{ij}z_{ij} \tag{1}$$

where θ_{ij} and z_{ij} represent measured near-surface soil moisture content and the thickness of the sampled soil profile (30 cm) respectively at location i, time j. A mean relative difference ($\bar{\delta}_{ij}$) was used to describe the difference between near-surface and site mean soil water storage for each preferred soil moisture period and for all sampling dates. The mean relative difference for each location during each period of interest was calculated as the time average of:

$$\delta_{ij}=\frac{S_{ij}-\bar{S}_{ij}}{\bar{S}_{ij}} \tag{2}$$

where $\bar{S}_{ij}$ is site mean near-surface soil water storage observed at time j. Time stability between successive measurement dates was determined by a Spearman correlation coefficient (r_s) described by Vachaud et al. (1985):

$$r_s=1-\frac{6\sum_{i=1}^{n}(R_i(j_2)-(R_i(j_1)))^2}{n(n^2-1)} \tag{3}$$

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀| |▶
◀ ▶
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

where n is the number of observations, $R_i(j_2)$ is the rank of S_{ij} at location i, time j_2, and $R_i(j_1)$ is the rank of S_{ij} at location i, time j_1 . The time stability between two sampling dates becomes more stable as r_s approaches 1, with perfect time stability occurring where r_s=1 (Vachaud et al., 1985).

3.3 Spatial correlations

The extent of influence of several spatially variable site characteristics on point mean near-surface soil moisture was tested with the Pearson correlation coefficient, r. Site characteristics included aspect; concavity and convexity; distance to the divide; distance to stream; elevation; maximum snow depth; percent coarse, sand, and fine soil fractions; percent live vegetative cover (by season); plan, profile, mean, longitudinal, and cross-section curvature; slope; soil depth; snow density at maximum snow depth; snow water equivalent (SWE) at maximum snow depth; and upslope contributing area. The null hypothesis was that soil moisture is not related to a particular site characteristic index or value, i.e. the specific site characteristic exerted no control on the distribution of soil moisture at the site, and r=0. For positive (+) or negative (–) correlations, the statistical significance of r was determined for α=0.05.

4 Results

To assess the relative importance of snow on the spatial variability of soil moisture we first present a summary of the surface characteristics of the catchment. Second, we explain the temporal soil moisture patterns in a single soil pit with continuously logging sensors to illustrate the general behavior through different hydrologic seasons. Third, we relate the spatial soil moisture patterns to the temporal patterns with particular emphasis on how the spatial variability changes with the mean. Fourth, we summarize the temporal stability, or the tendency for any given position to maintain its wetness rank relative the mean. Finally, we relate these spatial and temporal patterns to surface characteristics.

4.1 Surface descriptions

Surface descriptions for the Treeline site are summarized in Table A. The catchment contains aspects from 48 to 226° and encompasses land surface slopes of 7 to 46° (13 to 80%). For description, the catchment is divided into three approximately equal portions. The upper (NW) third contains the channel head and is much less confined and more dissected than the middle third. Hillslope lengths (from ridge to slope base) in the upper third of the catchment are 60 to 75 m in length and are much longer than the hillslopes lower in the catchment. Hillslope topography in the upper portion consists of steep convex and concave angles. The middle third of the catchment is confined by steep convex northeast and southwest facing slopes. Slope lengths in this portion of the catchment are approximately 45 to 50 m. Stream gradient in the middle third is approximately 16%, the lowest for the entire catchment. The lower third of the catchment contributes flow to the stream below the middle weir (Fig. 1). This portion of the catchment opens topographically to the west and remains confined from the southwest by a moderate to steep hillslope averaging 55 m in length from ridge to stream (Fig. 1).

Mean soil depth for the catchment is approximately 0.46 m (range is 0.2 to 1.3 m) with the soil depth generally increasing from the catchment divide towards the channel (Fig. 2a). A secondary trend in soil depth corresponds to snow depth, with the deepest soils and snow drifts occurring mid slope on the SW part of the catchment (Fig. 2a and b). The average percentages of the coarse, sand, and fine soil fractions were 19, 76, and 6, respectively (Table A). The majority of surface rock was found in the northeastern most part of the catchment and along the eastern boundary, and the sandiest soil occurs in the upper third of the catchment (Fig. 2c), immediately upslope of seep channel junctions. Field observations have identified an illuvial clay layer of variable depth immediately above the soil-bedrock interface.

Snow accumulation (Fig. 2b) and snow water equivalent were generally greater in the southwest and central portions of the catchment, with some drifts forming on leeward sides of small seep channels. Average percent live canopy cover (Table A) through the autumn and winter seasons was approximately 9%. Live canopy cover averaged approximately 35% and 45% for the spring and summer seasons respectively. Leaf out began at the site in mid-March. Early spring season forbs and grasses reached heights of 7 cm by late March and shrub leaves began budding by early April. By late April grasses reached approximately 15 cm in height and overall canopy cover increased beyond 20%. By late May grasses at the site were approximately 25 cm in height and shrub cover neared its maximum. Plant cover reached its maximum in mid-June before some species began senescence.

4.2 Temporal soil moisture patterns at a soil profile

The annual soil moisture behavior was similar to that reported in McNamara et al. (2005) with relatively stable dry and wet periods separated by transition seasons (Fig. 3). Figure 3b depicts continuously logged moisture content at four depths in one soil pit. During the dry period, soil moisture ranged from 0.04 in the near-surface to 0.07 m^3 m^{-3} at depth. As the autumn rains commenced in December 2003 (Fig. 3a), soil moisture increased to approximately 0.21 m^3 m^{-3} (Fig. 3b) to a depth of 75 cm. However, soil moisture at the base of the soil profile (>75 cm) remained near 0.07 m^3 m^{-3} for an additional 25 days after the wet-up at 75 cm. McNamara et al. (2005) credited this phenomenon to the precipitation transition from rain to snow. When precipitation phase shifts from rain to snow in early winter additions to soil moisture decline and most storage occurs in the snowpack until the snow melts. The deep soil moisture content reached the wet stable state under a continuous snowpack in mid-January (Fig. 3). In March of 2004, air temperatures increased above 0°C and precipitation began falling predominantly as rainfall (Fig. 3a). The snowpack was completely melted by mid-March. By late May water input at the site decreased dramatically while evapotranspiration demands remained high. Near-surface (15 cm) soil moisture content peaked near 0.25 m^3 m^{-3} in mid-March, declined to 0.07 m^3 m^{-3} in late May following snowmelt, then returned to 0.22 $m^3\,m^{-3}$ following atypically intense spring rains after the wet-high flux period (Fig. 3b). Deep soil moisture peaked in mid-March at 0.37 $m^3\,m^{-3}$ and gradually declined before rising again to 0.22 $m^3\,m^{-3}$ following the late spring rains (Fig. 3b). Drydown followed the unusually high May rainfall and continued through June (Fig. 3b). By the end of the drydown period near-surface soil moisture content fell sharply to 0.07 $m^3\,m^{-3}$ and deep soil moisture decreased to 0.08 $m^3\,m^{-3}$ (Fig. 3b).

4.3 Spatio-temporal soil moisture patterns: relations between spatial variability and mean moisture

The spatial mean, maximum, and minimum moisture contents (Fig. 3b; Table B) display similar temporal patterns as the point-scale moisture contents (Fig. 3b). The maximum, minimum, range, and standard deviation of moisture content clearly increased with the mean (Fig. 4a and b). The relative variability as measured by the coefficient of variation (Fig. 4c), however, did not show any clear trend with spatial mean moisture content indicating that distribution of soil moisture scales with the mean. These results are in contrast with Famiglietti et al. (1999) and Hupert and Vanclooster (2002), who showed decreases in the standard deviation and the coefficient of variation with increasing mean moisture content, but in agreement with Western and Grayson (1998) and Famiglietti et al. (1998).

Mean relative differences of soil moisture exhibit seasonality among the wet ($MRD>0.10$) and dry ($MRD<-0.10$) points (Fig. 5). The extent of spatial-seasonal controls are underscored by the persistence in a wet MRD state at only two points (41 and 24), both of which were headwater seeps, and persistence in a dry MRD state at only point 20 (Fig. 5). Within the wet-drydown seasons, (11 March through 2 June) wet spots tended to stay wet and dry spots tended to stay dry relative to the mean. Soil moisture contents at upper elevation sample locations were generally lower than the site mean soil moisture content with exception of the wet-up period (Fig. 5). These locations are typified by low vegetative cover, shallow soils, and lower snow accumulation than the remainder of the catchment. These data suggest the upper elevation locations exceed site mean soil moisture conditions solely during the wet-up period (Fig. 5) when autumn rains occur. Positive soil moisture MRD values occur primarily in the central portion of the catchment, near the stream channel and ephemeral seeps (points 1, 8, 18, 23, 24, 25, 26, 41) and at locations subject to the greatest contributions of snow water input (points 4, 5, 9, 13, 14, 15, 57, 58). Positive soil moisture content is most pronounced near the channels early during the wet-high flux season, but also occurs at locations where snow accumulated as the catchment soil moisture declines with seasonal drydown (4 May through 2 June, Fig. 5).

4.4 Spatiotemporal correlations with soil moisture

Distance to divide showed the highest (+0.64 on 9 April 2004) and most consistent correlation with soil moisture, with significant positive correlations with soil moisture on 27 of the 38 sampling dates (Table 1). Other variables that were significantly, although weakly, correlated with soil moisture at least 10 times include snow density at time of maximum depth (+; 20), elevation (–; 19), SWE at time of maximum depth (+; 19), northing (–; 18), soil depth (+; 18), percent coarse (–; 15), distance to stream (–; 13), percent sand (+; 13), and snow depth at time of maximum depth (+; 13) (Table 1). In all cases the correlation coefficients show clear temporal trends and maximum correlations for the wet period from mid-April to early-May 2004 (Fig. 6). Following snowmelt, correlations between soil moisture and all tested variables weaken and become insignificant as near surface soil dries. Although our sampling period ended in June 2004, the previous year showed similar patterns with diminishing correlations through the summer and autumn.

The consistent negative correlations in soil moisture with elevation and northing, and positive correlations with distance to the divide indicate drier soil conditions at sample locations in the northern-most portion of the catchment and at higher elevations (Table 1). The correlation results are similar to patterns in mean relative differences (Fig. 5) indicating sample locations in the higher elevations and along ridges consistently represent soil moisture conditions drier than the site average soil moisture content. The spatiotemporal correlations for soil moisture and snow variables (Table 1) are further supported by mean relative difference data that indicate wetter conditions in the locations that accumulate snow and maintain a winter season-long snowpack (Figs. 2b and 5).

The time stability of soil moisture between successive sampling dates followed similar temporal correlation trends as site characteristics correlation coefficients (Fig. 6). Spearman correlation coefficients (r_s, Eq. 3) were lowest (below 0.40) during the drier periods of the year and were consistently between 0.65 and 0.82 through most of the wet period. Time stability between sampling was inconsistent during drydown and decreased to near 0.40 by the beginning of the dry period in 2004 (Fig. 6). These data suggest near perfect time stability of soil moisture during and immediately following snowmelt (wet period) and indicate these relationships break down during the drier periods of the year when transpiration demands are high and water input is low.

Although wet spots tended to remain wet and dry spots tended to remain dry relative to the mean, every point in the catchment experiences occasional large shifts in rank of mean relative difference. To assess the tendency for a position to switch ranks we developed a rank change index (RCI), which is the sum of the absolute values of the differences in rank between successive measurements. For example, points that held the wettest or dry position (rank 1 and 57) for every sample date would have an RCI of 0, and a point that swapped from rank 1 to rank 57 and vice versa ten times would have an RCI of 560. Only two surface characteristics were significantly correlated (α=0.05) with the RCI. Soil depth was negatively correlated (r=−0.36) indicating that locations with deep soils tend to maintain their wetness relative to the mean. Distance to stream was positively correlated (r=0.30) indicating that points closer to ridges go through larger or more frequent wet/dry cycles.

5 Discussion

5.1 The signature of snow

The spatial and temporal variability in the release of snow water may greatly influence the annual spatial distribution of soil moisture in water-limited headwater catchments with shallow soils. In this study distinct spatial patterns of soil moisture were observed that developed at different periods of the hydrologic season. A wet through drydown period persistence in wetter soil conditions was observed in the central and southwest portions of the catchment (Fig. 5). We attribute these distinct patterns and the timing of their development to differing regimes of snow accumulation and melt. The central portion of the catchment represents topographic convergence of several shallow soil hillslopes from the northern end of the catchment (Fig. 2a). Water input upslope from this location is high during the wet-up period due to early winter rainfall and oscillating snowmelt events on these south facing slopes. Soil moisture contents rise in the shallow soil profile until the threshold for lateral flow is reached. Grayson et al. (1997) and Western et al. (1999) reported similar patterns of transition from dry to wet conditions at sites in Australia. Both studies observed wetter conditions in areas of high local convergence during the dry to wet transition period, indicating topographic redistribution of soil moisture. We suggest this occurs in the wet-up period in the northern portion of the Treeline catchment due to high water input into sloping terrain over shallow soils. Topographic convergence near the channel head distributes lateral flow centrally in the basin where vertical and lateral flow combine to form a sub-surface source area (Fig. 5). Anderson et al. (1997) noted a similar source area responsible for streamflow initiation in a steep unchanneled basin in the Oregon Coast Range, USA. The study identified bedrock flow through a weathered bedrock layer along the soil-bedrock interface. Lateral flow through the bedrock layer intersected soil water infiltrating vertically in the soil profile near the channel head. The combined flow paths developed a variable sub-surface source area that dictated streamflow generation. We propose a similar development of the sub-surface source area observed in this study centrally located near the channel head (Fig. 5), formed by the lateral and vertical convergence of early snowmelt sources.

In contrast, delayed soil water input from snowmelt in the southwestern portion of the catchment propagates, along with the sub-surface source area, persistent soil moisture patterns through drydown. Snow accumulation during the wet-up and wet-low flux periods is substantially greater in the southwestern portion of the catchment (Fig. 2b). In this location, stored water in the snowpack is released into the soil profile during the wet-high flux period (McNamara et al., 2005) and increases soil moisture contents above the site mean soil moisture content (Fig. 5). These soil moisture conditions persist into the drydown period (Fig. 5) until evapotranspiration demands exceed water input and lateral flow discontinues (Grayson et al., 1997; Western et al., 1999). Soils in the northern portion of the catchment dry out first in the absence of snow water input (Fig. 5).

The influence of snow on soil moisture patterns in this study is consistent with Litaor et al. (2008) and contrasts Grant et al. (2004). Litaor et al. (2008) studied interrelationships of snow depth, SWE, snow disappearance rate, soil moisture (0–15 cm depth), vegetation, and terrain factors at a mountainous snow-dominated site in Colorado, USA. The study found significant correlations in snow disappearance and SWE and terrain factors that control snow distribution, and soil moisture was significantly correlated with snowfall and terrain. Soil water deficits in windblown areas were offset by rainfall and meltwater sources. Grant et al. (2004) investigated soil moisture patterns in a semi-arid snow-dominated mountainous catchment in Idaho and determined snow exerted little influence on the spatial and temporal variability of soil moisture. The study found percent clay and coarse fragment soil contents exerted the greatest influence (soil water storage) on soil moisture and suggested rapid passing of snowmelt contributions in excess of storage capacity through the sampled portion of the soil profile (0–75 cm depth) minimized the influence of snow water input. The stronger influence of snow water input in this study, in contrast with Grant et al. (2004), is attributed to more limited distribution and quantity of snow cover and the temporal variance in spatial snow water input into the soil profile as described above. The results from the studies cited here and from this study indicate seasonal soil moisture patterns in snow-dominated watersheds are a function of static and dynamic controls and that the relative contribution of those controls is partially dependent on their spatial expanse.

5.2 Interaction of static and dynamic controls on soil moisture

Although the static controls on soil moisture observed in this study and their seasonality are similar to those reported by others (Grayson et al., 1997; Western et al., 1999; Gómez-Plaza et al., 2001; Grant et al., 2004; Tromp-van Meerveld and McDonnell, 2006), the reasons for significance are strongly associated with static influences on snow distribution and melt. Significant correlations of soil moisture with aspect and topography variables during wet-up (Table 1) can be explained by the influence of these characteristics on early season snowmelt and sub-surface soil water routing in the northern portion of the catchment. Wetter soil moisture conditions that developed in the north-central portion of the catchment during this period (Fig. 5) resulted in hydrological processes commonly observed in more humid to semi-humid environments (Beven and Kirkby, 1979; O'Loughlin, 1981; Burt and Butcher, 1985; Moore et al., 1988; Barling et al., 1994; Anderson et al., 1997; Brocca et al., 2007). Shallow soils, steeply sloped terrain, and high water input facilitated wetting of the soil profile, initiation of lateral flow, and lateral routing of soil water to a growing, centrally located, sub-surface source area (Fig. 5). Significant negative correlations of soil moisture with northing, elevation, and distance to the divide and positive correlations with snowpack variables and soil depth during the ensuing wet-high flux period (Table 1) are explained by the distribution of available water (snowpack and soil water storage). Snowpack and soil depth and available soil water (sub-surface source area) were generally greater at lower elevations (decreasing northings) and farther from the slope divide. Positions near the slope divide are often windswept of snow or experience early season melt due to intense solar radiation. These correlations suggest the spatial domain of the dynamic influence of snowmelt on soil moisture patterns is dependent on how static variables like slope position and orientation influence snow pack development and retention of snow and early season meltwater (Litaor et al., 2008).

Grayson et al. (1997) suggested soil moisture patterns during wet preferred periods in semi-arid climates are the result of upslope influences, mainly lateral flow processes. Lateral flow processes were likely influencing soil moisture patterns during the wet-high flux period, but we suggest it was the preceding interaction of static properties like aspect and slope position with dynamic controls (snowfall and redistribution) that dictated the overall catchment soil moisture patterns from wet-up through drydown. During drydown, the available storage of snow water input dictated the persistence of high soil moisture contents in the catchment. Other studies have suggested soil water storage in deep soils and soil texture exert significant control on annual soil moisture patterns (Grant et al., 2004; Seyfried and Wilcox, 2006; Tromp-van Meerveld and McDonnell, 2006). The data presented in this study suggest both act as significant controls on soil moisture patterns by governing retention of wet period soil moisture throughout the year.

5.3 Scaling of moisture variability with spatial mean

Several studies have documented increases in soil moisture variability with increases in the mean (e.g. Famiglietti et al., 1999; Hupert and Vanclooster, 2002), while others have documented decreases in soil moisture variability with increases in the mean (e.g. Western and Grayson, 1998). Famiglietti et al. (2008) provides a comprehensive review of these studies as well an analysis of multiple data sets covering spatial scales from 2.5 m to 50 km. The contradictory observations concerning how variability changes with mean moisture content have motivated numerous studies to attempt to explain the structure of moisture variability from basic principles (i.e. , Albertson and Montaldo, 2003 and Teuling and Troch, 2005). Albertson and Montaldo (2003) suggested that topography controls variance during wet periods, but that the control is diminished during dry periods. They further showed that heterogeneous precipitation fields can either produce or destroy variance depending on background moisture conditions. Teuling and Troch (2005) constructed a hydrologic model that showed the main discriminating factor to determine if variability increase or decreases with mean moisture content is whether or not the soil dries below a critical moisture content, which is controlled by the interaction of soil and vegetation properties with precipitation.

We suggest that variable snow distribution coupled with the high relief and variable soil depths in small mountain watersheds imparts a signature of variability on soil moisture during snowmelt that persists even through the dry periods. This idea is supported by the following observations:

1. The standard deviation of moisture content scales linearly with the mean while the coefficient of variation remains relatively stable (Fig. 4),

2. $\mathrm{SWE}_{\mathrm{max},}$ distance to divide, and, and soil depth all have strong correlation with moisture content during wet-up and snowmelt that diminish but persist through drydown (Table 1), and

3. with few exceptions points within the watershed tend to maintain their wetness position.

Further, the positive relationship between mean moisture content and the standard deviation of moisture content exists during discrete wetting and drying periods as well as during prolonged stable dry periods (data not shown). That is, there is no threshold moisture content at which the variability-mean moisture content relationship changes, such as has been observed or modeled in many studies cited above.

Snowmelt creates heterogeneous precipitation fields in complex terrain due to redistribution by wind and to aspect-controlled differential melt patterns that does not commonly occur for rain except at much larger scales. Numerous studies have shown that heterogeneous rain fields create soil moisture variability at large scales (Famiglietti et al., 2008; Kim and Barros, 2002; Oldak et al., 2002). Snowmelt, therefore, imparts an initial variable to soil moisture over relatively small scales. This signature is enhanced as soil moisture is redistributed by topographic controls soon after snowmelt. Water migrates downslope where snow and soils tend to be deeper. Deep soils store moisture against evapotranspiration during dry period. We suggest when static landscape properties are strong sources of variability (topography, slope position, soil properties) the variability that these properties impose on soil moisture tends to persist.

6 Conclusions

We have shown that spatial distribution of snow, along with slope position, soil texture, and soil depth, has significant control on the spatial variability of moisture content throughout most of the hydrologic year. These relationships are strongest during the wet period and degrade as the catchment dries. As the catchment cycles through wet and dry periods, the relative spatial variability of soil moisture tends to remain unchanged. Further, points in the catchment tend to maintain their wetness rank with respect to the mean, with the exception of ridgetops that wet and drain rapidly. Wet locations tend to remain wetter than average, particularly in deep soils, and dry locations tend to remain dryer than average. We suggest that the static properties in complex terrain (slope, aspect, soil depth) impose first order controls on the spatial variability of snow and consequent soil moisture, and that the interaction of dynamic (timing of water input) and static properties propagate that relative constant spatial variability through the hydrologic year.

The results suggest snow exerts significant control on how water is retained in mid-elevation snow-dominated semi-arid catchments. It is expected that precipitation in mid-elevation mountain sites such as the Treeline site will transition from snow-dominated to rain-dominated in coming decades. The inference is that significant reductions in snow accumulation will strongly influence the processing of precipitation and the subsequent spatial and temporal distribution of soil moisture within these systems. The impacts of these changing hydrologic patterns on physical and biological processes are not investigated here, however, the implication is a conversion of snow-dominated to rain-dominated precipitation will significantly alter the seasonal availability of soil moisture for other ecosystem processes. Furthermore, predictive models will need to incorporate the requisite influences of static and dynamic variables on catchment processes.

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Table 1. Spatial correlations (r) of soil moisture and surface characteristics and level of significance (α). Correlations with $\alpha<0.05$ are bold.

Sample Date Pearson Correlation (r) and level of significance (α)		Northing (m)	Easting (m)	Elevation (m)	Soil Depth (m)	Aspect (°)	Profile Curvature	Planar Curvature	Mean Curvature	Long. Curvature	X-Section Curvature	Concavity	Convexity	Slope (°)	Contributing Area (m^2)	Distance to Divide (m)	Distance to stream (m)	Coarse %	Sand %	Fines %	Summer Cover %	Spring Cover %	Fall /Winter Cover %	Max. Snow Depth (cm)	Snow Density at Max. Depth (cm)	SWE at Max. Snow Depth (cm)
4/6/2003	r	**−0.39**	0.20	**−0.45**	**0.32**	−0.10	−0.17	0.10	−0.14	−0.15	−0.06	−0.01	−0.20	0.05	0.22	**0.43**	**−0.30**	**−0.34**	**0.31**	0.18	0.19	0.20	0.04	**0.27**	**0.30**	**0.30**
	α	**0.00**	0.13	**0.00**	**0.02**	0.47	0.21	0.48	0.30	0.27	0.64	0.94	0.13	0.71	0.10	**0.00**	**0.02**	**0.01**	**0.02**	0.19	0.15	0.14	0.75	**0.04**	**0.02**	**0.02**
4/7/2003	r	**−0.48**	0.12	**−0.53**	**0.29**	**−0.29**	−0.25	0.21	**−0.29**	**−0.26**	−0.22	**−0.29**	−0.23	0.24	0.16	**0.55**	**−0.45**	**−0.27**	0.24	0.17	0.18	0.14	0.11	**0.33**	**0.35**	**0.36**
	α	**0.00**	0.36	**0.00**	**0.03**	**0.03**	0.06	0.11	**0.03**	**0.05**	0.09	**0.03**	0.08	0.08	0.25	**0.00**	**0.00**	**0.04**	0.07	0.21	0.19	0.29	0.43	**0.01**	**0.01**	**0.01**
4/9/2003	r	**−0.29**	0.11	**−0.30**	**0.31**	−0.16	**−0.26**	0.11	**−0.28**	**−0.26**	−0.20	−0.14	**−0.32**	0.11	−0.04	**0.41**	−0.21	**−0.38**	**0.39**	0.07	0.14	0.10	0.08	0.12	**0.28**	0.19
	α	**0.03**	0.44	**0.02**	**0.02**	0.22	**0.05**	0.43	**0.03**	**0.05**	0.14	0.29	**0.01**	0.44	0.77	**0.00**	0.11	**0.00**	**0.00**	0.61	0.31	0.45	0.53	0.39	**0.03**	0.16
4/10/2003	r	−0.05	0.10	−0.16	0.16	0.25	−0.02	0.18	−0.09	−0.01	−0.19	0.01	−0.14	0.19	0.23	**0.42**	**−0.29**	0.00	0.01	−0.01	−0.02	−0.11	−0.15	0.15	0.15	0.16
	α	0.70	0.44	0.23	0.23	0.06	0.86	0.17	0.51	0.92	0.16	0.95	0.29	0.16	0.08	**0.00**	**0.03**	0.98	0.95	0.93	0.86	0.42	0.27	0.27	0.26	0.25
4/11/2003	r	**−0.50**	0.24	**−0.51**	**0.42**	−0.25	−0.14	0.18	−0.20	−0.15	−0.20	−0.17	−0.18	0.16	0.04	**0.32**	**−0.33**	−0.11	0.09	0.11	0.13	0.17	0.09	**0.42**	**0.49**	**0.49**
	α	**0.00**	0.08	**0.00**	**0.00**	0.06	0.30	0.17	0.14	0.27	0.14	0.20	0.19	0.23	0.77	**0.02**	**0.01**	0.41	0.52	0.41	0.34	0.22	0.48	**0.00**	**0.00**	**0.00**
4/17/2003	r	−0.23	0.11	−0.22	0.19	−0.01	−0.19	0.03	−0.19	−0.19	−0.10	−0.05	−0.25	0.20	0.11	**0.35**	−0.18	−0.21	0.24	−0.03	−0.10	−0.17	−0.11	**0.30**	**0.28**	**0.32**
	α	0.09	0.41	0.09	0.15	0.95	0.16	0.85	0.16	0.15	0.45	0.72	0.06	0.13	0.40	**0.01**	0.18	0.11	0.07	0.81	0.48	0.22	0.39	**0.02**	**0.03**	**0.02**
6/24/2003	r	**−0.31**	0.16	**−0.33**	**0.34**	−0.15	−0.21	−0.02	−0.17	−0.24	0.03	−0.03	−0.24	0.24	−0.05	**0.31**	−0.03	**−0.26**	0.25	0.10	0.05	0.11	0.17	0.24	0.24	**0.26**
	α	**0.02**	0.24	**0.01**	**0.01**	0.28	0.12	0.90	0.21	0.07	0.82	0.83	0.08	0.07	0.71	**0.02**	0.83	**0.05**	0.06	0.47	0.70	0.43	0.20	0.08	0.07	**0.05**
7/11/2003	r	−0.13	0.10	−0.17	0.08	−0.10	−0.23	**0.28**	**−0.28**	−0.22	**−0.26**	−0.18	**−0.30**	0.15	**0.27**	0.21	−0.10	−0.10	0.12	−0.01	−0.01	−0.06	−0.02	0.22	−0.08	0.13
	α	0.35	0.44	0.21	0.55	0.46	0.08	**0.04**	**0.03**	0.10	**0.05**	0.18	**0.02**	0.26	**0.04**	0.12	0.47	0.45	0.39	0.91	0.96	0.66	0.87	0.10	0.54	0.33
8/1/2003	r	**−0.38**	**0.30**	**−0.31**	**0.33**	−0.10	−0.15	−0.17	−0.04	−0.14	0.17	−0.09	0.01	**0.28**	−0.15	0.09	−0.06	**−0.26**	**0.31**	−0.08	0.14	0.24	0.14	0.19	**0.35**	**0.28**
	α	**0.00**	**0.03**	**0.02**	**0.01**	0.44	0.25	0.22	0.79	0.29	0.20	0.49	0.93	**0.04**	0.25	0.53	0.67	**0.05**	**0.02**	0.55	0.30	0.08	0.30	0.15	**0.01**	**0.03**
8/23/2003	r	**−0.42**	**0.45**	**−0.40**	**0.30**	**−0.37**	−0.03	0.05	−0.09	−0.06	−0.08	−0.01	−0.12	−0.08	0.08	0.02	0.03	−0.07	0.10	−0.07	0.14	0.14	0.16	**0.44**	0.18	**0.39**
	α	**0.00**	**0.00**	**0.00**	**0.02**	**0.00**	0.85	0.69	0.53	0.63	0.53	0.95	0.36	0.55	0.56	0.86	0.84	0.61	0.48	0.61	0.29	0.31	0.25	**0.00**	0.19	**0.00**
9/11/2003	r	−0.01	0.04	−0.01	0.08	0.06	0.01	−0.02	0.02	0.00	0.03	0.18	−0.11	**−0.42**	0.12	0.00	0.19	−0.22	0.23	0.04	−0.15	−0.12	−0.17	0.08	0.12	0.10
	α	0.93	0.78	0.92	0.54	0.65	0.93	0.88	0.90	0.98	0.80	0.17	0.43	**0.00**	0.37	1.00	0.15	0.11	0.09	0.78	0.28	0.36	0.21	0.57	0.35	0.47
10/28/2003	r	−0.11	0.14	−0.14	−0.06	0.03	**−0.27**	0.03	−0.22	**−0.27**	−0.04	−0.11	**−0.26**	0.04	−0.04	0.22	0.06	**−0.27**	**0.30**	−0.01	−0.09	−0.11	−0.02	0.11	0.17	0.13
	α	0.41	0.31	0.31	0.68	0.83	**0.04**	0.84	0.09	**0.04**	0.77	0.41	**0.05**	0.77	0.75	0.10	0.66	**0.04**	**0.02**	0.97	0.53	0.41	0.90	0.41	0.20	0.33
11/11/2003	r	0.09	0.03	0.08	−0.07	−0.02	0.05	−0.10	0.13	0.08	0.15	**0.27**	0.00	**−0.30**	0.00	−0.04	0.15	−0.08	0.04	0.14	−0.05	−0.17	**−0.26**	0.00	−0.04	−0.01
	α	0.50	0.84	0.58	0.58	0.86	0.69	0.48	0.35	0.55	0.26	**0.04**	0.98	**0.02**	0.98	0.79	0.25	0.55	0.75	0.29	0.70	0.20	**0.05**	0.99	0.77	0.95
11/18/2003	r	0.04	0.13	−0.01	−0.10	**0.30**	0.04	0.01	0.04	0.05	0.01	0.06	0.02	−0.04	−0.05	−0.04	−0.12	0.24	−0.24	−0.08	−0.06	−0.10	−0.04	0.00	0.02	0.01
	α	0.78	0.35	0.95	0.44	**0.02**	0.77	0.93	0.77	0.72	0.97	0.68	0.89	0.79	0.72	0.77	0.36	0.07	0.08	0.57	0.66	0.48	0.75	0.98	0.87	0.93
11/23/2003	r	−0.16	0.12	−0.17	0.13	0.00	−0.19	0.17	−0.18	−0.15	−0.16	−0.16	−0.16	−0.03	0.18	0.06	−0.12	−0.04	0.07	−0.06	**0.32**	0.15	0.05	0.05	0.11	0.08
	α	0.24	0.36	0.20	0.34	0.98	0.16	0.21	0.17	0.26	0.25	0.24	0.23	0.83	0.18	0.65	0.38	0.74	0.61	0.64	**0.02**	0.27	0.71	0.68	0.40	0.56
12/19/2003	r	0.11	0.18	0.05	−0.06	**0.35**	0.12	0.08	0.15	0.18	0.05	0.07	0.19	0.06	0.05	−0.10	0.16	0.13	−0.13	−0.03	−0.10	−0.15	**−0.28**	−0.06	−0.10	−0.08
	α	0.44	0.18	0.70	0.67	**0.01**	0.35	0.56	0.25	0.19	0.73	0.63	0.16	0.65	0.72	0.44	0.23	0.33	0.32	0.81	0.47	0.25	**0.04**	0.67	0.48	0.55
3/4/2004	r	**−0.29**	0.05	**−0.35**	0.19	0.07	−0.20	**0.28**	−0.22	−0.14	**−0.26**	−0.19	−0.20	**0.38**	0.16	**0.51**	**−0.58**	0.01	−0.03	0.04	−0.09	−0.13	−0.19	0.15	0.12	0.16
	α	**0.03**	0.73	**0.01**	0.15	0.61	0.15	**0.03**	0.10	0.29	**0.05**	0.15	0.14	**0.00**	0.23	**0.00**	**0.00**	0.92	0.83	0.76	0.49	0.32	0.15	0.26	0.38	0.24
3/9/2004	r	0.23	0.07	0.14	−0.19	**0.38**	0.08	−0.07	0.10	0.09	0.08	0.11	0.07	−0.05	0.09	0.03	−0.08	**0.30**	**−0.27**	−0.16	−0.17	**−0.35**	**−0.32**	−0.11	−0.13	−0.14
	α	0.08	0.63	0.30	0.16	**0.00**	0.54	0.61	0.44	0.51	0.55	0.40	0.58	0.69	0.50	0.82	0.57	**0.03**	**0.04**	0.22	0.21	**0.01**	**0.01**	0.40	0.32	0.30
3/11/2004	r	−0.06	0.13	−0.16	−0.08	**0.31**	**−0.26**	0.15	−0.23	−0.23	−0.13	−0.21	−0.20	0.25	−0.01	**0.37**	−0.19	−0.12	0.14	−0.05	−0.14	−0.22	−0.13	0.04	0.22	0.11
	α	0.65	0.35	0.24	0.53	**0.02**	**0.05**	0.28	0.08	0.09	0.32	0.12	0.13	0.06	0.93	**0.00**	0.17	0.39	0.29	0.73	0.29	0.10	0.34	0.74	0.11	0.43
3/16/2004	r	−0.19	0.09	−0.22	0.22	0.03	0.00	−0.07	−0.01	−0.01	−0.01	0.05	−0.05	0.15	0.01	**0.38**	−0.21	−0.20	0.21	0.01	−0.01	−0.09	−0.06	0.16	**0.41**	**0.26**
	α	0.16	0.52	0.10	0.10	0.85	0.97	0.59	0.94	0.97	0.92	0.74	0.72	0.26	0.92	**0.00**	0.11	0.14	0.11	0.96	0.93	0.50	0.67	0.24	**0.00**	**0.05**
3/19/2004	r	**−0.34**	0.15	**−0.37**	**0.37**	−0.11	−0.17	0.07	−0.19	−0.17	−0.13	−0.11	−0.21	0.18	0.05	**0.44**	**−0.28**	−0.20	0.22	−0.02	0.13	0.06	0.07	0.25	**0.45**	**0.35**
	α	**0.01**	0.28	**0.00**	**0.00**	0.42	0.20	0.61	0.16	0.21	0.32	0.43	0.12	0.18	0.74	**0.00**	**0.03**	0.15	0.10	0.86	0.35	0.64	0.62	0.06	**0.00**	**0.01**
3/23/2004	r	**−0.42**	0.25	**−0.45**	**0.31**	−0.05	−0.08	−0.01	−0.08	−0.09	−0.02	0.01	−0.13	0.20	0.04	**0.45**	**−0.31**	**−0.39**	**0.42**	0.00	0.09	0.03	0.03	**0.42**	**0.51**	**0.49**
	α	**0.00**	0.06	**0.00**	**0.02**	0.69	0.54	0.91	0.56	0.51	0.86	0.95	0.35	0.13	0.79	**0.00**	**0.02**	**0.00**	**0.00**	0.98	0.49	0.85	0.81	**0.00**	**0.00**	**0.00**
3/30/2004	r	**−0.42**	0.12	**−0.44**	**0.41**	−0.17	−0.10	0.13	−0.13	−0.08	−0.16	−0.11	−0.12	0.26	0.11	**0.50**	**−0.32**	**−0.39**	**0.41**	0.06	0.14	0.09	0.06	**0.34**	**0.40**	**0.39**
	α	**0.00**	0.36	**0.00**	**0.00**	0.20	0.47	0.34	0.33	0.55	0.24	0.40	0.39	0.05	0.39	**0.00**	**0.02**	**0.00**	**0.00**	0.68	0.29	0.52	0.66	**0.01**	**0.00**	**0.00**
4/2/2004	r	**−0.31**	0.21	**−0.35**	**0.28**	0.00	−0.17	0.02	−0.13	−0.15	−0.04	−0.02	−0.19	0.19	0.06	**0.43**	**−0.30**	**−0.28**	**0.31**	−0.02	0.09	−0.07	−0.08	0.24	**0.32**	**0.29**
	α	**0.02**	0.13	**0.01**	**0.04**	1.00	0.19	0.86	0.32	0.25	0.78	0.86	0.17	0.16	0.64	**0.00**	**0.03**	**0.03**	**0.02**	0.90	0.48	0.63	0.58	0.07	**0.01**	**0.03**
4/9/2004	r	**−0.47**	0.17	**−0.52**	**0.35**	−0.23	**−0.31**	**0.27**	**−0.35**	**−0.29**	**−0.31**	−0.21	**−0.38**	0.26	0.20	**0.64**	**−0.44**	−0.22	0.23	0.03	0.03	0.00	0.06	**0.38**	**0.41**	**0.42**
	α	**0.00**	0.22	**0.00**	**0.01**	0.09	**0.02**	**0.04**	**0.01**	**0.03**	**0.02**	0.11	**0.00**	0.05	0.13	**0.00**	**0.00**	0.11	0.09	0.81	0.83	0.98	0.66	**0.00**	**0.00**	**0.00**
4/19/2004	r	**−0.51**	0.23	**−0.52**	**0.34**	−0.16	−0.21	0.15	−0.23	−0.20	−0.17	−0.09	**−0.28**	0.18	0.14	**0.48**	**−0.37**	**−0.35**	**0.40**	−0.04	0.00	−0.01	0.01	**0.55**	**0.52**	**0.59**
	α	**0.00**	0.09	**0.00**	**0.01**	0.22	0.12	0.28	0.09	0.14	0.20	0.51	**0.04**	0.19	0.30	**0.00**	**0.00**	**0.01**	**0.00**	**0.79**	0.99	0.92	0.96	**0.00**	**0.00**	**0.00**
4/23/2004	r	**−0.47**	**0.28**	**−0.52**	**0.42**	−0.19	−0.14	0.15	−0.18	−0.14	−0.18	−0.03	−0.25	0.09	0.21	**0.52**	**−0.34**	**−0.33**	**0.30**	0.20	0.05	0.04	0.03	**0.48**	**0.45**	**0.50**
	α	**0.00**	**0.04**	**0.00**	**0.00**	0.15	0.29	0.28	0.18	0.31	0.18	0.80	0.06	0.51	0.12	**0.00**	**0.01**	**0.01**	**0.02**	0.14	0.70	0.75	0.83	**0.00**	**0.00**	**0.00**
5/1/2004	r	**−0.47**	**0.26**	**−0.49**	**0.38**	−0.20	**−0.30**	−0.01	−0.25	**−0.30**	−0.04	−0.08	**−0.32**	0.24	0.02	**0.52**	**−0.32**	**−0.40**	**0.43**	0.03	0.12	0.08	0.15	**0.41**	**0.42**	**0.46**
	α	**0.00**	**0.05**	**0.00**	**0.00**	0.13	**0.02**	0.94	0.06	**0.02**	0.78	0.55	**0.02**	0.08	0.90	**0.00**	**0.02**	**0.00**	**0.00**	0.84	0.36	0.55	0.26	**0.00**	**0.00**	**0.00**
5/4/2004	r	**−0.43**	**0.35**	**−0.45**	**0.41**	−0.08	−0.16	−0.10	−0.09	−0.17	0.09	0.02	−0.16	0.17	−0.02	**0.29**	−0.20	**−0.31**	**0.34**	0.00	0.17	0.14	0.20	**0.49**	**0.57**	**0.58**
	α	**0.00**	**0.01**	**0.00**	**0.00**	0.54	0.23	0.47	0.49	0.20	0.49	0.88	0.25	0.20	0.90	**0.03**	0.14	**0.02**	**0.01**	1.00	0.21	0.30	0.14	**0.00**	**0.00**	**0.00**
5/13/2004	r	−0.12	0.16	−0.22	0.06	0.19	−0.20	0.08	−0.19	−0.19	−0.10	−0.03	**−0.26**	−0.05	0.02	**0.37**	−0.14	−0.24	**0.27**	−0.05	−0.07	−0.11	0.04	0.20	0.24	0.23
	α	0.36	0.25	0.09	0.67	0.16	0.13	0.54	0.16	0.16	0.46	0.81	**0.05**	0.70	0.90	**0.00**	0.30	0.08	**0.04**	0.73	0.58	0.44	0.76	0.14	0.07	0.09
5/20/2004	r	**−0.35**	**0.27**	**−0.38**	**0.33**	−0.02	−0.02	0.02	−0.02	−0.01	−0.02	0.03	−0.05	0.16	0.15	**0.26**	−0.24	**−0.29**	0.24	0.24	0.11	0.08	−0.03	**0.33**	**0.33**	**0.36**
	α	**0.01**	**0.04**	**0.00**	**0.01**	0.89	0.87	0.86	0.90	0.93	0.90	0.80	0.72	0.23	0.26	**0.05**	0.08	**0.03**	0.07	0.07	0.40	0.56	0.81	**0.01**	**0.01**	**0.01**
5/25/2004	r	−0.21	0.22	**−0.30**	0.15	0.25	−0.09	0.18	−0.10	−0.05	−0.15	−0.02	−0.14	0.03	0.11	**0.29**	−0.19	−0.09	0.08	0.06	−0.17	−0.23	−0.19	0.25	**0.33**	**0.30**
	α	0.12	0.10	**0.03**	0.27	0.06	0.53	0.19	0.45	0.71	0.26	0.90	0.29	0.85	0.43	**0.03**	0.15	0.51	0.56	0.67	0.22	0.08	0.15	0.06	**0.01**	**0.02**
5/30/2004	r	−0.09	0.00	−0.13	0.12	0.17	−0.06	0.06	−0.06	−0.05	−0.06	0.01	−0.10	0.20	0.06	**0.39**	−0.17	−0.12	0.17	−0.14	−0.12	−0.19	−0.06	0.12	0.19	0.15
	α	0.49	0.99	0.33	0.37	0.21	0.67	0.66	0.66	0.73	0.67	0.92	0.45	0.13	0.67	**0.00**	0.20	0.39	0.20	0.30	0.37	0.15	0.66	0.39	0.15	0.27
6/2/2004	r	−0.21	0.09	−0.25	0.21	0.11	−0.09	0.10	−0.11	−0.07	−0.13	−0.05	−0.13	0.24	0.08	**0.38**	−0.19	−0.17	0.20	−0.03	−0.02	−0.08	−0.02	0.14	**0.26**	0.19
	α	0.12	0.50	0.06	0.12	0.40	0.52	0.46	0.43	0.61	0.34	0.74	0.33	0.07	0.56	**0.00**	0.15	0.20	0.14	0.85	0.87	0.57	0.89	0.31	**0.05**	0.16
6/13/2004	r	−0.07	0.12	−0.14	0.19	0.20	−0.22	0.21	−0.25	−0.19	−0.25	−0.27	−0.19	0.23	0.05	**0.29**	−0.25	−0.03	0.08	−0.17	−0.01	−0.11	0.03	0.04	0.21	0.10
	α	0.59	0.38	0.31	0.16	0.13	0.11	0.11	0.06	0.15	0.06	0.04	0.15	0.09	0.69	**0.03**	0.06	0.83	0.53	0.21	0.96	0.44	0.83	0.78	0.12	0.45
6/17/2004	r	−0.10	0.09	−0.16	0.21	0.16	−0.10	0.12	−0.13	−0.09	−0.16	−0.07	−0.15	0.16	0.05	**0.39**	−0.21	−0.09	0.19	**−0.28**	−0.18	−0.20	−0.04	0.21	0.20	0.22
	α	0.44	0.52	0.22	0.11	0.22	0.46	0.38	0.32	0.52	0.24	0.62	0.25	0.24	0.73	**0.00**	0.11	0.50	0.16	**0.04**	0.17	0.14	0.79	0.12	0.13	0.11
6/24/2004	r	−0.01	−0.06	−0.05	0.11	0.15	−0.21	**0.26**	**−0.26**	−0.19	**−0.27**	−0.14	**−0.30**	0.03	0.13	0.24	−0.10	0.08	0.03	**−0.38**	−0.18	−0.16	0.10	0.12	0.15	0.13
	α	0.95	0.66	0.71	0.42	0.27	0.12	**0.05**	**0.05**	0.15	**0.04**	0.31	**0.02**	0.82	0.33	0.07	0.44	0.57	0.80	**0.00**	0.18	0.25	0.44	0.39	0.27	0.34
6/30/2004	r	−0.04	0.04	−0.11	**0.43**	0.14	0.01	0.22	−0.10	0.03	**−0.28**	−0.11	−0.07	0.22	−0.01	**0.34**	−0.15	−0.03	0.11	−0.25	−0.07	−0.07	0.12	0.12	**0.27**	0.19
	α	0.76	0.78	0.41	**0.00**	0.31	0.91	0.10	0.46	0.85	**0.04**	0.41	0.61	0.10	0.97	**0.01**	0.25	0.82	0.41	0.06	0.59	0.58	0.39	0.39	**0.04**	0.15

Table A1. Surface characteristics observed at soil moisture sampling locations in the Treeline study site of the Dry Creek Experimental Watershed, near Boise, Idaho, USA, 2002–2003.

Sample Location	Northing (m)	Easting (m)	Aspect (˚)	Elevation (m)	Slope (%)	% Coarse Soil	% Sandy Soil	% Fine Soil	Soil Depth (m)	Summer Canopy Cover (%)	Spring Canopy Cover(%)	Winter/Fall Canopy Cover (%)
1	4842071	569374	92	1600	58	11	81	8	0.61	50	41	20
2	4842087	569382	133	1602	29	17	76	7	0.46	70	60	16
3	4842090	569372	147	1603	42	17	77	6	0.40	51	26	0
4	4842073	569362	69	1606	59	18	74	7	0.46	96	86	35
5	4842074	569353	67	1609	40	14	81	6	0.91	70	56	31
6	4842093	569359	114	1606	26	19	74	7	0.56	96	69	11
7	4842097	569345	106	1606	15	26	69	5	0.21	15	10	0
8	4842100	569331	75	1611	49	17	75	7	1.25	55	40	6
9	4842105	569318	67	1615	36	22	76	2	0.94	100	100	100
10	4842106	569309	75	1619	31	16	78	6	0.34	65	60	12
11	4842107	569301	70	1623	37	19	74	7	0.34	75	26	6
12	4842081	569323	48	1619	24	16	77	6	0.55	36	31	4
13	4842080	569334	66	1615	40	19	77	4	1.04	60	45	20
14	4842058	569335	88	1617	34	12	83	5	0.43	55	41	5
15	4842075	569345	66	1612	46	15	79	6	0.64	75	75	5
16	4842133	569291	109	1623	41	18	77	5	0.34	100	100	100
17	4842131	569301	113	1620	29	15	79	6	1.07	60	60	10
18	4842130	569316	187	1616	26	28	69	3	0.30	5	5	0
19	4842126	569329	215	1620	54	17	80	3	0.64	30	21	5
20	4842122	569341	204	1620	23	19	75	6	0.43	25	25	0
21	4842118	569352	164	1618	47	16	75	8	0.43	30	27	1
23	4842153	569338	226	1628	28	20	74	5	0.37	20	20	5
24	4842156	569325	209	1626	38	25	71	4	0.70	30	10	0
25	4842159	569311	175	1627	43	14	76	10	0.46	25	20	0
26	4842160	569297	157	1627	36	22	75	4	0.37	42	22	1
27	4842161	569286	116	1622	42	14	79	7	0.46	21	11	1
28	4842161	569277	111	1635	28	12	80	8	0.46	40	30	0
29	4842164	569269	101	1638	34	17	76	7	0.37	55	55	1
30	4842182	569274	131	1639	33	21	75	5	0.70	55	55	15
31	4842181	569286	128	1636	25	19	76	5	0.27	0	0	0
32	4842180	569299	191	1634	28	11	83	6	0.34	30	26	5
33	4842178	569311	198	1635	33	15	80	5	0.30	25	25	1
34	4842176	569321	180	1635	38	12	82	6	0.46	36	16	5
35	4842174	569333	207	1634	45	21	74	5	0.67	15	10	0

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀I | ▶I
◀ | ▶
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

Table A1. Continued.

Sample Location	Northing (m)	Easting (m)	Aspect (°)	Elevation (m)	Slope (%)	% Coarse Soil	% Sandy Soil	% Fine Soil	Soil Depth (m)	Summer Canopy Cover (%)	Spring Canopy Cover(%)	Winter/Fall Canopy Cover (%)
36	4842173	569345	205	1636	28	16	80	4	0.34	26	26	1
37	4842170	569355	169	1636	23	16	78	7	0.38	36	36	6
38	4842191	569339	162	1641	17	14	81	5	0.27	16	6	0
39	4842192	569332	178	1641	13	19	78	3	0.76	21	6	1
40	4842192	569321	171	1642	23	17	78	4	0.24	65	16	3
41	4842193	569312	208	1642	37	18	77	5	0.24	42	8	2
42	4842197	569300	198	1646	48	21	73	6	0.24	5	5	0
43	4842198	569290	174	1645	62	25	69	6	0.24	20	10	2
44	4842197	569279	147	1645	82	24	71	5	0.24	15	10	1
45	4842219	569276	153	1653	19	17	77	6	0.24	45	16	4
46	4842217	569290	173	1651	30	21	76	3	0.30	65	41	5
47	4842216	569302	153	1650	35	23	74	4	0.24	5	1	0
48	4842213	569313	154	1649	29	21	74	5	0.27	36	41	6
50	4842229	569296	158	1655	19	19	74	6	0.27	66	36	10
51	4842230	569285	141	1657	21	43	53	4	0.24	51	51	10
52	4842231	569278	161	1656	26	24	71	4	0.49	70	61	15
54	4842197	569266	154	1648	48	27	67	6	0.27	0	0	0
55	4842217	569267	155	1653	17	19	76	5	0.27	55	55	10
56	4842183	569262	126	1643	40	25	69	6	0.46	81	71	15
57	4842138	569280	107	1631	66	12	80	8	0.49	55	45	0
58	4842139	569269	108	1637	31	14	81	4	0.46	40	40	0
22A	4842155	569354	196	1632	27	18	77	6	0.35	50	32	5
22B	4842130	569354	189	1625	50	30	65	6	0.58	70	70	5
Mean	4842152	569315	143	1630	36	19	76	6	0.46	45	35	9
SD	49	32	47	15	14	5	5	2	0.23	26	25	19
CV	0.00	0.00	0.33	0.01	0.38	0.29	0.07	0.28	0.50	0.58	0.72	2.09
Max	4842231	569382	226	1657	82	43	83	10	1.25	100	100	100
Min	4842058	569262	48	1600	13	11	53	2	0.21	0	0	0
Range	172	120	177	56	69	32	30	8	1.04	100	100	100

Title Page
Abstract
Introduction
Conclusions
References
Tables
Figures
◀◀
▶▶
◀
▶
Back
Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

Table A2.

Sample Location	Convexity (unitless)	Concavity (unitless)	Planar Curvature (unitless)	Mean Curvature (unitless)	Longitudinal Curvature (unitless)	Cross Section Curvature (unitless)	Profile Curvature (unitless)
1	−0.505	−2.473	0.415	−1.489	−1.209	−0.280	−0.690
2	−0.201	−1.299	0.317	−0.750	−0.642	−0.108	−0.545
3	0.607	−1.998	3.477	−0.695	0.212	−0.908	0.192
4	0.234	−0.563	0.704	−0.164	0.106	−0.270	0.086
5	−0.256	−0.614	0.711	−0.435	−0.144	−0.291	−0.114
6	−0.479	−1.405	2.614	−0.942	−0.263	−0.678	−0.239
7	−0.766	−1.198	1.926	−0.982	−0.499	−0.482	−0.456
8	−0.244	−0.342	0.310	−0.293	−0.150	−0.143	−0.113
9	−0.030	−0.657	0.892	−0.343	−0.018	−0.325	−0.015
10	1.266	−1.252	1.268	0.007	0.443	−0.436	0.375
11	0.944	−0.023	−0.144	0.460	0.418	0.042	0.369
12	1.433	0.328	−1.002	0.880	0.689	0.191	0.653
13	1.805	0.351	−0.469	1.078	0.889	0.189	0.710
14	1.118	0.093	−2.237	0.605	0.052	0.553	0.048
15	−0.228	−0.728	0.617	−0.478	−0.195	−0.283	−0.147
16	−0.319	−2.584	0.318	−1.452	−1.268	−0.183	−0.825
17	−0.058	−1.303	0.341	−0.681	−0.553	−0.127	−0.455
18	−0.429	−1.065	1.799	−0.747	−0.285	−0.462	−0.259
19	0.575	−0.517	0.320	0.029	0.193	−0.164	0.136
20	1.538	0.542	−0.625	1.040	0.734	0.307	0.531
21	3.675	−0.219	−0.545	1.728	1.458	0.270	1.048
23	0.782	0.032	−0.367	0.407	0.299	0.108	0.265
24	−0.179	−1.067	1.247	−0.623	−0.120	−0.503	−0.096
25	0.872	0.072	−0.266	0.472	0.366	0.106	0.293
26	0.378	−0.485	0.549	−0.053	0.155	−0.208	0.127
27	0.244	−0.566	−0.228	−0.161	−0.279	0.118	−0.196
28	1.992	0.246	−0.317	1.119	0.991	0.128	0.789
29	−0.483	−0.872	1.270	−0.678	−0.247	−0.431	−0.209
30	0.940	−0.761	0.453	0.089	0.250	−0.161	0.210
31	0.191	−0.100	0.133	0.046	0.091	−0.046	0.077
32	−0.118	−0.903	1.293	−0.510	−0.104	−0.406	−0.091
33	0.869	0.616	−0.919	0.743	0.405	0.337	0.335
34	2.127	0.559	−0.518	1.343	1.051	0.292	0.694
35	1.364	−1.232	1.139	0.066	0.602	−0.536	0.446

Table A2. Continued.

Sample Location	Convexity (unitless)	Concavity (unitless)	Planar Curvature (unitless)	Mean Curvature (unitless)	Longitudinal Curvature (unitless)	Cross Section Curvature (unitless)	Profile Curvature (unitless)
36	0.950	0.289	−0.445	0.619	0.459	0.160	0.383
37	0.555	0.171	−0.478	0.363	0.192	0.171	0.161
38	1.670	0.429	−2.149	1.049	0.562	0.487	0.522
39	1.518	−0.222	0.362	0.648	0.755	−0.108	0.665
40	0.821	−0.202	−0.470	0.310	0.064	0.246	0.044
41	2.739	0.061	−0.627	1.400	1.128	0.272	0.871
42	−0.960	−1.659	1.581	−1.310	−0.581	−0.729	−0.435
43	0.485	−0.665	0.390	−0.090	0.163	−0.253	0.096
44	−0.144	−1.880	0.131	−1.012	−0.927	−0.085	−0.547
45	−0.160	−0.427	0.934	−0.294	−0.154	−0.140	−0.149
46	3.586	−1.047	0.553	1.270	1.607	−0.338	1.000
47	3.347	−0.044	−0.087	1.652	1.604	0.048	1.072
48	1.740	0.395	−1.200	1.068	0.719	0.348	0.637
50	1.379	−0.790	0.167	0.294	0.342	−0.047	0.304
51	1.774	0.674	−1.349	1.224	0.838	0.386	0.745
52	1.350	−0.545	1.023	0.402	0.652	−0.250	0.598
54	1.179	−0.017	−0.149	0.581	0.498	0.083	0.333
55	2.298	0.154	−0.451	1.226	1.123	0.103	1.041
56	0.297	−0.904	0.456	−0.303	−0.161	−0.142	−0.140
57	1.434	−0.805	−1.032	0.315	−0.203	0.518	−0.145
58	1.582	0.507	−0.804	1.045	0.789	0.255	0.684
22A	0.798	0.086	−1.364	0.442	0.064	0.378	0.057
22B	1.773	0.045	−1.615	0.909	0.126	0.783	0.091
Mean	0.854	−0.487	0.138	0.183	0.230	−0.046	0.190
SD	1.072	0.770	1.077	0.813	0.620	0.347	0.459
CV	1.26	−1.58	7.81	4.44	2.70	−7.48	2.42
Max	3.675	0.674	3.477	1.728	1.607	0.783	1.072
Min	−0.960	−2.584	−2.237	−1.489	−1.268	−0.908	−0.825
Range	4.636	3.258	5.714	3.217	2.876	1.691	1.897

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀I | ▶I
◀ | ▶
Back | Close
Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Table A3.

Sample Location	Topographic Wetness Index (unitless)	Upslope Contributing Area (m^2)	Slope Distance to Catchment Divide (m)	Slope Distance to Stream (m)	Maximum Snow Depth (cm)	Snow Density at Max. Snow Depth (unitless)	Snow Water Equiv. at Max. Depth (cm)
1	4.28	27	63.3	10.0	58.4	0.311	18.2
2	6.65	105	39.8	45.0	56.4	0.334	18.8
3	2.27	5	32.8	31.2	57.3	0.299	17.1
4	2.82	14	50.0	20.0	59.4	0.302	18.0
5	4.43	34	41.7	19.1	60.5	0.303	18.4
6	9.86	2775	40.8	2.0	61.4	0.276	16.9
7	8.44	568	41.8	12.1	64.2	0.315	20.3
8	4.34	45	44.9	27.1	68.3	0.340	23.3
9	4.64	36	40.2	12.1	68.5	0.327	22.6
10	2.26	5	32.1	17.1	65.1	0.310	20.3
11	3.66	10	21.0	19.1	62.2	0.310	19.2
12	2.53	5	17.6	42.1	63.8	0.321	20.6
13	4.03	30	27.5	34.1	63.0	0.315	20.0
14	3.25	12	18.8	48.3	61.1	0.312	19.2
15	4.58	38	33.5	29.1	61.4	0.308	19.0
16	2.57	8	40.4	24.1	41.9	0.329	13.8
17	2.42	5	52.7	14.1	46.1	0.347	15.7
18	7.76	528	56.2	17.1	57.8	0.307	17.5
19	3.11	11	40.3	17.1	54.6	0.325	17.9
20	5.19	48	30.1	19.1	55.7	0.330	18.6
21	1.79	6	14.6	43.3	52.9	0.303	16.3
23	3.10	9	33.5	50.4	50.6	0.325	16.5
24	5.13	72	39.5	21.2	51.4	0.320	16.4
25	3.60	21	54.4	15.0	51.6	0.311	16.0
26	7.33	467	62.3	0.0	49.6	0.293	14.6
27	5.35	69	51.9	40.4	49.3	0.282	14.0
28	2.24	5	44.4	47.4	48.5	0.279	13.7
29	5.51	65	35.7	59.5	47.4	0.279	13.4
30	3.32	12	46.8	52.4	47.4	0262	12.6
31	2.47	5	57.4	7.1	41.4	0.197	8.1
32	5.92	135	45.8	20.0	52.9	0.287	15.0
33	3.67	17	40.6	39.1	64.2	0.309	20.0
34	4.34	30	37.2	39.1	55.9	0.309	17.4
35	3.56	22	34.4	38.3	46.2	0.311	14.4

Table A3. Continued.

Sample Location	Topographic Wetness Index (unitless)	Upslope Contributing Area (m^2)	Slope Distance to Catchment Divide (m)	Slope Distance to Stream (m)	Maximum Snow Depth (cm)	Snow Density at Max. Snow Depth (unitless)	Snow Water Equiv. at Max. Depth (cm)
36	3.46	11	21.3	74.5	54.2	0.300	16.3
37	2.50	5	3.5	81.0	52.0	0.289	15.2
38	3.77	10	10.4	74.5	51.4	0.311	16.0
39	5.70	50	16.3	58.3	48.5	0.307	14.9
40	2.58	5	23.1	54.1	50.8	0.295	15.1
41	1.90	5	34.4	39.1	52.7	0.287	15.3
42	3.94	25	38.3	37.1	48.5	0.270	13.2
43	4.85	91	41.6	15.0	45.4	0.259	11.9
44	3.84	32	34.4	21.2	45.4	0.257	11.8
45	3.22	7	16.9	41.2	43.2	0.254	11.0
46	3.97	19	22.8	35.0	37.2	0.262	9.7
47	3.36	9	21.2	61.2	44.8	0.265	11.8
48	2.25	5	7.7	59.1	55.4	0.265	14.6
50	3.41	8	6.1	65.0	43.5	0.265	11.5
51	2.83	5	7.7	52.1	42.0	0.261	11.0
52	5.49	15	0.6	56.2	43.0	0.259	11.2
54	2.63	11	29.4	66.6	46.2	0.262	12.2
55	5.17	15	11.4	45.4	49.6	0.251	12.5
56	3.76	28	29.2	59.5	44.2	0.283	12.7
57	1.60	5	30.5	34.1	60.7	0.319	19.4
58	2.30	5	16.8	51.2	59.0	0.315	18.6
22A	3.47	10	3.2	53.3	51.2	0.303	15.5
22B	2.17	6	4.9	50.0	43.6	0.291	12.9
Mean	3.94	99	31.5	37.2	52.8	0.295	15.7
SD	1.70	379	16.0	19.8	7.6	0.028	3.3
CV	0.43	3.84	0.51	0.53	0.14	0.09	0.21
Max	9.86	2775	63.3	81.0	68.5	0.347	23.3
Min	1.60	5	0.6	0.0	37.2	0.197	8.1
Range	8.26	2770	62.7	81.0	31.3	0.149	15.2

Table B1. Point near-surface soil moisture contents measured at 57 points in the Treeline study site of the Dry Creek Experimental Watershed, near Boise, Idaho, USA, 2003–2004.

	Point Soil Moisture Content ($m^3\,m^{-3}$) by Sampling date																		
Sample Location	6 April 2003	7 April 2003	9 April 2003	10 April 2003	11 April 2003	17 April 2003	24 June 2003	11 July 2003	1 August 2003	23 August 2003	11 September 2003	28 October 2003	11 November 2003	18 November 2003	23 November 2003	19 December 2003	4 March 2004	9 March 2004	11 March 2004
1	0.208	0.263	0.201	0.133	0.193	0.135	0.077	0.054	0.065	0.120	0.049	0.049	0.052	0.073	0.074	0.165	0.197	0.	0.249
2	0.200	0.225	0.192	0.094	0.160	0.109	0.070	0.064	0.049	0.102	0.050	0.050	0.086	0.135	0.149	0.243	0.187	0.212	0.309
3	0.196	0.219	0.143	0.134	0.182	0.090	0.066	0.071	0.048	0.100	0.041	0.052	0.049	0.129	0.142	0.252	0.190	0.208	0.290
4	0.191	0.179	0.187	0.175	0.159	0.114	0.061	0.050	0.046	0.087	0.037	0.050	0.053	0.100	0.069	0.122	0.192	0.197	0.230
5	0.195	0.224	0.186	0.120	0.187	0.125	0.065	0.051	0.062	0.084	0.033	0.040	0.055	0.095	0.091	0.159	0.187	0.192	0.222
6	0.238	0.213	0.138	0.182	0.145	0.125	0.054	0.077	0.042	0.082	0.051	0.040	0.054	0.091	0.128	0.185	0.197	0.212	0.206
7	0.130	0.204	0.116	0.125	0.239	0.111	0.045	0.063	0.041	0.080	0.051	0.050	0.068	0.115	0.063	0.157	0.192	0.217	0.272
8	0.176	0.180	0.175	0.165	0.161	0.155	0.065	0.050	0.042	0.074	0.049	0.037	0.057	0.085	0.090	0.160	0.187	0.188	0.224
9	0.188	0.197	0.145	0.110	0.161	0.103	0.056	0.062	0.054	0.108	0.043	0.034	0.052	0.136	0.117	0.157	0.190	0.192	0.212
10	0.198	0.214	0.147	0.107	0.142	0.115	0.038	0.048	0.055	0.047	0.026	0.041	0.038	0.112	0.069	0.150	0.190	0.190	0.236
11	0.135	0.192	0.135	0.124	0.139	0.110	0.049	0.036	0.036	0.056	0.037	0.051	0.068	0.068	0.107	0.129	0.189	0.191	0.222
12	0.185	0.199	0.155	0.090	0.169	0.135	0.054	0.062	0.051	0.135	0.064	0.049	0.059	0.092	0.102	0.128	0.188	0.192	0.189
13	0.187	0.230	0.182	0.114	0.177	0.135	0.100	0.074	0.057	0.110	0.049	0.047	0.066	0.076	0.056	0.159	0.186	0.190	0.246
14	0.194	0.234	0.192	0.096	0.158	0.142	0.053	0.051	0.057	0.075	0.053	0.061	0.048	0.104	0.116	0.181	0.188	0.188	0.251
15	0.194	0.211	0.201	0.149	0.182	0.151	0.073	0.056	0.055	0.060	0.050	0.053	0.082	0.071	0.100	0.179	0.187	0.188	0.245
16	0.168	0.206	0.190	0.081	0.160	0.109	0.080	0.045	0.052	0.034	0.043	0.062	0.034	0.051	0.070	0.095	0.117	0.128	0.252
17	0.198	0.227	0.164	0.120	0.167	0.111	0.054	0.032	0.060	0.060	0.054	0.049	0.047	0.094	0.110	0.174	0.193	0.197	0.239
18	0.178	0.207	0.129	0.126	0.124	0.110	0.051	0.052	0.046	0.061	0.057	0.044	0.067	0.088	0.064	0.180	0.232	0.242	0.302
19	0.205	0.215	0.186	0.159	0.186	0.131	0.066	0.060	0.055	0.060	0.057	0.048	0.041	0.190	0.121	0.187	0.212	0.218	0.279
20	0.126	0.122	0.116	0.086	0.114	0.082	0.050	0.040	0.053	0.041	0.050	0.025	0.047	0.124	0.068	0.148	0.202	0.200	0.144
21	0.182	0.201	0.118	0.111	0.150	0.092	0.045	0.036	0.034	0.052	0.039	0.040	0.052	0.100	0.079	0.190	0.196	0.209	0.203
23	0.235	0.238	0.147	0.185	0.119	0.138	0.054	0.026	0.052	0.046	0.041	0.041	0.063	0.142	0.103	0.154	0.180	0.197	0.302
24	0.278	0.278	0.289	0.233	0.289	0.189	0.075	0.069	0.052	0.072	0.041	0.045	0.041	0.145	0.121	0.196	0.276	0.283	0.343
25	0.201	0.169	0.157	0.160	0.172	0.092	0.050	0.046	0.035	0.040	0.039	0.053	0.081	0.154	0.080	0.181	0.197	0.207	0.327
26	0.256	0.281	0.262	0.260	0.119	0.220	0.061	0.043	0.031	0.037	0.050	0.061	0.064	0.070	0.120	0.189	0.272	0.280	0.348
27	0.196	0.231	0.160	0.145	0.118	0.108	0.086	0.073	0.046	0.062	0.045	0.049	0.050	0.075	0.057	0.117	0.205	0.210	0.244
28	0.240	0.325	0.231	0.147	0.253	0.126	0.086	0.061	0.048	0.063	0.064	0.022	0.060	0.074	0.057	0.156	0.182	0.192	0.220
29	0.194	0.229	0.220	0.066	0.134	0.132	0.038	0.062	0.052	0.066	0.063	0.058	0.080	0.072	0.078	0.105	0.173	0.187	0.255
30	0.184	0.176	0.152	0.172	0.154	0.108	0.070	0.056	0.041	0.066	0.041	0.055	0.059	0.086	0.141	0.172	0.203	0.208	0.257
31	0.203	0.127	0.152	0.095	0.085	0.090	0.058	0.060	0.049	0.060	0.046	0.050	0.065	0.088	0.075	0.155	0.196	0.227	0.202
32	0.202	0.192	0.190	0.137	0.144	0.126	0.055	0.042	0.050	0.063	0.056	0.061	0.058	0.102	0.124	0.169	0.204	0.207	0.253
33	0.229	0.229	0.167	0.215	0.193	0.152	0.064	0.071	0.047	0.058	0.050	0.061	0.068	0.076	0.074	0.177	0.155	0.192	0.305
34	0.236	0.200	0.174	0.170	0.112	0.099	0.061	0.072	0.057	0.056	0.052	0.046	0.082	0.076	0.106	0.237	0.225	0.222	0.244
35	0.116	0.143	0.162	0.185	0.207	0.132	0.072	0.059	0.046	0.052	0.053	0.062	0.055	0.058	0.053	0.175	0.207	0.210	0.210
36	0.179	0.134	0.161	0.142	0.112	0.144	0.111	0.057	0.062	0.121	0.054	0.072	0.045	0.075	0.055	0.236	0.180	0.190	0.321
37	0.166	0.106	0.153	0.152	0.145	0.113	0.055	0.062	0.045	0.062	0.061	0.059	0.046	0.084	0.071	0.204	0.133	0.203	0.212
38	0.143	0.121	0.171	0.067	0.084	0.112	0.039	0.046	0.045	0.081	0.039	0.050	0.079	0.078	0.072	0.107	0.087	0.217	0.219
39	0.162	0.159	0.148	0.108	0.136	0.114	0.040	0.053	0.049	0.072	0.057	0.055	0.079	0.076	0.082	0.142	0.136	0.198	0.232
40	0.118	0.136	0.147	0.119	0.094	0.114	0.045	0.067	0.041	0.066	0.044	0.067	0.085	0.104	0.108	0.178	0.141	0.252	0.205
41	0.143	0.177	0.099	0.180	0.140	0.148	0.054	0.043	0.053	0.067	0.050	0.048	0.046	0.140	0.093	0.192	0.183	0.313	0.356
42	0.118	0.121	0.118	0.105	0.087	0.110	0.045	0.069	0.043	0.054	0.045	0.040	0.044	0.105	0.066	0.145	0.173	0.192	0.238
43	0.153	0.203	0.159	0.149	0.125	0.132	0.051	0.064	0.049	0.062	0.034	0.041	0.052	0.110	0.090	0.169	0.197	0.241	0.305
44	0.095	0.189	0.114	0.120	0.108	0.114	0.047	0.063	0.045	0.052	0.030	0.037	0.050	0.108	0.089	0.153	0.222	0.222	0.279
45	0.171	0.122	0.165	0.084	0.088	0.090	0.054	0.049	0.033	0.049	0.049	0.043	0.081	0.112	0.101	0.204	0.178	0.166	0.241
46	0.157	0.143	0.150	0.113	0.099	0.079	0.010	0.047	0.055	0.052	0.033	0.030	0.060	0.094	0.099	0.185	0.211	0.208	0.242
47	0.132	0.152	0.124	0.069	0.112	0.104	0.046	0.045	0.050	0.052	0.042	0.038	0.056	0.076	0.078	0.183	0.140	0.154	0.255
48	0.140	0.157	0.135	0.093	0.096	0.088	0.050	0.038	0.046	0.056	0.044	0.042	0.047	0.090	0.075	0.181	0.146	0.228	0.191
50	0.143	0.172	0.142	0.139	0.078	0.128	0.050	0.042	0.042	0.065	0.062	0.035	0.062	0.163	0.124	0.205	0.134	0.287	0.252
51	0.146	0.132	0.102	0.117	0.173	0.066	0.047	0.046	0.039	0.082	0.049	0.035	0.060	0.148	0.079	0.180	0.142	0.272	0.156
52	0.135	0.131	0.128	0.085	0.096	0.067	0.041	0.045	0.038	0.055	0.041	0.036	0.058	0.042	0.049	0.164	0.140	0.181	0.189
54	0.119	0.123	0.126	0.105	0.080	0.144	0.058	0.045	0.039	0.067	0.041	0.053	0.060	0.112	0.090	0.254	0.184	0.192	0.177
55	0.129	0.172	0.121	0.117	0.129	0.113	0.055	0.060	0.034	0.072	0.048	0.037	0.056	0.148	0.070	0.170	0.173	0.171	0.173
56	0.189	0.168	0.133	0.149	0.139	0.092	0.063	0.059	0.043	0.039	0.041	0.038	0.051	0.076	0.116	0.169	0.189	0.193	0.240
57	0.211	0.198	0.146	0.098	0.198	0.133	0.069	0.064	0.069	0.048	0.043	0.056	0.060	0.081	0.067	0.196	0.204	0.210	0.269
58	0.188	0.134	0.159	0.151	0.173	0.104	0.059	0.041	0.054	0.056	0.048	0.035	0.054	0.073	0.107	0.155	0.181	0.196	0.252
22A	0.200	0.145	0.154	0.121	0.128	0.127	0.055	0.057	0.046	0.047	0.047	0.030	0.062	0.103	0.115	0.135	0.223	0.252	0.289
22B	0.186	0.147	0.118	0.107	0.108	0.085	0.047	0.042	0.073	0.062	0.035	0.037	0.060	0.116	0.094	0.225	0.194	0.211	0.254
Mean	0.178	0.186	0.158	0.131	0.145	0.118	0.058	0.054	0.048	0.067	0.047	0.046	0.059	0.099	0.091	0.172	0.185	0.209	0.247
SD	0.039	0.047	0.037	0.040	0.044	0.027	0.016	0.012	0.009	0.022	0.009	0.011	0.013	0.030	0.025	0.034	0.033	0.032	0.047
CV	0.217	0.250	0.230	0.307	0.301	0.228	0.277	0.216	0.182	0.325	0.184	0.227	0.213	0.301	0.275	0.200	0.176	0.154	0.189
Max	0.278	0.325	0.289	0.260	0.289	0.220	0.111	0.077	0.073	0.135	0.064	0.072	0.086	0.190	0.149	0.254	0.276	0.313	0.356
Min	0.095	0.106	0.099	0.066	0.078	0.066	0.010	0.026	0.031	0.034	0.026	0.022	0.034	0.042	0.049	0.095	0.087	0.128	0.144
Range	0.183	0.219	0.190	0.194	0.211	0.154	0.101	0.051	0.042	0.101	0.038	0.050	0.052	0.148	0.100	0.159	0.188	0.185	0.212

Table B1. Continued.

Point Soil Moisture Content ($m^3 m^{-3}$) by Samplingdate

Sample Location	16 March 2004	19 March 2004	23 March 2004	30 March 2004	2 April 2004	9 April 2004	19 April 2004	23 April 2004	1 May 2004	4 May 2004	13 May 2004	20 May 2004	25 May 2004	30 May 2004	2 June 2004	13 June 2004	17 June 2004	24 June 2004	30 June 2004
1	0.257	0.245	0.222	0.193	0.175	0.178	0.148	0.200	0.164	0.138	0.204	0.222	0.163	0.185	0.139	0.138	0.121	0.074	0.118
2	0.223	0.217	0.168	0.187	0.172	0.136	0.115	0.175	0.132	0.122	0.183	0.213	0.196	0.144	0.134	0.127	0.116	0.096	0.104
3	0.188	0.179	0.163	0.180	0.154	0.131	0.117	0.135	0.111	0.094	0.168	0.224	0.168	0.187	0.151	0.126	0.113	0.102	0.119
4	0.256	0.196	0.231	0.194	0.179	0.169	0.135	0.172	0.129	0.128	0.145	0.194	0.121	0.174	0.162	0.117	0.111	0.082	0.090
5	0.289	0.272	0.218	0.204	0.185	0.170	0.149	0.201	0.163	0.121	0.166	0.221	0.181	0.189	0.151	0.134	0.130	0.119	0.117
6	0.199	0.176	0.177	0.195	0.159	0.162	0.127	0.190	0.119	0.096	0.149	0.240	0.159	0.178	0.153	0.116	0.113	0.104	0.108
7	0.165	0.157	0.162	0.161	0.147	0.146	0.125	0.151	0.109	0.095	0.137	0.178	0.156	0.176	0.112	0.123	0.112	0.101	0.100
8	0.258	0.258	0.203	0.204	0.188	0.159	0.153	0.180	0.168	0.148	0.204	0.203	0.164	0.182	0.156	0.131	0.120	0.108	0.135
9	0.181	0.198	0.182	0.192	0.162	0.161	0.140	0.187	0.149	0.148	0.190	0.221	0.168	0.172	0.161	0.133	0.139	0.144	0.145
10	0.207	0.181	0.184	0.182	0.144	0.160	0.125	0.154	0.116	0.100	0.163	0.190	0.148	0.131	0.104	0.089	0.104	0.081	0.099
11	0.231	0.192	0.189	0.152	0.156	0.137	0.112	0.140	0.121	0.085	0.122	0.177	0.158	0.147	0.130	0.083	0.101	0.090	0.087
12	0.201	0.228	0.216	0.199	0.178	0.160	0.136	0.188	0.117	0.112	0.141	0.231	0.146	0.168	0.131	0.121	0.116	0.097	0.117
13	0.235	0.227	0.200	0.199	0.177	0.174	0.155	0.184	0.144	0.117	0.093	0.206	0.147	0.210	0.135	0.125	0.145	0.125	0.139
14	0.249	0.195	0.204	0.198	0.189	0.154	0.141	0.148	0.164	0.120	0.164	0.202	0.154	0.171	0.174	0.112	0.117	0.106	0.101
15	0.232	0.226	0.218	0.200	0.174	0.171	0.161	0.182	0.156	0.095	0.186	0.231	0.165	0.185	0.164	0.134	0.130	0.096	0.110
16	0.207	0.222	0.186	0.176	0.138	0.138	0.115	0.120	0.138	0.102	0.177	0.163	0.103	0.186	0.145	0.133	0.106	0.115	0.110
17	0.261	0.215	0.190	0.199	0.176	0.152	0.112	0.160	0.124	0.097	0.119	0.213	0.145	0.159	0.134	0.119	0.100	0.105	0.116
18	0.242	0.243	0.162	0.149	0.167	0.198	0.181	0.200	0.132	0.110	0.234	0.174	0.254	0.207	0.157	0.140	0.145	0.180	0.113
19	0.260	0.272	0.248	0.213	0.184	0.169	0.143	0.160	0.152	0.113	0.215	0.185	0.149	0.178	0.151	0.142	0.133	0.106	0.140
20	0.143	0.083	0.134	0.116	0.120	0.105	0.118	0.105	0.090	0.088	0.136	0.141	0.165	0.107	0.107	0.064	0.090	0.083	0.090
21	0.160	0.174	0.162	0.170	0.140	0.100	0.105	0.129	0.085	0.070	0.129	0.201	0.142	0.136	0.130	0.121	0.082	0.087	0.119
23	0.351	0.226	0.235	0.199	0.167	0.161	0.117	0.180	0.153	0.143	0.206	0.239	0.213	0.246	0.192	0.141	0.128	0.112	0.098
24	0.321	0.305	0.264	0.263	0.243	0.212	0.194	0.228	0.142	0.137	0.201	0.264	0.251	0.266	0.292	0.233	0.227	0.156	0.143
25	0.317	0.206	0.201	0.172	0.169	0.158	0.094	0.229	0.141	0.132	0.197	0.243	0.176	0.206	0.171	0.113	0.106	0.081	0.130
26	0.438	0.427	0.325	0.281	0.274	0.240	0.213	0.222	0.179	0.141	0.229	0.227	0.183	0.259	0.246	0.207	0.191	0.155	0.144
27	0.262	0.177	0.196	0.210	0.172	0.174	0.125	0.164	0.153	0.108	0.160	0.225	0.167	0.183	0.169	0.095	0.101	0.091	0.108
28	0.263	0.274	0.217	0.232	0.195	0.162	0.164	0.218	0.137	0.102	0.165	0.230	0.190	0.172	0.176	0.100	0.135	0.112	0.110
29	0.167	0.253	0.178	0.190	0.173	0.199	0.135	0.189	0.165	0.090	0.185	0.172	0.168	0.183	0.155	0.105	0.099	0.119	0.115
30	0.211	0.181	0.180	0.171	0.159	0.135	0.112	0.166	0.119	0.099	0.185	0.180	0.141	0.188	0.157	0.117	0.133	0.083	0.122
31	0.110	0.132	0.136	0.145	0.144	0.120	0.079	0.120	0.126	0.067	0.185	0.179	0.117	0.186	0.122	0.115	0.126	0.096	0.092
32	0.167	0.183	0.185	0.183	0.188	0.132	0.153	0.171	0.133	0.106	0.184	0.213	0.159	0.200	0.145	0.134	0.152	0.128	0.131
33	0.224	0.244	0.269	0.185	0.160	0.138	0.154	0.176	0.135	0.117	0.197	0.256	0.176	0.167	0.101	0.112	0.140	0.095	0.118
34	0.215	0.198	0.161	0.195	0.159	0.144	0.099	0.136	0.108	0.087	0.184	0.239	0.185	0.232	0.144	0.127	0.135	0.099	0.109
35	0.266	0.249	0.227	0.198	0.175	0.170	0.148	0.175	0.137	0.105	0.183	0.246	0.218	0.247	0.195	0.165	0.166	0.127	0.159
36	0.217	0.174	0.230	0.174	0.177	0.163	0.131	0.115	0.137	0.108	0.094	0.135	0.102	0.190	0.185	0.110	0.143	0.153	0.145
37	0.197	0.153	0.124	0.146	0.158	0.105	0.123	0.164	0.102	0.106	0.187	0.202	0.174	0.169	0.162	0.137	0.101	0.106	0.097
38	0.297	0.197	0.151	0.149	0.137	0.117	0.112	0.142	0.112	0.095	0.164	0.158	0.139	0.152	0.107	0.099	0.112	0.097	0.112
39	0.196	0.179	0.162	0.148	0.143	0.130	0.106	0.144	0.109	0.099	0.160	0.172	0.125	0.141	0.100	0.106	0.111	0.096	0.109
40	0.152	0.185	0.188	0.151	0.224	0.117	0.111	0.146	0.129	0.113	0.229	0.179	0.156	0.232	0.139	0.146	0.125	0.116	0.119
41	0.321	0.211	0.243	0.228	0.219	0.146	0.143	0.176	0.179	0.144	0.190	0.230	0.201	0.276	0.211	0.152	0.119	0.094	0.131
42	0.156	0.131	0.118	0.135	0.110	0.096	0.096	0.123	0.099	0.085	0.137	0.179	0.130	0.145	0.106	0.119	0.118	0.115	0.105
43	0.270	0.157	0.137	0.155	0.168	0.141	0.099	0.141	0.102	0.084	0.133	0.198	0.158	0.174	0.160	0.143	0.086	0.100	0.126
44	0.152	0.132	0.122	0.132	0.144	0.118	0.095	0.080	0.094	0.077	0.085	0.134	0.121	0.156	0.106	0.104	0.122	0.124	0.102
45	0.185	0.122	0.115	0.129	0.138	0.108	0.097	0.083	0.096	0.085	0.142	0.155	0.139	0.143	0.103	0.112	0.085	0.084	0.094
46	0.229	0.171	0.135	0.165	0.155	0.105	0.087	0.108	0.094	0.082	0.120	0.175	0.151	0.158	0.129	0.131	0.100	0.086	0.105
47	0.184	0.138	0.148	0.146	0.119	0.132	0.100	0.133	0.107	0.096	0.145	0.161	0.102	0.142	0.110	0.094	0.134	0.095	0.114
48	0.175	0.161	0.141	0.148	0.147	0.103	0.089	0.119	0.120	0.098	0.162	0.172	0.136	0.152	0.122	0.104	0.124	0.109	0.098
50	0.181	0.175	0.148	0.147	0.116	0.110	0.067	0.121	0.090	0.103	0.138	0.179	0.139	0.094	0.099	0.143	0.104	0.115	0.093
51	0.192	0.153	0.095	0.090	0.098	0.088	0.062	0.102	0.085	0.061	0.109	0.156	0.096	0.133	0.076	0.083	0.073	0.076	0.104
52	0.149	0.134	0.130	0.137	0.124	0.093	0.054	0.117	0.087	0.076	0.124	0.166	0.141	0.132	0.101	0.104	0.064	0.089	0.114
54	0.156	0.157	0.132	0.180	0.143	0.139	0.085	0.132	0.093	0.074	0.168	0.191	0.184	0.197	0.155	0.117	0.121	0.121	0.108
55	0.157	0.133	0.141	0.166	0.135	0.102	0.089	0.124	0.086	0.086	0.158	0.208	0.153	0.171	0.133	0.111	0.124	0.099	0.097
56	0.228	0.185	0.129	0.163	0.143	0.119	0.092	0.090	0.081	0.065	0.141	0.190	0.117	0.179	0.118	0.101	0.111	0.093	0.129
57	0.234	0.219	0.214	0.199	0.175	0.166	0.165	0.178	0.142	0.131	0.153	0.220	0.160	0.206	0.172	0.170	0.149	0.111	0.102
58	0.304	0.189	0.193	0.191	0.142	0.111	0.161	0.164	0.116	0.145	0.179	0.223	0.156	0.246	0.181	0.130	0.109	0.110	0.107
22A	0.212	0.223	0.195	0.154	0.178	0.136	0.118	0.168	0.132	0.100	0.217	0.252	0.181	0.182	0.142	0.119	0.115	0.086	0.097
22B	0.128	0.163	0.149	0.154	0.165	0.101	0.082	0.119	0.115	0.131	0.136	0.223	0.158	0.160	0.122	0.115	0.109	0.082	0.090
Mean	0.222	0.197	0.181	0.177	0.163	0.143	0.122	0.155	0.125	0.105	0.164	0.200	0.158	0.180	0.146	0.124	0.120	0.105	0.113
SD	0.061	0.054	0.045	0.033	0.031	0.032	0.032	0.036	0.026	0.023	0.035	0.032	0.032	0.037	0.037	0.027	0.026	0.021	0.017
CV	0.274	0.273	0.246	0.189	0.187	0.222	0.263	0.233	0.207	0.216	0.211	0.159	0.202	0.209	0.255	0.220	0.219	0.203	0.147
Max	0.438	0.427	0.325	0.281	0.274	0.240	0.213	0.229	0.179	0.148	0.234	0.264	0.254	0.276	0.292	0.233	0.227	0.180	0.159
Min	0.110	0.083	0.095	0.090	0.098	0.088	0.054	0.080	0.081	0.061	0.085	0.134	0.096	0.094	0.076	0.064	0.064	0.074	0.087
Range	0.328	0.344	0.230	0.190	0.175	0.151	0.159	0.149	0.099	0.088	0.148	0.129	0.157	0.181	0.216	0.169	0.163	0.106	0.072

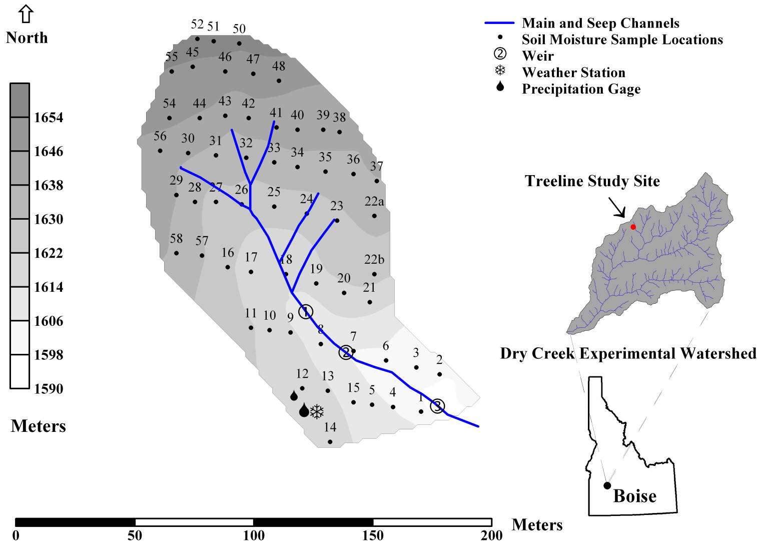

Fig. 1. Location and instrumentation of the Treeline study site in the Dry Creek Experimental Watershed, near Boise, Idaho, USA.

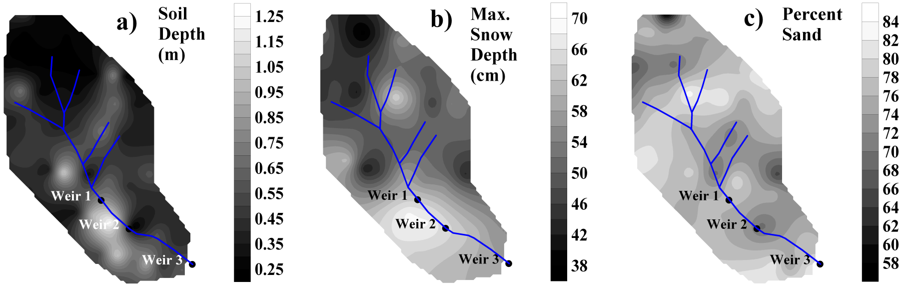

Fig. 2. Measured soil depths **(a)**, snow depths at maximum accumulation **(b)**, and percent sand content of the soil **(c)** at the Treeline site.

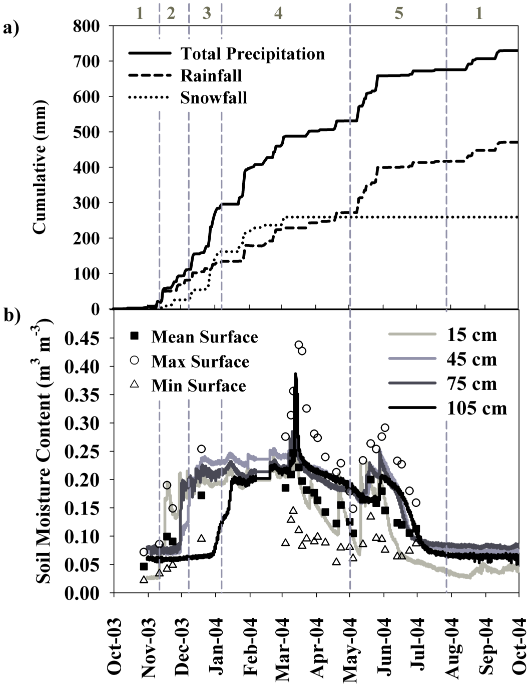

Fig. 3. Timing of the precipitation **(a)** and the dry – 1, wet-up – 2, wet-low flux – 3, wet-high flux – 4, and drydown – 5 preferred soil moisture periods **(b)** observed at Treeline during the 2003/2004 water year. The curves show soil moisture contents observed at 15, 45, 70, and 105 cm depths in a time domain reflectometry (TDR) instrumented soil pit of a deep soil profile. Symbols depict mean, maximum, and minimum near-surface measurements **(b)** recorded at soil moisture sampling locations (using portable TDR) along the study grid.

Title Page
Abstract
Introduction
Conclusions
References
Tables
Figures
◀▶
◀
▶
Back
Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

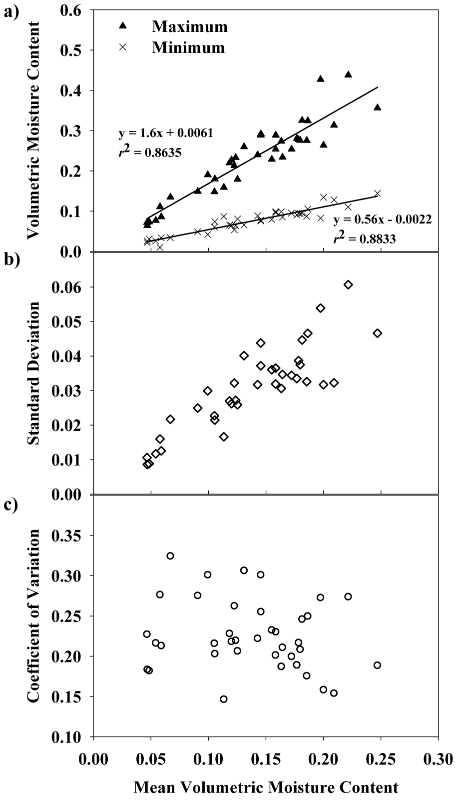

Fig. 4. Maximum and minimum **(a)**, standard deviation **(b)**, and coefficient of variation **(c)** of soil moisture contents ($m^3\,m^{-3}$) for individual sampling dates versus the respective sampling date site mean volumetric soil moisture content ($m^3\,m^{-3}$).

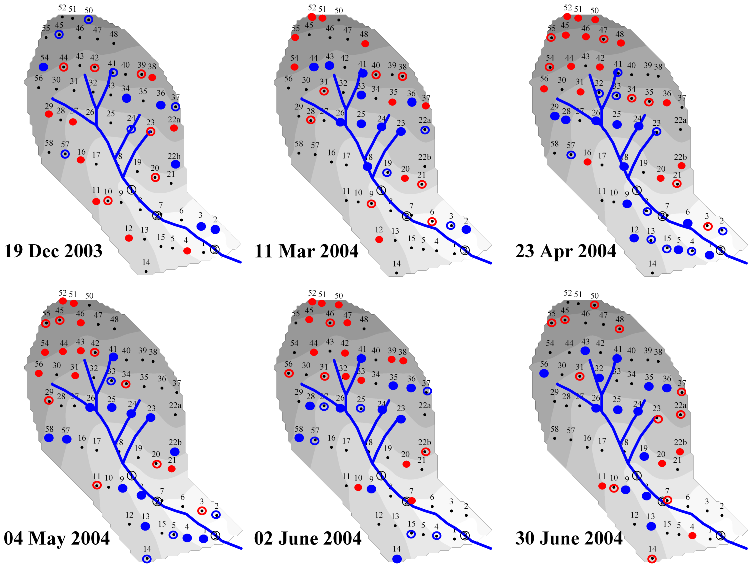

Fig. 5. Mean relative difference (MRD) in soil moisture content by sampling location for representative dates during wet-up (19 December 2003), wet-high flux (11 March 2004, 23 April 2004), initial drydown (4 May 2004), following spring rain (2 June 2004) and final drydown (30 June 2004). Points having positive MRD are indicated by blue, negative MRD by red, relative difference from the mean greater than 0.10 is indicated by open circles and greater than 2.0 is indicated by filled circles.

Title Page
Abstract Introduction
Conclusions References
Tables Figures
◀| |▶
◀ ▶
Back Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

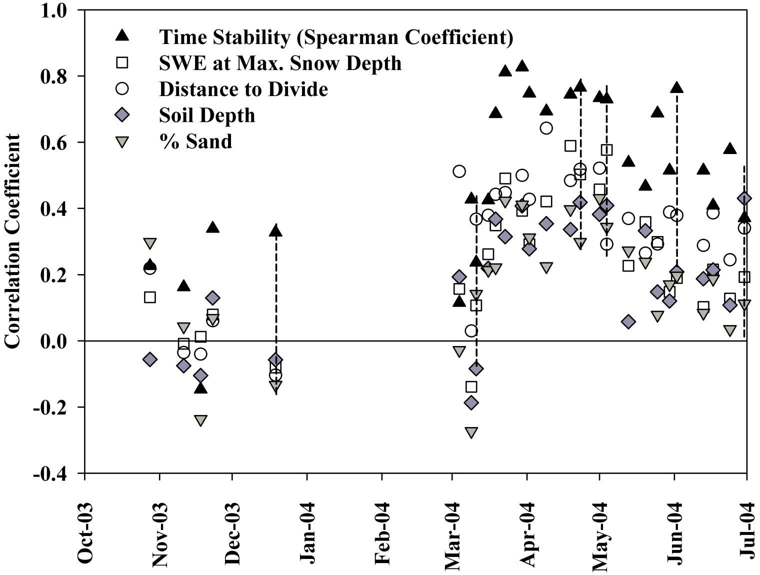

Fig. 6. Pearson correlation coefficients, r, of measured point soil moisture contents and site characteristics and Spearman correlation coefficients, r_s, for time stability between successive soil moisture sampling periods. Dashed lines indicate dates selected as representative of hydrologic states.