DISSERTATION

SEASONAL PRECIPITATION AND SOIL MOISTURE DYNAMICS OF A HYPERARID WASH IN THE SONORAN DESERT, U.S.A.

Submitted by

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ABSTRACT

SEASONAL PRECIPITATION AND SOIL MOISTURE DYNAMICS OF A HYPERARID WASH IN THE SONORAN DESERT, U.S.A.

Precipitation and runoff in arid and hyperarid landscapes is infrequent and both spatially and temporally variable, and the relationship between these hydrologic components and vegetation, soils, and geomorphology in these environments is complex and not well understood. In this study, precipitation and soil moisture were monitored beneath three cover types in three locations across two geomorphic surfaces in the Yuma Wash watershed, located in the Lower Colorado River Valley of the Sonoran Desert, on the US Army Yuma Proving Grounds in Yuma, Arizona. Monitoring, sampling, and characterization occurred from July 2006 to February 2010. Six tipping bucket rain gages and sixty time domain reflectometry soil moisture sensors recorded moisture inputs and storage on a middle to late Pleistocene age alluvial terrace, and a younger, Holocene age alluvial wash. Sensors were spatially distributed in the lower, middle and upper locations of the watershed, beneath bare ground at 2.5, 25, 50, and 100 cm, and beneath the dripline radius of *Olneya tesota* and *Parkinsonia microphylla*, at 25, 50, and 100 cm depths. These data suggest that precipitation is highly variable in space and time, and is generally greater than the surrounding valley bottoms of Yuma Proving Grounds. Findings also suggest that soils beneath the dripline radius of these plant species on terraces are wetted more frequently and to greater depths in response to smaller magnitude and lower intensity storm events relative to soils beneath the same species on washes, and relative to bare ground soils. Threshold precipitation conditions necessary to generate changes in soil moisture were compared across surfaces, and illustrate that the vesicular structure in the A (Av) horizons beneath desert pavement plays a key role in redistribution of moisture as runon to *O. tesota* and *P. microphylla* on terraces, and that soils beneath the dripline radius of both species on washes receive moisture only during rainfall events exceeding 30 mm. There is also some evidence to suggest precipitation and near surface soil moisture may be greater in the upper basin relative to the mid- and lower basin on both surfaces, but at depths of 25-100 cm, soil moisture responses were difficult to interpret due to local soil properties not quantified in this study. The influence of soil temperature on the imaginary permittivity component of soil moisture readings due to high soluble salt content, the presence of enriched clay layers, soil compaction and induration is discussed. Findings highlight the need to quantify these age-dependent soil pedogenic and hydrologic properties when assessing soil moisture response to spatially variable precipitation in these water-limited environments. Implications for management of military lands are discussed.

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CHAPTER 1

INTRODUCTION AND GENERAL METHODOLOGICAL APPROACH

The general format of this dissertation begins with a statement of purpose, the objectives of the research and specific questions and hypotheses addressed, and the general methodological approach outlined in Chapter 1. An introduction to the topic of drylands hydrology follows, with an emphasis on the hydrologic components and processes that constitute the focus of this study, and background information on the research study site. Chapter 2 provides detail on instrumentation, measurement theory, data collection protocol, and methods of analyses. Results of the study are provided in Chapter 3, followed by a discussion of the research contribution to drylands hydrology in Chapter 4, and its implications for arid lands management in the 21^{st} century.

1.1 Statement of Purpose and Research Relevance

This research was designed with the aim of understanding how seasonal precipitation is partitioned in space and time in an ephemeral, alluvial wash in the southwestern US, and how soils within the top meter of two distinct geomorphic surfaces respond to moisture inputs. The physiogeographic region of study is Yuma Wash, a hyperarid ephemeral watershed located in the Lower Colorado River Valley region of the Sonoran desert in the southwestern United States (Figure 1.1). Yuma Wash drains an area of approximately 186 km^2 and is politically bound within the United States Army Yuma Proving Ground (YPG). This military installation is the Department of Defense (DoD) primary desert environmental test center and spans approximately 3390 km^2 of the Sonoran Desert (Figure 1.2). The research was co-funded by the U.S. Army

Research Office and the National Science Foundation, and was designed around four premises outlining the importance of desert hydrology to these agencies:

Figure 1. Physiographic location of study area: Yuma Wash, Lower Colorado River Valley Subdivision, Sonoran Desert, USA.

(1) Arid and hyperarid regions exhibit unique rainfall and runoff characteristics. Annual precipitation rarely exceeds 250 mm in arid environments and 100 mm for hyperarid regions, and multiple years in which rainfall is considerably less are common. Yet a single storm event can deliver the entire annual allotment of precipitation over a period of hours. Convective precipitation, driven in part by seasonal differential heating of desert floors, can cause intense, localized flash flooding, yet most streams are dry ninety-eight percent of the year (Reid et al, 1998). Pulsed rainfall events such as this result in highly dynamic and non-linear hydrologic responses, in part because of the partial area coverage of these storms (Goodrich et al, 1997), but also because of marked differences in surface and subsurface features common in desert landscapes. These non-linear processes have only recently received mathematical attention in landscape-evolution, hydrologic and climate simulation modeling. To date, data required to verify these processes are severely limited for arid and hyperarid regions, thus limiting the testability of these models in dryland environments.

(2) The relationship between vegetation, soils, and geomorphology influences seasonal water partitioning in arid and hyperarid landscapes. Water is the principal limiting resource in desert ecosystems, and the extent to which plants can access it depends in large part on the characteristic precipitation they receive, the surface and subsurface soil and morphological features on which they establish, and the adaptive strategies employed

Figure 1.2. Political boundary of the US Army Yuma Proving Grounds and location of Yuma Wash.

by each species. Documentation of these interactive processes is also limited for arid and hyperarid systems.

(3) Conventional water balance methods do not provide accurate estimates of hydrologic response in arid and hyperarid environments. There are several reasons for this. First, highly variable precipitation coupled with the sparse network of meteorological stations in most arid and hyperarid regions limits the accuracy of rainfall estimates. Second, poor documentation of highly localized, ephemeral runoff characterized by high rates of transmission loss constrains regional estimates of streamflow and groundwater recharge. Third, estimates of potential evapotranspiration (ET_p) commonly used to estimate evaporative losses typically exceed actual evapotranspiration (ET_a) in such water-limited systems by an order of magnitude or more, so that even small errors in estimates can result in large discrepancies in overall water balances. Documentation of the seasonal and spatial characteristics of precipitation and soil moisture response across variable terrain provides an opportunity to improve water balance estimates for arid and hyperarid regions.

(4) Military and public land managers require accurate estimates of landscape response to precipitation for flood prediction and control, erosion management, sustainable use of scarce water resources, and the maintenance of ecological integrity to sustain their respective missions. As a relatively undisturbed site located within the boundaries of the Yuma Proving Grounds, Yuma Wash provides a unique setting for establishing baseline hydrologic, geomorphic, and vegetative conditions required for arid/hyperarid lands management. The current research effort is predated by a few notable studies. In 1995, Ayres Associates was tasked with the first inventory of the biophysical landscape of Yuma Wash that included characterization of geomorphology, hydrology and vegetation. Unfortunately, the study occurred during two of the

driest years on record, so precipitation and soil moisture data collected in two locations in the alluvial wash were extremely limited. While this initial effort provided valuable general information on present day landscape elements in Yuma Wash (Ayres Associates, 1996), there remained a pressing need to understand process relationships among these elements and, in particular, the linkages between seasonal precipitation, soil moisture, and plant water use. The current research aims at quantifying two of these linkages through direct measurement of precipitation and soil moisture across two geomorphic surfaces that comprise most of the Yuma Wash watershed. Given recent trends in human population expansion in arid and hyperarid regions, historical documentation of drought and increased concern over water scarcity in these regions, understanding the hydrodynamics of dryland systems is emerging as an important focal area for hydrologic research.

1.2 Research questions and hypotheses

The study was designed with the aim of understanding how precipitation is partitioned in space and time in the Yuma Wash watershed, and how soil moisture varies within the top meter of soil on two geomorphic surfaces. Two primary objectives and several basic research questions were addressed toward this end, and several working hypotheses were postulated as a framework for addressing the research questions:

Objective 1: Documentation of how the amount and rate of precipitation vary in space and time in Yuma Wash.

Question 1: Are there significant differences in the amount or rate of precipitation by geomorphic surface?

- *H_o: The amount and rate of precipitation do not vary significantly by geomorphic surface.*
- *H_a: The amount and rate of precipitation vary significantly by geomorphic surface.*

Question 2: Are there significant differences in the amount or rate of precipitation by location?

- *H_o: The amount and rate of precipitation do not vary significantly by location.*
- *H_a: The amount and rate of precipitation vary significantly by location.*

Question 3: Are there significant differences in the amount or rate of precipitation by year or season?

- *H_o: The amount and rate of precipitation do not vary significantly by season or year.*
- *H_a: The amount and rate of precipitation vary significantly by season or year.*

Objective 2: Documentation of how soil moisture varies in space and time in response to precipitation in Yuma Wash.

Question 1: Are there significant differences in soil moisture by geomorphic surface?

- *H_o: Soil moisture does not vary significantly by geomorphic surface.*
- *H_a: Soil moisture varies significantly by geomorphic surface.*

Question 2: Are there significant differences in soil moisture by cover type?

- *H_o: Soil moisture does not vary significantly by cover type.*
- *H_a: Soil moisture varies significantly by cover type.*

Question 3: Are there significant differences in soil moisture by basin location ?

- H_o: *Soil moisture does not vary significantly by location.*
- H_a: *Soil moisture varies significantly by location.*

Question 4: Are there significant differences in soil moisture by season or by year?

- H_o: *Soil moisture does not vary significantly by season or year.*
- H_a: *Soil moisture varies significantly by season or year.*

1.3 General Methodological Approach

This field-based study commenced in July 2006 using instrumentation that was operational in the Yuma Wash watershed through February, 2010. Data were collected and analyzed from a suite of hydrometeorological instrumentation deployed in three general locations in Yuma Wash (lower, middle, and upper basin) on two varying age geomorphic surfaces (relict alluvial terraces and alluvial washes) (Figure 1.3). Six fully instrumented meteorological stations (ECOV and MET) and six soil moisture stations (SF) provided data for this study on precipitation, soil moisture and soil temperature in the top 1 meter of soil. These stations also measured a suite of additional variables required to estimate evapotranspiration and plant sapflux as part of a larger study that is beyond the scope of this dissertation. Coordinates, elevations, and distances between stations are provided in Table 1.1, along with the type of geomorphic surface and the general basin location associated with each station.

Precipitation and soil moisture data were analyzed on an event, seasonal, and annual basis, and statistical analyses were conducted to determine whether significant differences existed in various space and time domains. Programming code for data collection from all instrumentation and for initial data post-processing is provided in Appendix A. Calibration procedures for soil moisture probes are provided in Appendix B, and statistical code for data analysis is provided in Appendix C. Graphical and tabular output from these analyses that are not included within Section 3 are provided in Appendix D. Data were initially post-processed using MatLab® 7.10.0/R2010a computational software (The Mathworks, Inc., 1994-2010), Excel 2010 (Microsoft, 2010), and Minitab® 15.1.30.0. (Minitab, Inc, 2007). Statistical analyses were conducted using R© 2.11.1/2010 statistics software (The R Foundation for Statistical Computing, 2010). To provide a physiographic context for this research, the topic of drylands hydrology is presented next, with an emphasis on the hydrologic processes that constitute the focal areas of the study.

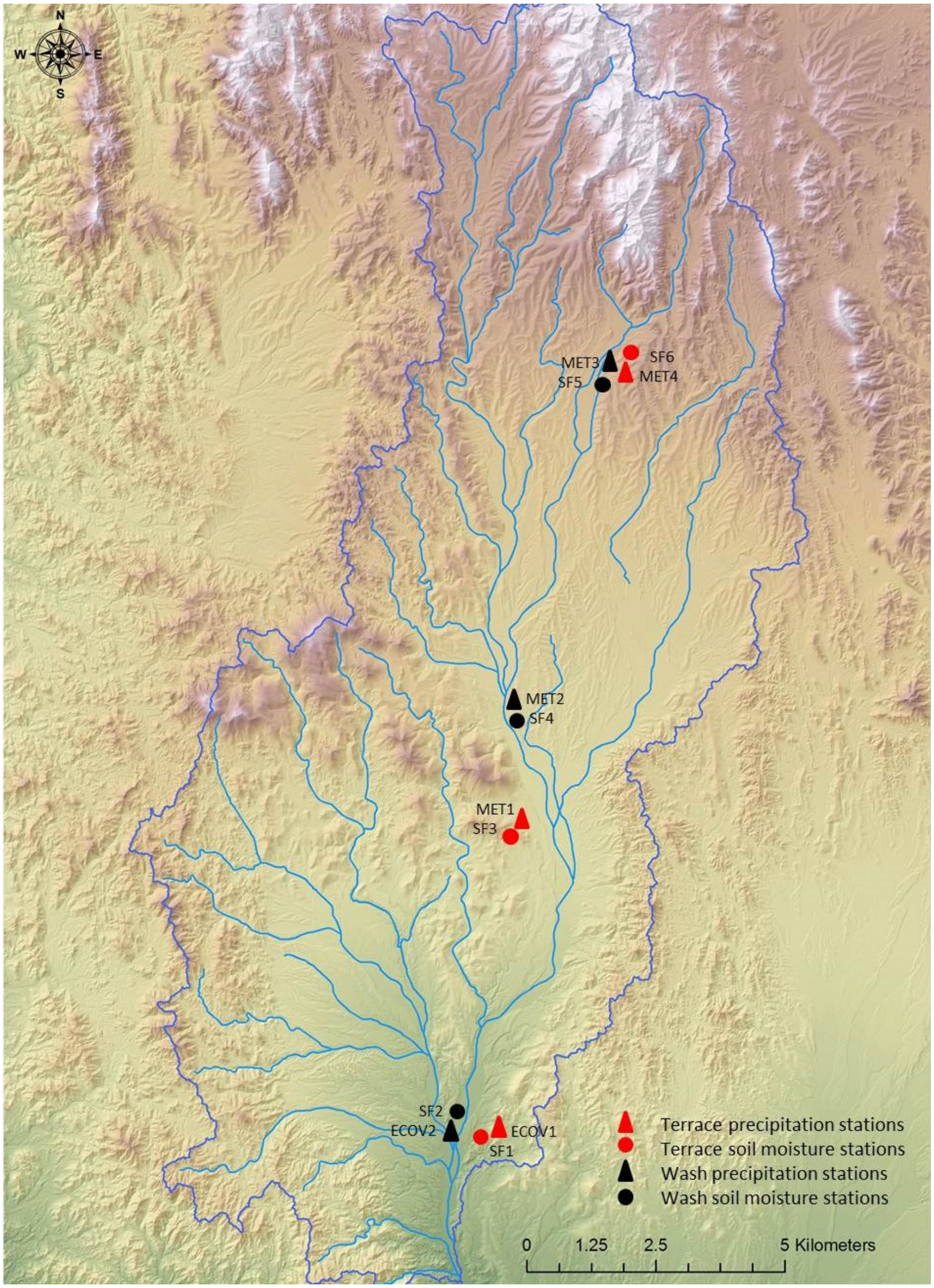


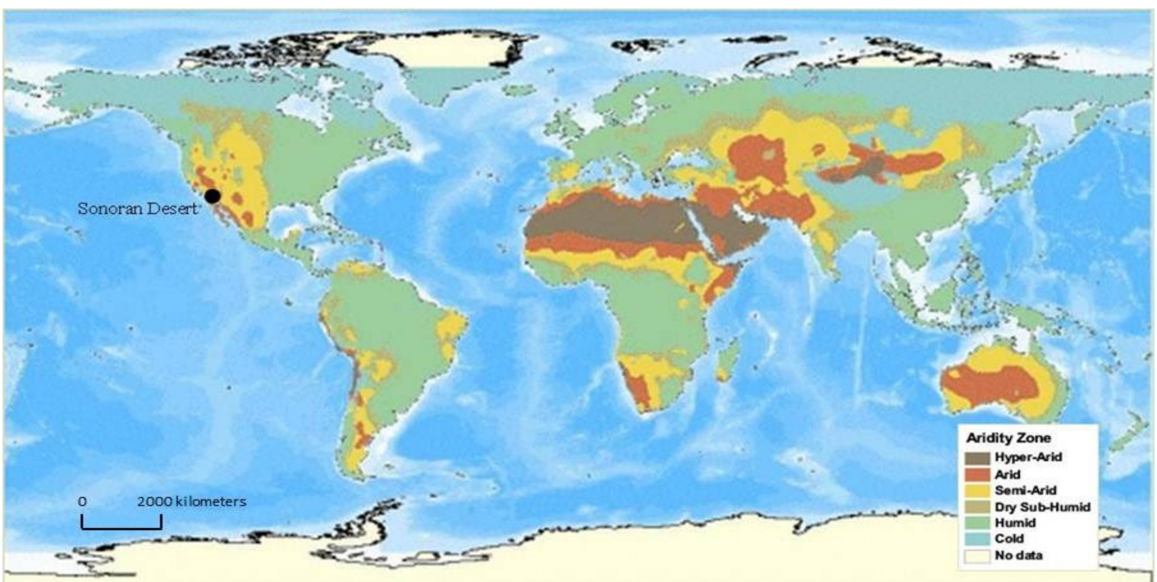
Figure 1.3. Hydrometeorological instrumentation deployed in Yuma Wash. ECOV and MET stations measured precipitation and soil moisture at 2.5 cm beneath bare ground. SF stations measured soil moisture at 25, 50, and 100 cm beneath bare ground, *P. microphylla* and *O. tesota*. Stations in red are located on relict alluvial terrace surfaces, and stations in black are located on alluvial wash surfaces.

Table 1.1. UTM coordinates and elevations, distance between stations, basin location, and geomorphic surface for each station deployed in Yuma Wash.

Station	Easting (m)	Northing (m)	Elevation (m)
ECOV1-SF1	730851	3662979	124
ECOV2-SF2	730696	3662625	114
MET1-SF3	732655	3668287	197
MET2-SF4	732243	3670182	211
MET3-SF5	734064	3678490	339
MET4-SF6	734056	3678430	361
	Proximity (km)	**Location**	**Geomorphic Surface**
ECOV1-SF1/ECOV2-SF2	0.39	Lower/Lower	Terrace/Wash
ECOV1-SF1/MET1-SF3	5.61	Lower/Middle	Terrace/Terrace
ECOV1-SF1/MET2-SF4	7.34	Lower/Middle	Terrace/Wash
ECOV1-SF1/MET3-SF5	15.84	Lower/Upper	Terrace/Wash
ECOV1-SF1/MET4-SF6	15.78	Lower/Upper	Terrace/Terrace
ECOV2-SF2/MET1-SF3	5.99	Lower/Middle	Wash/Terrace
ECOV2-SF2/MET2-SF4	7.72	Lower/Middle	Wash/Wash
ECOV2-SF2/MET3-SF5	16.22	Lower/Upper	Wash/Wash
ECOV2-SF2/MET4-SF6	16.16	Lower/Upper	Wash/Terrace
MET1-SF3/MET2-SF4	1.94	Middle/Middle	Terrace/Wash
MET1-SF3/MET3-SF5	10.3	Middle/Upper	Terrace/Wash
MET1-SF3/MET4-SF6	10.24	Middle/Upper	Terrace/Terrace
MET2-SF4/MET3-SF5	8.51	Middle/Upper	Wash/Wash
MET2-SF4/MET4-SF5	8.45	Middle/Upper	Wash/Terrace
MET3-SF5/MET4-SF6	0.1	Upper/Upper	Wash/Terrace

1.4 State of the Science: Drylands Hydrology

Drylands are defined hydrologically as areas where potential evapotranspiration (ET_p) exceeds precipitation throughout the year or part of it, and conditions of seasonal or permanent soil moisture deficit occur (D'Odorico and Porporato, 2006). Consequently, they can be found in regions that are either isolated from ocean moisture sources, or are located beneath semi-permanent high pressure systems, as in the subtropical zone of 30 degrees latitude north and south of the equator. The importance of drylands hydrology is underscored by the fact that drylands cover over 45 per cent of Earth's surface, and close to a third of the world's human population lives in these regions (Safriel, 2005). Drylands are collectively represented by hyperarid, arid, semiarid, and dry subhumid regions on Earth (WRI, 2002) (Figure 1.4). The interior landscapes of western North America, western South America, Australia, and the Tibetan plateau are examples of regional areas separated from oceanic moisture by expansive mountain ranges, which stall prevailing winds, creating a leeside rainshadow effect and inland aridity. The Central Eurasian deserts lie in the center of a large continental land mass, which also precludes moisture from reaching them. On the west coast of the southern hemisphere continents, cool ocean currents further limit evaporation and inland moisture penetration, creating drylands in these regions (Bull and Kirkby, 2002). Earth's subtropical region is largely arid, resulting in large part from an area of high pressure where global circulation patterns create



Classification	Mean annual P (mm)	PET (mm/yr)	Aridity Index	Global Land Area
Hyperarid	< 100	>2000	AI < 0.05	7.5%
Arid	100-250	2000-1250	0.05 < AI <0.20	12.1%
Semiarid	250-500	1250-1000	0.20 < AI < 0.50	17.7%
Dry Subhumid	500-800	1000-1250	0.50 < AI <0.65	9.9%

Figure 1.4. Drylands are collectively represented by hyperarid, arid, semiarid, and subhumid zones. Study area within the Sonoran Desert is denoted in black to provide a global reference. (*Sources: WRI, 2002; UNEP, 1992; Mainguet, 1994*)

semi-permanent temperature inversions, preventing vertical convection and stalling precipitation mechanisms. Many of the world's largest deserts are subtropical, including the Sonoran Desert of North America.

1.4.1 Climate in Drylands

While drylands are typically classified according to their relative degree of aridity, approaches to quantifying aridity are varied (Meigs, 1953; Thornthwaite and Mather (1955); Budyko, 1958; Noy-Meir, 1973; UNEP, 1992; Mainguet, 1994). A combination of precipitation, temperature, energy fluxes, and estimates of potential evapotranspiration (ET_p) via direct or indirect measurement is typically employed to develop indices of dryness. The aridity index as adopted by UNEP (1992) was used here to denote drylands of the world and to classify the study area for this research as hyperarid. UNEP's aridity index is defined as: $AI_u = P/ET_p$ where P is the average annual precipitation, and ET_p is the potential evapotranspiration, expressed in units of millimeters. Mean annual precipitation recorded across the Lower Colorado River Valley Subdivision of the Sonoran Desert since the 1950s has ranged from 72-107 mm, and pan evaporation ET_{pan} recorded at a single station from 1920-2005 has averaged 2520 mm (WRCC, 2009). Assuming ET_p is approximately 75 per cent of pan evaporation (Eagleman, 1967), this region of the Sonoran Desert has an aridity index between 0.038-0.057, with a mean of 0.047.

Dryland precipitation results from four general atmospheric processes: orographic effects, convection, frontal activity, and tropical cyclonic dissipation. The southwestern United States, western China, portions of India, and the high deserts of western South America are drylands subject to regional scale orographic effects (Graf, 1988). Convective storms driven by seasonal differential heating of the land surface are typically seasonal, intense, of short duration, and restrictive in areal extent (storm cells only a few to tens of kilometers in diameter that collectively extend to regions less than 70-100 km^2 in size) (Branson et al., 1981), and can cause localized flash flooding. Frontal precipitation occurs over much larger spatial scales (storm cells up to 100 km in diameter with collective areal extents of hundreds to thousands of square kilometers), tends to be of longer duration but lesser intensity than convective storms, and may or may not generate runoff, depending primarily on storm duration and antecedent soil moisture conditions. Less frequent but equally important to most drylands are tropical cyclones. These storm systems originate in maritime tropical air masses in the doldrums near the equator, and are characterized by a large low pressure center and numerous thunderstorms that produce strong winds, heavy rain, and often cause widespread flooding across inland surfaces affected by them. Each type of precipitation is thought to play an important ecological role in drylands, albeit over different spatial and temporal scales. For example, cyclonic precipitation is believed to contribute to significant groundwater recharge at greater depths than seasonal convective and frontal precipitation, and therefore may play a strong ecological role over broad areas on decadal time scales.

1.4.2 Climate in the southwestern US Drylands

In the southwestern US, cool season frontal precipitation typically recharges soil moisture across the region, and controls woody plant growth and regeneration that occurs later in the year during summer months, whereas convective precipitation received during the summer monsoon drives the annual grass production (Betancourt, 2007). Concern about the implications of a warming trend in the Southwest has directed recent research toward understanding the variability in Southwest climate at diurnal to multi-decadal scales. The Climate Assessment (CLIMAS) project, a National Oceanic and Atmospheric Association (NOAA) climate change initiative, is one effort toward this end, and much of the following discussion is based on a review of climate in the Southwest by Sheppard et al (2002) funded under this initiative, and a review of climate variability and change in the Southwest by Betancourt (2007).

Low but highly variable inter- and intra-annual precipitation, clear skies, and year-round warm temperatures over much of the Southwest describe the climate of this region in a broad sense. These features are due in large part to a semi-permanent subtropical high-pressure ridge over the region. The Southwest is located between the mid-latitude and subtropical atmospheric circulation regimes, and this positioning relative to shifts in these regimes is the fundamental reason for the region's climatic variability. Complex topography, including orographic effects from mountain ranges, and the Southwest's geographical proximity to moisture sources of the eastern Pacific Ocean, the Gulf of California, and the Gulf of Mexico also contribute to the climatic variability (Sheppard et al, 2002).

For much of the Southwest, seasonal precipitation is bimodal, characterized by a highly variable winter-early spring December-March, an arid late spring and foresummer April-June, monsoonal rains July-September with the importance of monsoonal rainfall decreasing westward, and a dry autumn October-November. Summer precipitation typically takes the form of convective storms that build as moist air-masses moving inland from the Pacific meet rising thermal air-masses created from intense solar radiation striking the desert floor. These isolated storm cells deliver high-intensity, short-duration rains that are typically limited in spatial extent to a few to tens of square kilometers. During winter months, frontal storm tracks that typically move inland from the Pacific to the northwest and Great Plains region are occasionally diverted to the Southwest, bringing low-intensity, long-duration rains of broad spatial extent to the region.

More so than frontals, summer convective storms frequently result in flash flooding in active channel washes, and only infrequently do frontal storms deliver rainfall patterns that produce runoff. Occasionally, dissipating tropical cyclones bring a third source of additional moisture in the late summer and early fall, when moisture is steered inland over several days by low-pressure troughs and cut-off lows (Betancourt, 2007). Equivalent in spatial variability but often greater in overall extent than convective storms, these high-intensity systems can produce extensive but highly discontinuous flooding, such as tropical storm Octave in October 1983 (Webb and Betancourt 1992) and tropical storm Nora in 1997 (Merritt and Wohl, 2003).

1.4.2.1 Influence of El Nino Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) on southwestern US Climate

Interannual variability in fall, winter and early spring precipitation is modulated in part by the El Niño Southern Oscillation (ENSO), where an increase in sea-surface temperature (SST) of the eastern equatorial Pacific Ocean is accompanied by a shift of the active center of atmospheric convection from the western to the central equatorial Pacific (Sheppard et al, 2002). The opposite of El Niño are La Niña conditions, which usually result in dry winters for the Southwest. The Oceanic Niño Index (ONI), defined as the three-month running mean SST departures in the Niño 3.4 region of the Pacific Ocean, is the principle measure used by NOAA for defining, monitoring, and predicting El Niño and La Niña. El Niño or La Niña *conditions* occur when monthly Niño 3.4 OISST values meet or exceed +/- 0.5^{o}C (positive shifts indicative of El Niño and negative of La Niña) along with consistent atmospheric features. If persistent over five consecutive overlapping three-month periods, conditions are considered to be either an El Niño or a La Niña *episode*. The influence of ENSO on precipitation in the Southwest since the 1950's is documented in Table 1.2. In general, the correlation between La Niña and

Table 1.2. Historical influence of El Niño and La Niña on climate in the southwestern U.S.A.. (*Source: Betancourt, 2007; NOAA, 2010*)

El Niño (wet years in southwestern US)	La Niña (dry years in southwestern US)
1957-58, 1965-66, 1972-73, 1977-78, 1982-83, 1987-88,1991-92, 1994-95, 1997-98, 2004-05, 2006-07, 2009-10	1950-51, 1954-56, 1964-65, 1973-74, 1975-76,1988-1989, 1996-97, 2000-2001, 2007-08

precipitation deficits is stronger than between El Niño and precipitation surpluses. Variability in summer monsoonal precipitation is less clearly tied to large-scale climatic indices like ENSO, and Eastern Pacific autumnal tropical storms appear to be less frequent in El Niño years, albeit those that do occur have a greater tendency to track into Mexico or the southwestern US.

A third important oceanic influence on winter climate of the Southwest is the Pacific Decadal Oscillation (PDO), which has been defined as temporal variation in sea-surface temperatures across the Northern Pacific Ocean. Interannual variability in precipitation increases in the Southwest when the effects of ENSO and PDO amplify each other (Sheppard et al, 2002). Knowledge of the influence of El Niño on climatic patterns and hydrologic processes in drylands of the Southwest has been enhanced in part by nearly half a century of research conducted at the Walnut Gulch Experimental Watershed, a semiarid landscape located in the transition zone between the Sonoran and Chihuahuan deserts. Much of the interannual variability in precipitation reported for the Walnut Gulch watershed and across the southwestern US has been tied to El Niño cycles (Andrade and Sellers, 1988; Woolhiser et al., 1993; Betancourt, 2007), with a notable increase in the number of El Niño events that have resulted in wetter winters in the Southwest from 1980-1990 (Trenberth and Hoar, 1996). Additional emphasis has been on analyses of the spatiotemporal variation in precipitation (Syed et al., 2003; Ferriera, 1990; Nichols et al., 2002), on the influence of elevation, aspect, and latitude, development of depth-area curves (Osborn, 1984; Osborn and Lane, 1972; Osborn et al., 1980), and the application of precipitation patterns to rainfall/runoff modeling (Osborn and Lane, 1972; Goodrich et al., 1990; Hanson and Woolhiser, 1990). An analysis by Nichols et al. (2002) of forty years of precipitation data from six rain-gages in Walnut Gulch has revealed a general increase in the number of non-summer precipitation events since 1956, but no significant change in the event-magnitude, duration, or intensity was apparent. An increase in the number of summer monsoon events was also reported, albeit with an actual decrease in the amount of rainfall per event. It has been speculated that these trends are coincident with changes in vegetation that have occurred in Walnut Gulch during this period, though no direct comparisons were reported (Nichols et al., 2002).

1.4.2.2 The North American Monsoon

The most defining climatic feature of the Southwest is the North American monsoon. By definition, a monsoon is a distinctive seasonal change in wind direction of at least 120° (Ramage, 1971), including mid-tropospheric winds (Bryson and Lowry, 1955), albeit this and other monsoons are more commonly associated with the seasonal rains brought by the wind reversals. The effect of the monsoon extends over much of the western US and northwestern Mexico, and is fed by seasonally warm land surfaces and atmospheric moisture supplied by the nearby maritime sources (Sheppard et al., 2002). Onset of the monsoon usually occurs in June over Mexico, and by the first week in July over the Southwest US, and is related to the retreat of the westerlies and simultaneous advance of the subtropical high-pressure ridge over the region. In addition, a thermal low-pressure area forms over the Lower Colorado River Basin (Adams and Comrie, 1997; Higgins et al., 1999). Up to half of the annual rainfall of Arizona and New Mexico can occur as monsoonal storms from July through September, and this precipitation is much more variable in space than cool season frontal precipitation, but tends to be more predictable in time. Conversely, cool season precipitation is highly synchronized across large areas, yet quite variable in time, and contributes on average, thirty percent of the annual rainfall in the Southwest (Barry and Chorley, 1998).

The monsoon period in the Southwest is notable for having considerable intraseasonal variability in the form of periods of heavy thunderstorm activity and substantially drier periods (Hales, 1972; Brenner, 1974), as well as interannual and decadal scale variation in duration and intensity. Throughout the monsoon season, intense surface heating and high topographic relief in the region contribute to atmospheric instability, and total cloud cover variation of as much as forty percent may be observed within a few days, reflecting latitudinal changes in anticyclonic activity in association with subtropical ridging over the Southwest (Carleton, 1986; Carleton et al., 1990). Diurnal variation in precipitation is also pronounced during the North American monsoon season and can be linked to differences in daily surface heating and convection. Specifically, the change from daytime cyclonic circulation to nighttime anticyclonic circulation causes precipitation to increase in evening hours and decrease during morning hours, a pattern that follows the strong influence of thermal heating (Sellers and Hill, 1974). Diurnal variability in convective activity and precipitation during the monsoon season has been shown to depend as well upon geographic location in the region (Maddox et al., 1991, 1995, Watson et al., 1994). Convective activity tends to peak in the early afternoon over the Colorado Plateau, in the early evening over southern Arizona and the Sonoran Highlands, and in the late evening and/or nighttime in the low desert areas of southern and central Arizona as well as northwestern Mexico and its coastal lowlands (Sheppard et al., 2002). This pattern occurs in part when mid-level cold air derived from afternoon thunderstorms over mountain areas is advected to lower desert areas during evenings (Hales, 1977). On interannual and decadal time scales, monsoonal variation has been attributed to expansion of the Bermuda subtropical ridge and an intensification of the surface low in southwestern Arizona (Bryson and Lowry, 1955; Green and Sellers, 1964). Wet summers in Arizona have been associated with a northward shift of the subtropical ridge, while a southward shift of the subtropical ridge has been linked to dry summers (Carleton et al., 1990; Comrie and Glenn, 1998).

1.4.2.3 Paleoclimate variation in the Southwest

The following discussion on paleoclimate reconstruction for the Southwest is continued in part from Sheppard et al. (2002), and based on prior research on historical changes in moisture for the region conducted by Cook et al. (1999), temperature reconstruction by Briffa et al. (1992), and review of the paleorecord of climate variability by Betancourt (2007). A consistent feature of both instrumental and tree-ring records of hydroclimate in the western US is decadal-to-multidecadal (D2M) variability, characterized by alternating and widespread droughts and pluvials (Betancourt, 2007). The combined paleomodern climate record shows at least three occurrences of multi-decadal variation (50 to 80 yr) of alternating dry to wet, and the amplitude of this variation appears to have increased since the 1700s (Fritts, 1991; Dettinger et al., 1998). No less than 13 episodes of drought and 10 episodes with above-average precipitation are reported for southeastern Arizona for 1866–1961 (Cooke and Reeves, 1976). Some notable examples of D2M variability include an abrupt switch from the megadrought in the late 1500s to the megapluvial in the early 1600s, and the bracketing of epic droughts in the 1930s and 1950s by two of the wettest episodes (1905-1920 and 1965-1995) in the last millennium (Betancourt, 2007).

Tree-ring data for the Southwest US extend back in time for up to a thousand years, and integrate well the influences of both temperature and precipitation on climate variation. They are therefore useful for reconstructing climate at longer time scales than meteorological records are available for. In the Southwest, instrumental records date back only 100-120 years. A commonly used climate variable in paleo-precipitation studies is the Palmer Drought Severity Index (PDSI), which is a single metric derived from the variation in precipitation and temperature, with consideration of other environmental factors (e.g., soil type) (Palmer, 1965). Tree growth typically responds to moisture availability during the growing season (late spring-early autumn for much of the Southwest), the availability of which is often linked to stored winter frontal precipitation rather than summer monsoonal moisture (Fritts, 1976). So, in general, moisture-ring width growth relationships are positive (i.e., above-average moisture increases ring width), and summer growing season PDSI values reflect moisture and temperature conditions not only during the growing season, but from the year prior to the growing season (i.e., prior September through current August) (Sheppard et al., 2002). Several tree-ring chronologies from the Southwest show an unprecedented trend of increasing tree growth beginning in the mid-1970s. This recent growth release may be a response to mild, wet winters and springs associated with El Niño events (Swetnam and Betancourt, 1998), as well as to the prevalence of the warm phase of the PDO that began in 1977 (Sheppard et al., 2002).

With respect to annual variation, the instrumental record of summer PDSI appears to be typical when compared to that the past 300 years. However, the recent multi-decadal pattern of PDSI shows strong amplitude (Sheppard et al., 2002). Temperature records (instrumental and tree-ring derived) also suggest a recent warming trend outside the natural variation in the last 400 years, one which has been noted at the hemispherical and global scales (Mann et al., 1998, 1999). Both increases in the amplitude of multi-decadal variability in precipitation and an overall increase in Southwest temperatures during the instrumental period have potential short and long term ecological and societal implications for the region.

1.4.3 Soil Moisture Dynamics in Drylands

The complex interactions of precipitation, infiltration, evaporation and transpiration, and runoff in dryland environments are controlled to a large extent by soil water content, and the hydraulic properties of soils that affect water fluxes at the soil-vegetation-atmosphere interface. In water-limited drylands, heat, water vapor, and carbon fluxes at the near-surface atmosphere are modulated by soil moisture dynamics via interactions between vegetation and soils at the root zone, which in turn influences moisture content and stability of the atmospheric boundary layer (D'Odorico and Porporato, 2006). These hydrologic processes provide direct feedbacks to the water, carbon, and other nutrient cycles at multiple scales, and thus merit considerable attention in hydrologic studies.

Water is a primary factor leading to soil formation from the weathering of parent material, with additional influences of climate, vegetation, and topography that determine soil physical properties. Pedogenic processes are time-dependent and therefore vary across different geomorphic landforms. Across alluvial fans, periods of entrenchment and subsequent in-filling induced by climate change, tectonic activity, or some internal mechanism (Schumm, 1973) shift the locus of deposition and often involve re-working of previously deposited, poorly sorted sediments (Harvey, 1989). This type of punctuated deposition followed by long periods of stability results in surfaces of varying ages and therefore varying degrees of pedogenic development (Parker, 1995). The development of argillic or petrocalcic horizons in fan deposits is reflective of older desert soils, and these features have a significant influence on soil hydrology. By restricting soil permeability, they retard infiltration and commonly define the vertical extent of rooting zones of many plants (Hamerlynck et al., 2002). This results in the lateral extension of root systems that can then accelerate subsurface flow through the development of pipes and macropores. Soil moisture profiles above these indurated horizons may hold significant moisture following a rainfall event. However, it is likely that these profiles also experience a higher degree of seasonal amplitude in moisture availability than do younger soils beneath active fluvial surfaces (Hamerlynck et al., 2002).

Differences in soil hydrology on alluvial fan surfaces in deserts have also been attributed to down-gradient fining, where coarser soils on upper fan surfaces are associated with higher infiltration rates and a greater diversity of plants, and finer soils on lower fan surfaces are correlated with higher surface runoff rates, increased evaporation, concentration of salts through capillary action, and lower vegetation diversity (Phillips and MacMahon, 1978; Yang and Lowe, 1956; Bowers and Lowe, 1986; Key et al., 1984). However, other studies suggest the relationship between soil properties, vegetative communities, and fan position is not straightforward and is more significantly related to properties such as depth to an impermeable horizon, and the presence or absence of desert pavement surfaces (Smith et al., 1995). In a study of 18 woody plant species growing on three geomorphic surfaces (active washes, relict terraces with desert pavements, and upland hillslopes), Smith et al. (1995) found that plants growing on pavement surfaces underlain by fine-textured soils with petrocalcic horizons showed a general trend in higher seasonal stress marked by reductions in stomatal conductance and water potential during summer months, whereas the same species growing in adjacent washes showed less variation in seasonal transpiration. Hamerlynck et al. (2002) found similar seasonality in vegetative response from *Larrea tridentata* across different geomorphic surfaces in the Mojave Desert. Xylem pressure potentials and photosynthetic assimilation declined rapidly during summer months in plants growing on pavement surfaces in comparison to plants growing in younger aged wash surfaces. In contrast, however, no discernible differences in water potential or photosynthetic activity were found for *Ambrosia dumos* across the same surfaces. Similarities in plant physiological response across different geomorphic surfaces were attributed to potentially greater plasticity in gas exchange and water-use efficiency of *Ambrosia* (Monson et al., 1992; Schuster et al., 1992; Ehleringer, 1994), and the ability of this species to vary its rooting volumes in different soils in order to maintain a similar soil moisture regime as highlighted in earlier studies of this species (Ehleringer, 1994; Jones, 1984).

Recent investigations on vegetation-soil moisture interactions following pulsed rainfall events reveal a number of time and space-dependent mechanisms that likely influence soil moisture in arid drylands. Several studies comparing subcanopy and intercanopy soil moisture have found subcanopy soils to have higher soil moisture content relative to intercanopy patches (e.g., D'Odorico et al., 2007, Zeng and Zeng, 1996; Bhark and Small, 2003; Zeng et al., 2004; Breman and Kessler, 1995; Scholes and Archer, 1997). D'Ordorico et al. (2007) found this contrast in soil moisture to be greater with increasing aridity, and suggest that these studies support recent theories that a positive feedback may exist between canopy cover and the preferential establishment of seedlings (Lejeune et al., 2002; Scholes and Archer, 1997; Caylor et al., 2003), and the pattern of woody vegetation distribution (Lefever and Lejeune, 1997). Using results from a simplified, minimalist model of vegetation-soil moisture dynamics at the patch scale, D'Odorico et al. (2007) also hypothesize that intercanopy soils that are too dry for woody vegetation growth and survival, contrasted with subcanopy soils that are moist enough to support seedling regeneration, support the presence of two potentially stable states of arid drylands—vegetated and unvegetated. This has implications for climate change scenarios, where even small changes in one or more environmental variables could result in large and irreversible shifts to a state with no canopy cover. That is, if a shift in climatic or other anthropogenic influence resulted in vegetation removal, the system might then remain in a stable, bare soil state and recover only in the unlikely event of a reverse shift in climatic or other disturbance variables. The rapid pace of desertification reported in many regions of the world has been attributed to exactly this type of shift (D'Odorico et al., 2007). Other mechanisms supporting higher moisture contents in subcanopy soils include increased infiltration enhanced by stemflow and extensive rooting systems, reduced evaporative losses under canopy cover, reduction in rain splash soil compaction, and lateral redistribution of water via runoff (Moran et al., 2010). Other studies have shown contrasting results (i.e., lower subcanopy root-zone soil moisture relative to intercanopy moisture) (Hamerlynck et al., 2002; Potts et al., 2010; Moran et al., 2010), and this trend has been attributed to a variety of mechanisms, including plant canopy interception, and higher transpiration response by woody plants to subcanopy soil moisture availability. Moran et al. (2010) investigated soil moisture response to precipitation pulses in the subcanopy and intercanopy space of shrubland community dominated by *L. tridentata, A.constricta, P. incanum, and F.Cernua*, and found soil moisture content to be higher in the intercanopy spaces than beneath the subcanopy at depths of 15 to 30 cm, with no significant differences in near surface subsoil (~to 5 cm), and no differences in subcanopy and intercanopy soil moisture that could be attributed to differences in precipitation characteristics. They suggest that root densities contribute to higher soil moisture depletion via transpiration as the possible mechanism to explain these differences, citing prior research documenting differences in evaporative losses that have been attributed to near surface (5 cm) soil moisture depletion, and transpiration rates that have been correlated with losses at 30 cm (Cavanaugh et al., 2010). Collectively, these studies reveal the complex relationship between hydrologic processes, pedogenic development, vegetation, and the geomorphic history of a basin that influences surface and subsurface water partitioning in arid drylands.

1.4.4 Hydrogeomorphology of Drylands

Soil moisture in arid and hyperarid environments is influenced not only by direct precipitation, but also by seasonal runoff/runon processes. Although drylands are areas that receive little rain, much of their surface detail can be traced to fluvial processes (Graf, 1988). Ephemeral streams are the predominant fluvial forms in dryland environments, yet documentation of their hydrologic and geomorphic behavior is particularly challenging for reasons previously discussed in Section 1.1. Convective precipitation can cause intense, localized flash flooding, and yet most streams in hyperarid and arid lands are dry the majority of the year. Differences in surface and subsurface features common in dryland landscapes contribute to this complexity. Sparse vegetation combined with seasonally intense precipitation results in high rates of overland flow and hillslope erosion by wash processes. Like vegetation, however, runoff is spatially patchy and highly variable, and high rates of transmission loss occur over short distances in most ephemeral drainage networks, restricting water, sediment and solute transport to short term, localized, seasonal pulses during or immediately following storm events. Consequently, soils weather slowly, and their products tend to remain *in situ* relative to more humid environments. This is reflected in part by channel bed and bank substrates that are characteristically coarse grained and devoid of clay minerals, and the presence of duricrusts and evaporites in upland soils (Bull and Kirkby, 2002). In Yuma Wash, desert pavements underlain by a thin vesicular layer of soil a few centimeters thick comprised mainly of silt and clay create a surface veneer over much of the upland relict terraces adjacent to the alluvial wash network.

When wetted, these surfaces quickly saturate, causing overland flow as sheetflow to subsequently concentrate as run-on in rills and gullies on portions of this geomorphic surface that have been locally stripped of this surface material. Desert pavement surfaces are most common in arid and hyperarid regions of the world, and provide important hydrologic linkages to channel networks in adjacent valley bottoms.

Sporadic but rapid runoff and high erosion rates result in high drainage densities in arid and hyperarid drylands, where gullying or badland development may result in headwater areas, and braided, anastomosing, or compound channeling develops further downstream. The combined tendency of storm intensity to decrease with areal extent, high channel transmission losses, and a higher frequency of discontinuous channels relative to humid regions tends to lessen the rate of increase in downstream discharge in dryland ephemeral channels. In many cases, flow rates actually decrease in a downstream direction, with the exception of localized reaches receiving tributary inputs.

Transmission losses during storm events are highly variable and depend on both storm characteristics (e.g., spatiotemporal distribution, intensity) and channel and hillslope properties (e.g., substrate composition, antecedent soil moisture, vegetative cover and other roughness elements, hydraulic geometry, slope). Data from arid and semi-arid basins on low flows show higher attenuation rates over shorter distances, whereas larger volume runoff events tend to lose a lower percentage of their flows over the same initial distance (Walters, 1990; Renard and Laursen, 1975; Renard and Keppel, 1966; Goodrich et al., 1997). Reduced bed and bank roughness, higher sediment concentrations, and higher velocities that commonly accompany high flows may account for this trend. In braided ephemeral channels with significant interfluve vegetation such as Yuma Wash, the relationship between transmission loss and flow volume may actually reverse at some threshold discharge value. At low flows, when discharge is confined to single channels devoid of vegetation, velocity is controlled largely by channel geometry with relatively few roughness elements. As flow overtops interfluvial bars, vegetation and topography act to increase roughness, thus reducing flow velocity, increasing infiltration, and promoting aggradation. This relationship may again reverse at even higher flow volumes, when the effects of vegetation on additional bed roughness are insignificant relative to increased flow volumes, velocities, and associated sediment concentrations.

Transmission loss during runoff/run-on events can be an important source of groundwater recharge and moisture required for plant growth in drylands. Losses ranging from 33 percent to 98 percent by volume over channel reaches 4-33 km in length have been reported for a variety of storm and runoff volumes in ephemeral streams (Renard and Keppel, 1966; Lane et al., 1971; Renard and Laursen, 1975; Walters, 1990; Reid et al., 1995; Sharma and Murthy, 1995; Greenbaum et al., 1998; Dunkerley and Brown, 1999). Attempts to standardize losses in a single channel for comparative purposes have focused on quantifying percent loss within the first kilometer of a reach for a given volume of flow, but variability in data remains high (1-18 percent loss by volume). A comprehensive analysis of runoff and transmission losses over an 11-year period in the Walnut Gulch experimental watershed confirms this type of dissipative behavior in semi-arid ephemeral systems, and identifies a threshold area of 37-60 ha where basin response to precipitation becomes non-linear with scale (Goodrich et al., 1997). However, the high degree of inter- and intrannual variability in precipitation in dryland environments, particularly in arid and hyperarid regions, adds an additional challenge to documenting hydrologic events and to understanding the hydrologic behavior of these systems over time. Consequently, most attempts to quantify associated runoff response and transmission losses to channels, between channel flow and sediment transport (Schick et al., 1987; Laronne et al., 1992; Reid et al., 1995; Dunkerley and Brown, 1999), and flow events and geomorphic response (Hooke and Mant, 2000; Merritt and Wohl, 2003), have been restricted to a single or few isolated storm events. The high cost of deployment and maintenance of instrumentation in these harsh climates has also restricted many of these studies to retrodiction from high flow marks, debris piles, and channel resurveys. Despite these challenges, documenting runoff/runon processes and transmission losses in Yuma Wash would be an important follow-on investigation to the current research, and would add to the current knowledge base on fluvial processes in arid and hyperarid drylands.

1.5 Site Description: Yuma Wash, United States Army Yuma Proving Grounds, Arizona, U.S.A.

The Yuma Wash watershed provides an excellent landscape for investigating the hydrologic response of a hyperarid landscape to seasonal precipitation. It is located in the hyperarid Lower Colorado River Valley (Figure 1), where precipitation since 1958 has averaged 93 mm per annum (Phillips and Comus, 2000). Three distinct storm types occur in this region. During winter months, frontal storm tracks that typically move inland from the Pacific to the Northwest and Great Plains regions are occasionally diverted to the Southwest, bringing to Yuma Wash low-intensity, long-duration rains broad in spatial extent. Generally, frontal storms are not runoff producing. By contrast, summer precipitation takes the form of convective storms that build as moist air-masses moving inland from the Pacific meet rising thermal air-masses created from intense solar radiation striking the desert floor. These isolated storm cells deliver high-intensity, short-duration rains that are typically limited in spatial extent to a few to tens of square kilometers. More so than frontals, convective storms frequently result in flash flooding in active channel washes. Occasionally, dissipating tropical cyclones bring a third source of additional moisture toward the end of the summer monsoon season. Equivalent in spatial variability but often greater in overall extent than convective storms, these high-intensity systems have historically resulted in extensive, but highly discontinuous flooding over several hundreds of square kilometers in the Lower Colorado River Valley (Betancourt, 2007).

In 1995, the US Army Waterways Experimental Station, Colorado State University, and Ayres Associates were tasked with inventorying the biophysical landscape of Yuma Wash in an effort to provide a baseline characterization of a hyperarid region within which the United States Department of Defense (DoD) maintains training and testing facilities. Two tipping bucket rain gages were installed in Yuma Wash as part of that effort. Data collected from this study, and a subsequent study by Howe and Wohl beginning in 2001, suggest annual rainfall may be slightly higher than the regional average, and higher in headwater areas, suggesting an orographic influence on precipitation in Yuma Wash (Ayres Associates, 1996; Howe and Wohl, 2002-2004).

Runoff characteristics from both tropical cyclonic (Merritt and Wohl, 2003) and convective (Howe and Wohl, 2003, unpublished data) precipitation have been documented in Yuma Wash. Data from several convective storms recorded from 2001-2003 suggest a nearly instantaneous and highly localized channel response to convective precipitation. Hurricane Nora (1997) was a significant tropical storm that caused extensive flash flooding in Yuma Wash. Merritt and Wohl (2003) investigated the geomorphic response of a 19 km reach of the main channel to Hurricane Nora, which delivered approximately 79 mm of rainfall to the Wash over a three-day period. Maximum storm intensity was estimated at 9 mm/hr, and maximum peak discharge was estimated at 240 m^3/sec. Total spatial extent of flooding was not documented, but an analysis of channel changes before and after the flood revealed scour-and-fill patterns related to a threshold relationship between channel depth and interfluve bar characteristics (Merritt and Wohl, 2003). Channel aggradation generally occurred in wider, braided reaches where flows were unconstrained and greater roughness of vegetation on bars facilitated deposition, while degradation occurred mainly in narrow reaches where flows were confined to channels and subchannels. However, the lack of instrumentation for monitoring channel flow or sediment transport restricted analyses to flow reconstruction using high water marks and repeat cross-sectional surveys, and precipitation characteristics were derived from only two stations. Maximum precipitation intensity during Nora may have exceeded that recorded by the two tipping buckets deployed, as several precipitation events recorded during the current investigation reflect considerably higher maximum storm intensities than those estimated for this event.

Yuma Wash is surrounded on three sides by mountainous terrain that comprises nearly half of the basin area. This topographic relief likely introduces additional variability in precipitation via orographic effect, perhaps more so in the upper reaches due to increased elevation, and restricts the lower and middle reaches of the active channel network to a relatively narrow valley floor in comparison to other washes in this region (Ayres Associates, 1996). Three distinct geomorphic surfaces comprise the surface area of the basin, and have been regionally classified as old, intermediate, and young alluvial fan surfaces aged primarily by their soil development (Christenson and Purcell, 1985) (Figure 1.5). Old alluvial surfaces are extensive, and correlate approximately with the middle-Pleistocene pediment surface of Morrison (1985).

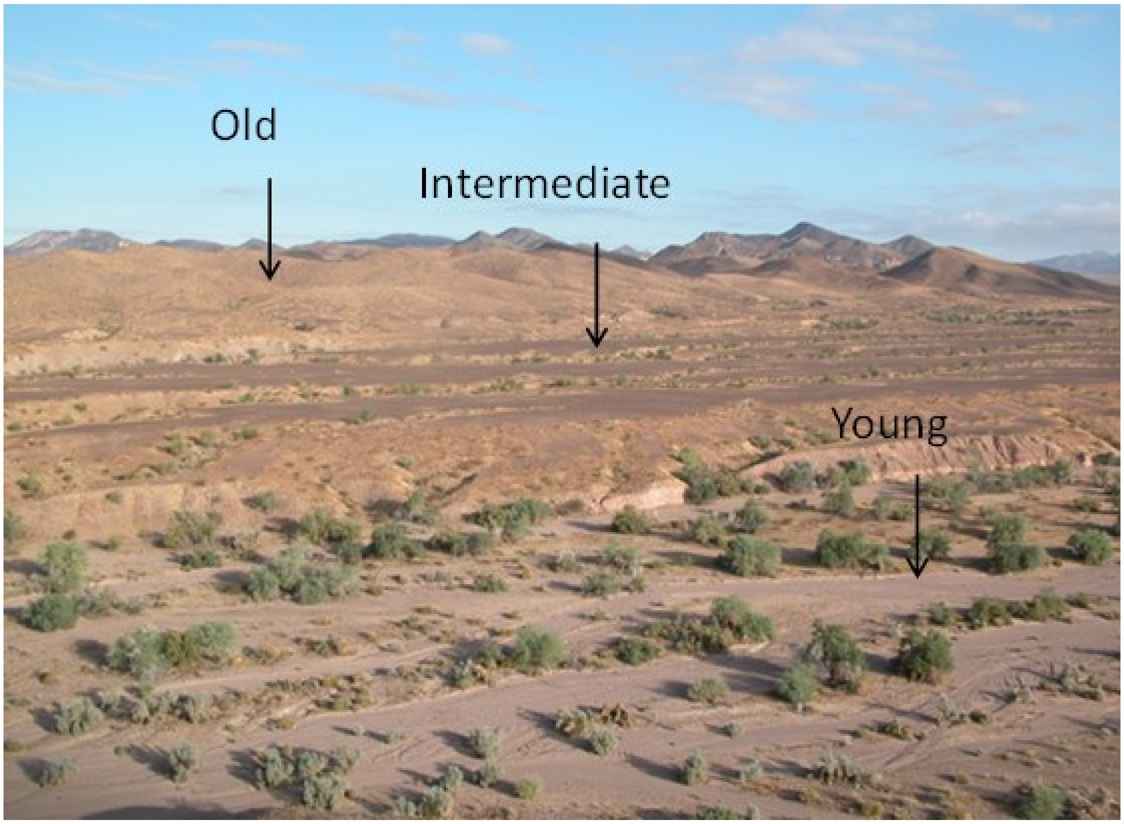


Figure 1.5. **Three geomorphic surfaces in Yuma Wash. Old surfaces are roughly middle Pleistocene pediments, Intermediate relict terrace surfaces are late-middle to late Pleistocene alluvial fans that today are mantled in desert pavement and often varnished, and Young alluvial wash surfaces are Holocene in age and reflect predominant modern fluvial activity.**

They are characterized by ridge and valley topography, highly dissected parallel and dendritic drainage, and rise in places tens of meters above the active channel network. Intermediate surfaces correlate generally with late-middle Pleistocene to late-Pleistocene alluvial fans, and appear as relatively flat, mantled desert pavement surfaces with a conspicuous patina (desert varnish) over much of their surface area. These pavement surfaces consist of a single layer of stones ranging in size from 1 to 5 cm, underlain by a gravel poor, finely textured vesicular A horizon. Where this surface layer has been stripped away, vegetation concentrates in small rills and gullies, where sheetflow across intact pavements likely concentrates as runon. Deeper dissection of these surfaces from 2 to 10 meters comprises the modern, or young alluvial drainage network. Young alluvial fan deposits are Holocene in age, and are characterized by a bar-and-swale topography that reflects modern fluvial activity of a compound channel network. Throughout the remainder of this paper, the term relict alluvial terraces, or terraces for brevity, is used interchangeably to reference intermediate-aged surfaces, and the term alluvial washes, or washes for brevity, is used interchangeably to reference younger-aged surfaces.

Of particular significance to the current research are the distinct soil properties that distinguish these surfaces hydrologically. The soils of Yuma Wash are comprised of four complexes: (1) Riverbend family-Carrizo family complex, (2) the Cristobal family-Gunsight family gypsiferous substratum complex, (3) the Gunsight family-Chuckwalla family gypsiferous substratum complex, and (4) the Lithic Torriorthents and Typic Torriorthents soils. Each of these complexes is described in detail in the soil survey for YPG (NRCS, 1991), and series descriptions are provided here in Tables 1.3-1.8.

Soils on the alluvial wash surfaces are comprised of the Riverbend series. They are deep, poorly sorted, with moderate to high infiltration capacities and low runoff potential. Permeabilities under saturated conditions in the Riverbend family (wash bar-and-swale deposits) can reach up to 150 mm per hour, and more than 500 mm per hour in the Carrizo family (modern stream channel deposits). Intermediate relict terraces are comprised of the Cristobal family-Gunsight family complex. The Cristobal family soils (terrace pavements) have low permeability (15 mm per hour under saturated conditions), high runoff potential, high salt contents, and high susceptibility to erosion if pavement surfaces are disturbed (McFadden et al., 1987; Abrahams and Parsons, 1991; Ayres Associates, 1996).

Table 1.3. Description and classification of Riverbend soil series.

Riverbend Soil Series	*Description*: Deep, excessively drained, formed in stratified fan alluvium. Riverbend soils are on fan terraces and fan remnants and have slopes of 2 to 15 percent.
	Classification: Sandy-skeletal, mixed, hyperthermic Typic Haplocalcids
	A—0 to 2 inches; brown(7.5YR 5/4) very cobbly sandy loam, brown (7.5YR 4/4) moist; moderate medium platy structure; soft, friable, nonsticky and nonplastic; common fine roots; many fine irregular pores; 25 percent cobble and 30 percent gravel; strongly effervescent; moderately alkaline (pH 7.9); abrupt wavy boundary. (1 to 10 inches thick).
	Bw--2 to 7 inches; brown (7.5YR 5/4) very gravelly sandy loam, brown (7.5YR 4/4) moist; weak medium subangular blocky structure; soft, friable, nonsticky and nonplastic; common fine roots; common fine tubular pores; 5 percent cobble and 30 percent gravel; strongly effervescent; moderately alkaline (pH 8.0); abrupt wavy boundary. (0 to 8 inches thick)
	Bk1--7 to 18 inches; light brown (7.5YR 6/4) very cobbly loamy sand, brown (7.5YR 5/4) moist; massive; loose, nonsticky and nonplastic; common very fine roots; many fine irregular pores; 20 percent cobble and 30 percent calcium carbonate coated gravel; many large soft calcium carbonate accumulations; violently effervescent, 12 percent calcium carbonate equivalent; moderately alkaline (pH 8.0); clear wavy boundary.
	Bk2--18 to 34 inches; light brown (7.5YR 6/4) very gravelly loamy sand, brown (7.5YR 5/4) moist; single grain; loose, nonsticky and nonplastic; few very fine roots; common fine irregular pores; 40 percent calcium carbonate coated gravel; common medium soft calcium carbonate accumulations; violently effervescent, 16 percent calcium carbonate equivalent; moderately alkaline (pH 8.2); clear wavy boundary.
	Bk3--34 to 60 inches; brown (7.5YR 5/4) very gravelly sand, brown (7.5YR 4/4) moist; single grain; loose, nonsticky and nonplastic; few very fine roots; common fine irregular pores; 10 percent cobble and 45 percent calcium carbonate coated gravel; strongly effervescent, 10 percent calcium carbonate equivalent; moderately alkaline (pH 8.0). (Combined thickness of the Bk horizons is 40 to 56 inches.)

Table 1.4. Description and classification of Carrizo soil series.

Carrizo Soil Series	*Description*: extremely gravelly sand, rangeland and wildlife habitat. (Colors are for dry soil unless otherwise noted.) The soil surface is covered by approximately 70 percent gravel, 6 percent cobbles and 4 percent stones.
	Classification: Sandy-skeletal, mixed, hyperthermic Typic Torriorthents
	A –0 to 5 centimeters (0 to 2 inches); pale brown (10YR 6/3) extremely gravelly sand, brown (10YR 4/3) moist; massive; slightly hard, very friable, nonsticky and nonplastic; few very fine roots; common very fine interstitial pores; 55 percent gravel, 6 percent cobbles and 4 percent stones; slightly effervescent; moderately alkaline (pH 8.0); abrupt smooth boundary. (2.5 to 10 centimeters thick)
	C –5 to 152 centimeters (2 to 60 inches); pale brown (10YR 6/3) stratified extremely gravelly and very gravelly coarse sand, brown (10YR 4/3) moist; massive to single grain; soft, slightly hard, or loose, very friable, nonsticky and nonplastic; common very fine and few fine roots; many very fine and few fine and medium interstitial pores; averages 55 percent gravel, 10 percent cobbles and 5 percent stones; very slightly effervescent and slightly effervescent; moderately alkaline (pH 8.4) and slightly alkaline (pH 7.8).

Table 1.5. Description and classification of Cristobal soil series.

Cristobal Soil Series	*Description*: The Cristobal series consists of very deep, well drained soils that formed in fan alluvium. Cristobal soils are on fan terraces and have slopes of 0 to 20 percent.
	Classification: Loamy-skeletal, mixed, superactive, hyperthermic, Typic calcicargids
	Ez--0 to 2 inches; pale brown (10YR 6/3) extremely gravelly loam, dark brown (10YR 3/3) moist; moderate thin and medium platy structure; slightly hard, very friable, slightly sticky and slightly plastic; many very fine vesicular pores; 60 percent fine and medium gravel; strongly effervescent; strongly saline; moderately alkaline (8.2); abrupt smooth boundary. (1/2 to 3 inches thick)
	Btkz1--2 to 6 inches; red (2.5YR 5/6) very gravelly clay loam, dark red (2.5YR 3/6) moist; moderate and strong very fine granular structure; soft, very friable, moderately sticky and moderately plastic; many fine irregular pores; few faint clay films on faces of peds; 35 percent fine gravel with underside coated with calcium carbonate; few fine and medium soft calcium carbonate accumulations; strongly effervescent; strongly saline; moderately alkaline (pH 8.2); clear wavy boundary. (2 to 10 inches thick)
	Btkz2--6 to 10 inches; yellowish red (5YR 5/6) very gravelly clay loam, dark reddish brown (5YR 3/4) moist; moderate and strong fine granular structure; soft, very friable, moderately sticky and moderately plastic; many very fine irregular pores; few to common faint clay films on faces of peds; 50 percent fine and medium gravel with underside coated with calcium carbonate; common fine and medium soft calcium carbonate accumulations; common very fine and fine salt crystals; strongly effervescent; strongly saline; moderately alkaline (pH 8.2); clear wavy boundary. (4 to 5 inches thick)
	Btkz3--10 to 17 inches; yellowish red (5YR 4/6) extremely gravelly clay loam, dark reddish brown (5YR 3/4) moist; weak fine and medium subangular blocky structure; slightly hard, very friable, moderately sticky and moderately plastic; many very fine tubular pores; few faint clay films on faces of peds and lining pores; 70 percent fine and medium gravel with underside coated with calcium carbonate; many fine and medium soft calcium carbonate accumulations; common very fine and fine salt crystals; strongly effervescent; strongly saline; moderately alkaline (pH 8.2); clear wavy boundary. (6 to 12 inches thick)
	Btkz4--17 to 25 inches; yellowish red (5YR 5/6) very gravelly sandy clay loam, dark reddish brown (5YR 3/4) moist; weak fine subangular blocky structure; slightly hard, very friable, moderately sticky and slightly plastic; many very fine tubular pores; few faint clay films on faces of peds and lining pores; 60 percent fine, partially calcium carbonate coated gravel; common fine and medium soft calcium carbonate accumulations; common very fine salt crystals; strongly effervescent; strongly saline; moderately alkaline (pH 8.2); clear wavy boundary. (7 to 12 inches thick)
	Btkz5--25 to 35 inches; reddish yellow (7.5YR 6/6) very gravelly clay loam, brown (7.5YR 4/4) moist; weak fine subangular blocky structure; slightly hard, very friable, moderately sticky and slightly plastic; many very fine tubular pores; few faint clay films lining pores; 60 percent fine, partially calcium carbonate coated gravel; many fine and medium soft calcium carbonate accumulations; common very fine salt crystals; strongly effervescent; strongly saline; moderately alkaline (pH 8.2); clear wavy boundary. (6 to 11 inches thick)
	Btkz6--35 to 60 inches; light brown (7.5YR 6/4) very gravelly clay loam, brown (7.5YR 5/4) moist; weak fine subangular blocky structure; slightly hard, very friable, slightly sticky and slightly plastic; many very fine tubular pores; few faint clay films lining pores; 60 percent fine gravel; strongly effervescent; strongly saline; moderately alkaline (pH 8.2).

Table 1.6. Description and classification of Gunsight soil series.

Gunsight Soil Series	*Description:* The Gunsight series consists of very deep, somewhat excessively drained, strongly calcareous soils that formed in alluvium from mixed sources. Gunsight soils are on fan terraces or stream terraces and have slopes of 0 to 60 percent.
	Classification: Loamy-skeletal, mixed, superactive, hyperthermic Typic Haplocalcids
	A--0 to 2 inches; light brown (7.5YR 6/4) very gravelly loam, brown (7.5YR 4/4) moist; weak medium platy structure; slightly hard, very friable, nonsticky and slightly plastic; few very fine roots; many very fine and fine irregular pores; 50 percent gravel; strongly effervescent; moderately alkaline (pH 8.2); abrupt smooth boundary. (2 to 4 inches thick)
	Bw--2 to 10 inches; pink (7.5YR 7/4) very gravelly loam, brown (7.5YR 5/4) moist; massive; slightly hard, friable, nonsticky and slightly plastic; few fine and medium roots; common very fine irregular pores; 50 percent gravel; violently effervescent; few fine calcium carbonate filaments; moderately alkaline (pH 8.3); clear wavy boundary. (8 to 16 inches thick)
	Bk1--10 to 18 inches; white (N 8/) and pinkish gray (7.5YR 7/2) extremely gravelly loam, pinkish gray (7.5YR 7/2) and brown (7.5YR 5/4) moist; massive; hard, friable, slightly sticky and slightly plastic; few fine and medium roots; common very fine irregular pores; 70 percent calcium carbonate coated gravel; violently effervescent; many large calcium carbonate masses; strongly alkaline (pH 8.5); gradual wavy boundary. (6 to 10 inches thick)
	Bk2--18 to 32 inches; pinkish white (7.5YR 8/2), pinkish gray (7.5YR 7/2) and pink (7.5YR 7/4) extremely gravelly sandy loam, pinkish gray (7.5YR 7/2) and brown (7.5YR 5/4) moist; massive; hard, friable, slightly sticky and moderately plastic; few very fine roots; common very fine irregular pores; 75 percent calcium carbonate coated gravel; violently effervescent; many large calcium carbonate masses; moderately alkaline (pH 8.3); gradual wavy boundary. (12 to 20 inches thick)
	Bk3--32 to 60 inches; pinkish white (7.5YR 8/2), pinkish gray (7.5YR 7/2) and pink (7.5YR 7/4) very gravelly loam, pinkish gray (7.5YR 7/2) and brown (7.5YR 5/4) moist; massive; hard, friable, slightly sticky and moderately plastic; common very fine irregular pores; 40 percent calcium carbonate coated gravel; violently effervescent; many large calcium carbonate masses; moderately alkaline (pH 8.3).

Table 1.7. Description and classification of Cacique (formerly Chuckwalla) soil series.

Cacique (formerly Chuckwalla) Soil Series	*Description:* consists of moderately deep, well drained soils that formed in sandy alluvium. Cacique soils are on basin floors and have slopes of 0 to 5 percent.
	Classification: Fine-loamy, mixed, superactive, thermic Argic Petrocalcids
	A--0 to 2 inches; reddish brown (5YR 5/4) sandy loam, reddish brown (5YR 4/4) moist; generally massive with some weak medium platy structure in upper part; slightly hard, very friable; nonsticky and nonplastic; many very fine and fine irregular pores; slightly alkaline; abrupt smooth boundary. (1 to 5 inches thick)
	Bt1--2 to 6 inches; reddish brown (5YR 5/4) sandy loam, reddish brown (5YR 4/4) moist; weak coarse prismatic structure parting to weak medium subangular blocky; hard, firm, nonsticky and nonplastic; few fine roots; few fine tubular pores; few insect burrows, 2 to 10 mm in diameter, some empty and some filled with fine earth; clay coatings on sand grains; generally noneffervescent with few discontinuous effervescent areas; slightly alkaline; clear smooth boundary. (3 to 10 inches thick)
	Bt2--6 to 12 inches; reddish brown (5YR 5/4) sandy clay loam, reddish brown (5YR 4/4) moist; weak coarse prismatic structure parting to weak medium subangular blocky; firm, slightly sticky and slightly plastic; few fine roots; few fine tubular pores; few insect burrows, 2 to 10 mm in diameter, some empty and some filled with fine earth; sand grains have coatings of clay; generally noneffervescent with a few discontinuous areas that are effervescent; slightly alkaline; clear smooth boundary. (6 to 10 inches thick)
	Btk1--12 to 19 inches; reddish brown (5YR 5/4) sandy clay loam, reddish brown (5YR 4/4) moist; moderate coarse prismatic structure parting to weak medium subangular blocky; hard, firm, slightly sticky and slightly plastic; few fine roots; few fine tubular pores, lined with calcium carbonate; common calcium carbonate filaments on faces of peds; insect burrows, 2 to 10 mm in diameter, a few partially empty but most filled with fine earth; clay coatings on sand grains; strongly effervescent; slightly alkaline; clear wavy boundary. (6 to 11 inches thick)
	Btk2--19 to 25 inches; mixed reddish brown (5YR 5/4) and pinkish white (7.5YR 8/2) sandy clay loam, reddish brown (5YR 4/4) and pink (7.5YR 7/4) moist; weak coarse prismatic structure parting to weak medium subangular blocky; hard, firm, slightly sticky and slightly plastic; few fine roots; few fine tubular pores, some lined with calcium carbonate; common calcium carbonate nodules and filaments; sand grains in reddish brown parts coated with clay; strongly effervescent; moderately alkaline; abrupt smooth boundary. (4 to 8 inches thick)

Table 1.8. Description and classification of Cacique (formerly Chuckwalla) soil series.

Cacique (formerly Chuckwalla) Soil Series	Bkm1--25 to 34 inches; pink (7.5YR 8/4) and very pale brown (10YR 8/2) calcium carbonate-cemented material, pink (7.5YR 7/4) and very pale brown (10YR 8/3) moist; alternating subhorizons, 1 mm to 5 cm thick of laminar calcium carbonate and massively cemented, nonlaminar material; very weak, very coarse prisms, several feet in diameter; extremely hard; stains of reddish yellow (5YR 7/6) and reddish yellow (5YR 6/6) occur in upper part, primarily along cleavage planes but in places penetrating the cemented material; sand grains separated by calcium carbonate; strongly effervescent; moderately alkaline; clear wavy boundary. (0 to 35 inches thick)
	Bkm2--34 to 57 inches; very pale brown (10YR 8/2) calcium carbonate-cemented material, very pale brown (10YR 8/3) moist; weak very coarse prisms, several feet in diameter; extremely hard; sand grains separated by calcium carbonate; strongly effervescent; slightly alkaline; clear wavy boundary. (6 to 36 inches thick)
	Bk1--57 to 76 inches; very pale brown (10YR 8/2) calcium carbonate nodules, very pale brown (10YR 8/3) moist; medium and very coarse subangular blocky structure; nodules are very and extremely hard, and are discontinuously cemented together into clusters; small amounts of internodular material is pink (7.5YR 8/4), light brown (7.5YR 6/4) moist; and is a sandy loam, single grained and loose; strongly effervescent; slightly alkaline; clear wavy boundary.
	Bk2--76 to 102 inches; about 70 percent very pale brown (10YR 8/2) calcium carbonate nodules, very pale brown (10YR 8/3) moist; medium and very coarse subangular blocky structure; very and extremely hard; about 30 percent pink (7.5YR 8/4) sandy loam, light brown (7.5YR 6/4) moist; massive and soft; strongly effervescent; moderately alkaline; clear wavy boundary.
	Bk3--102 to 118 inches; light brown (7.5YR 6/4) sandy loam, brown (7.5YR 5/4) moist; massive; soft, discontinuous carbonate coatings on sand grains; few calcium carbonate nodules, very pale brown (10YR 8/2), range from hard to extremely hard; strongly effervescent; moderately alkaline; clear wavy boundary.
	C--118 to 130 inches; pale brown (10YR 6/3) sand, brown (10YR 4/3) moist; massive; soft; few slightly effervescent zones; slightly alkaline.

Sideslope soils along terrace surface margins and rills and gullies that dissect this geomorphic surface comprise the Gunsight family, where pavement surfaces and the Av horizon have been removed through erosion. These soils have moderate permeabilities (up to 150 mm per hour) and moderate runoff potentials. Soil hydrologic properties on alluvial hillslopes vary with relative topographic position. Summit and shoulder soil complexes have moderate runoff potential, whereas side slope complexes have rapid runoff potentials.

High salt contents and poor plant-water relationships on both terraces and hillslope surfaces are believed to restrict vegetation cover to approximately five to ten percent of the total areal extent, whereas wash bar and swale topography within the alluvial wash network supports vegetative communities that cover twenty five to thirty percent of this surface (see Figure 6). On terraces, most vegetation is concentrated in small order drainages that provide hydrologic connectivity to the alluvial wash network on the valley floor.

The present-day vegetation in Yuma Wash is characteristic of the Lower Sonoran Desert and has been in place for several thousand years. The vegetation classification of Sonoran desertscrub (Turner and Brown, 1994) has been used to delineate species compositions into six series; five from the Lower Colorado River Valley subdivision (Saltbrush, Galleta, Creosote-Bursage, Brittlebush, and Mixed Scrub series), and one (Palo Verde-Mixed Cacti series) from the Arizona Upland Subdivision. Plot studies on species distribution and abundance conducted since 1995 suggest the following perennial plants may play a significant ecological role in Yuma Wash: *Larrea tridentata* (creosote), *Ambrosia dumosa* (white bursage), *Parkinsonia microphylla* (Foothill Palo Verde), *Psorothamnus spinosa* (smoketree), and *Olneya tesota* (Ironwood) (Green, 2003). *L. tridentata* and *A. dumosa* are the most abundant species found on terraces and upland hillslopes, but are not as common in active washes. The relative abundance of these two shrubs has been associated with time-dependent soil properties across different geomorphic surfaces (McAuliffe, 1994; Hamerlynck et al, 2002). *Larrea* is usually found on surfaces with weakly developed soils of Holocene age, or on erosionally truncated soils from early Pleistocene deposits, whereas *Ambrosia* is more often found on Pleistocene age surfaces with soils that have well-developed argillic horizons that impede deep infiltration of water (McAuliffe, 1994; McDonald et al, 1995). Shallow root systems and drought-dormancy allow *Ambrosia* to persist on seasonally available moisture from precipitation. *Larrea* lacks the capacity for drought dormancy, and has therefore developed a more extensive rooting system that can exploit deeper and more persistent water supplies (Smith et al, 1997). *P. spinosa* is abundant in active washes, has deep tap roots, but is considered facultatively pheatophytic and is limited in range to this area of the Sonoran Desert. This species is highly stress tolerant but responds significantly to precipitation and streamflow events in Yuma Wash (Green, 2003).

P. microphylla and *O. tesota* are found on young alluvial wash and relict alluvial terrace surfaces, and are both considered to be generally phreatophytic (partially or completely reliant on saturated zone groundwater). Because they grow on relict terraces where groundwater may not be reachable or is more highly variable than in the alluvial wash network, these species are thought to also rely on seasonal soil water that is recharged from runon events (Smith et al, 1997). Tap and lateral rooting systems allow both of these species to exploit ground and deep vadose-zone water, as well as seasonally available shallow water sources from rainfall. *P. microphylla* is a drought-deciduous tree with photosynthetically active green bark that contributes to over 70 percent of its carbon gain, and will only produce an ephemeral leaf canopy after sufficient rains (Szarek and Woodhouse, 1978). Stem photosynthesis is under greater diffusive limitation and displays greater water use efficiency, representing allocation for long term hardiness, compared to ephemeral leaves which represent opportunistic allocation (Comstock and Ehrlinger, 1988). *O. tesota* is considered an evergreen, but will shed a large portion of its leaf surface during periods of drought, which is the sole carbon-fixing portion of this species.

Each of these previous studies illustrate the biophysical complexities associated with water partitioning in desert environments, and thus provides an extensive baseline from which to advance our understanding of arid lands hydrology. This study focused on quantifying the soil moisture response to seasonal precipitation beneath *P. microphylla O. tesota,* and bare ground on both relict alluvial terraces and alluvial washes in Yuma Wash. It was expected that desert pavement and the underlying vesicular horizon would play a role in redistributing moisture as runon to adjacent vegetated cover on relict terraces (Figure 1.6). Details on the methodological approach, measurement theory, and analyses of precipitation and soil moisture and temperature data collected toward this end are presented next.

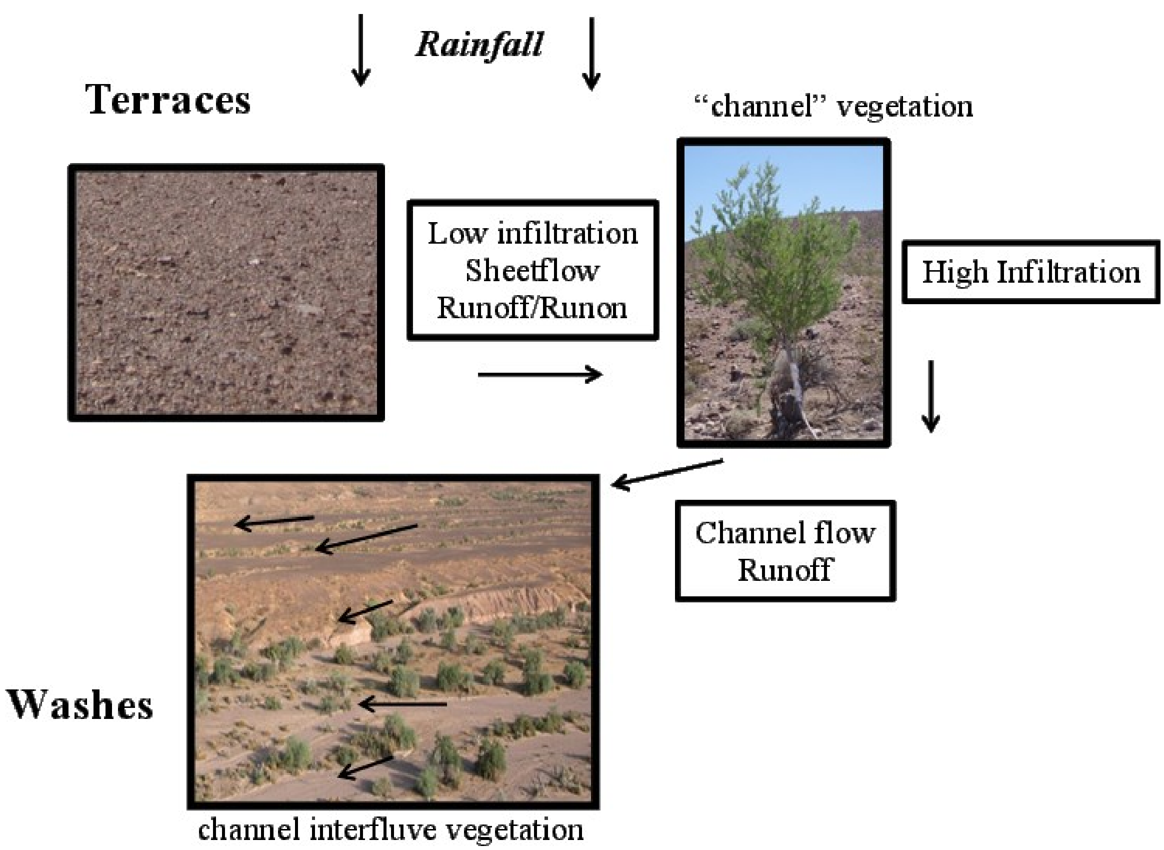


Figure 1.6. Schematic representation of runoff and runon processes in Yuma Wash.

CHAPTER 2

MATERIALS AND MEASUREMENT METHODS, MEASUREMENT THEORY AND ANALYTICAL APPROACH

2.1 Materials and measurement methods

To quantify the seasonal precipitation and soil moisture characteristics across two distinct geomorphic surfaces in Yuma Wash, six fully instrumented meteorological stations (Figures 2.1-2.2), and six stations designed to measure subsurface soil moisture and soil temperature (Figures 2.3-2.4) (Campbell Scientific, Inc.) were deployed in Yuma Wash beginning in spring 2006, and were operative from July 2006 through February 2010. Meteorological and soil moisture stations were positioned in three basin locations—lower, middle, and upper Yuma Wash (see Figure 1.3). Location selection was primarily based on representative geomorphic, soil, and vegetative features, and proximity of stations on different geomorphic surfaces in each general location (lower, middle, upper) to within 2 km of each other. Terrace sites with both *P.microphylla* and *O.tesota* species located within 100 meters of adjacent, intact desert pavement surfaces, and wash sites with the same species located along channel margins were also primary selection criteria. Station locations and relative distances are provided in Figure 1.3 and Table 1. A total of 6 tipping bucket rain gages, 60 soil moisture probes, and 60 soil temperature probes were operative during the study.

In each of the basin locations, a single meterological station and a single soil moisture station was deployed on each of two geomorphic surfaces—a relict alluvial terrace, and an alluvial wash (Figures 2.1-2.4). Each meteorological station had a single tipping bucket rain gage at 2 m above ground surface (TE525, Campbell Scientific, Inc.). Tipping bucket rain gages were programmed to be event-triggered, and dataloggers (CR23x and CR5000, Campbell

Figure 2.1. MET3 meteorological station on the upper basin wash surface. One of six meteorological stations deployed in Yuma Wash. Tipping bucket rain gage is shown in photo center.

Figure 2.2. MET4 meteorological station on the upper basin relict terrace surface. One of six meteorological stations deployed in Yuma Wash. Tipping bucket rain gage is shown in photo left, and soil moisture and soil temperature probes at 2.5 cm are located in the subsurface of photo center.

Figure 2.3. SF5 station on upper wash surface. One of six soil moisture and soil temperature stations deployed in Yuma Wash. Instrumentation was emplaced beneath bare ground at 25, 50, and 100 cm (photo center), and at 25, 50, and 100 cm beneath *P. microphylla* (photo right), and *O. tesota* (photo left).

Figure 2.4. SF3 station on middle terrace surface. One of six soil moisture and soil temperature stations deployed in Yuma Wash. Instrumentation was emplaced beneath bare ground at 25, 50, and 100 cm (area not shown), and at 25,50, and 100 cm beneath *P. microphylla* (photo right), and *O. tesota* (photo left).

Scientific, Inc.) outputted precipitation totals in 5-minute and 15-minute intervals. One soil water content reflectometer (CS616, Campbell Scientific, Inc.) and four soil temperature probes (TCAV, Campbell Scientific, Inc.) were deployed at each of the six meteorological stations at 2.5 cm to measure near surface soil moisture and soil temperature (Figure 2.5). Data were recorded at 60-second intervals, which were averaged and outputted every 15 minutes from dataloggers. Programming code for data collection is provided in Appendix A.

Soil moisture stations were each instrumented with a total of nine soil water content reflectometers and nine soil temperature sensors (CS616, Campbell Scientific, Inc). Soil pits were excavated and soil moisture probes were installed horizontally in the vertical side walls at 25, 50, and 100 cm (Figures 2.6-2.7). Three sensors were emplaced beneath bare ground (ground surfaces otherwise devoid of woody vegetation, with minimal to no seasonal grass or forb cover), and three each within the dripline radius of a single *Parkinsonia microphylla* and *Olneya tesota* tree at each of the six sites. Soil samples were collected from each pit at depths of 2.5, 25, 50, and 100 cm in the area immediately adjacent to each probe location, and all soil water content reflectometers were laboratory-calibrated for moisture content to each soil type prior to installation (Figure 2.8). Calibration procedures and coefficients assigned to each probe are provided in Appendix B. Data were recorded at 60-second intervals, which were averaged and outputted every 15-minutes from CR1000 data loggers (Campbell Scientific, Inc.). Soil temperature sensors (T107, Campbell Scientific, Inc.) were installed beside each soil moisture probe at 25, 50, and 100 cm, thus allowing moisture readings to be corrected for temperature fluxes, a variable known under certain soil conditions to introduce measurement error in the type of soil moisture probe deployed (see Section 2.2.3).

Figure 2.5. Soil moisture and soil temperature instrumentation installed at 2.5-4cm beneath bare ground at each of six meteorological (MET/ECOV) stations in Yuma Wash.

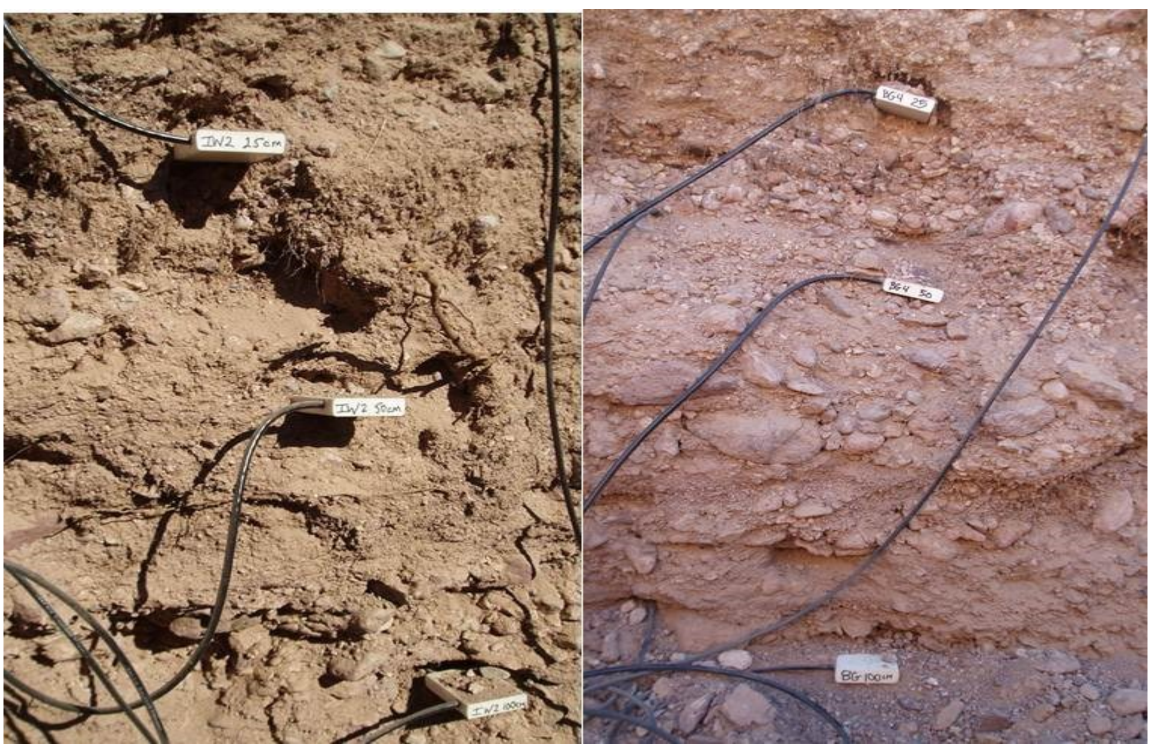


Figure 2.6. Soil moisture and soil temperature instrumentation installed at 25, 50, and 100cm beneath bare ground, *P. microphylla*, and *O. tesota* at six soil moisture (SF) stations in Yuma Wash.

Figure 2.7. Excavation of soil pits to one meter depth in Yuma Wash.

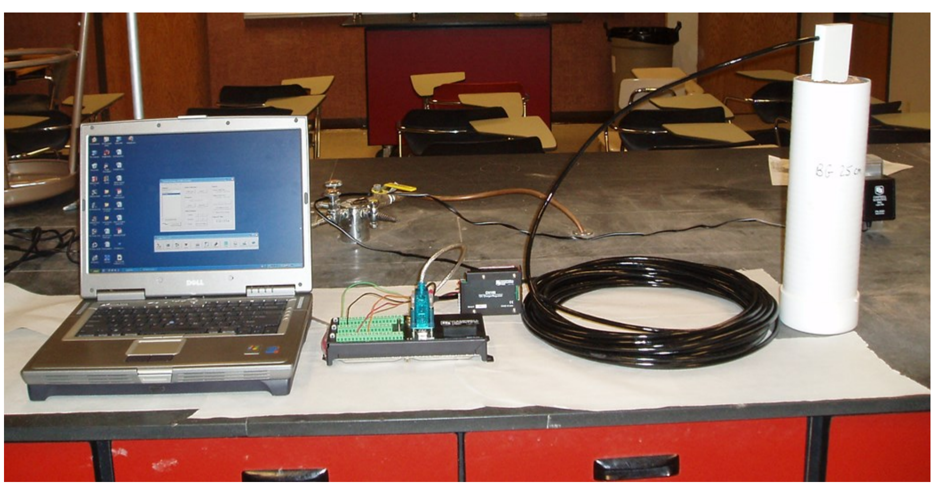


Figure 2.8. Laboratory calibration of soil moisture instrumentation installed in Yuma Wash.

2.2 Measurement Theory

2.2.1 TE525 and TB4 Tipping Bucket Rain Gages

The TE525 is an adaptation of the standard Weather Bureau tipping bucket rain gage, and consists of a 15 cm diameter collector with a recording tip of 0.254 mm per tip. At rainfall rates of up to 10 mm/hr, accuracy of the gage is +/-1 percent; between 10-20 mm/hr, accuracy is +0/-3 percent, and above 20 mm/hr, +0/-5 percent. A funnel collects and channels precipitation into a small tipping gage, which after a pre-set amount of precipitation falls, tips, dumping the collected water and sending an electrical signal to an attached datalogger, which records the precipitation.

2.2.2 CS616 Water Content Reflectometer

The CS616 water content reflectometer is a probe designed to estimate volumetric water content of a soil using the electromagnetic techniques of time domain reflectometry and transmission line oscillation. The probe consists of two stainless steel rods, 30 cm in length, connected to a printed circuit board. A shielded four-conductor cable is connected to the circuit board to supply power, enable the probe, and monitor the pulse output. Transmission line oscillators generate consecutive voltage pulses from inside the probe head. Pulses travel down the steel rods and back, where the arrival of the reflected pulse triggers the next pulse. The travel time of the pulse is dependent upon the dielectric permittivity (ε) of the medium surrounding the rods, and the real permittivity (ε') component of the dielectric permittivity is dependent on the water content. Permittivity is a measure of how an electric field affects, and is affected by, a dielectric medium such as soil. In the application of soil science, it describes how much electric flux is generated per unit charge provided to a soil, and is measured in Farads per meter (F/m).

The ability of a dielectric medium to transmit (or 'permit') an electric field is a complex quantity with both real (ε') and imaginary (ε") components. Real permittivity (ε') is related to stored energy in the soil, and imaginary permittivity (ε") is related to the dissipation of energy, or dialectric losses, within the soil. Soils with a high clay fraction tend to attenuate the pulse signal (and thus increase the recorded travel time of a pulse, or 'output period', which is used to compute soil moisture) because of the tight bonds clays form with water, reducing its polarization and adding an imaginary component to the dielectric permittivity. Electrical conduction through the soil is another primary component of the imaginary permittivity of a soil, and depends upon the ionic content of the soil. The major contributor to soil electrical conductivity is the presence of free ions from dissolution of soil salts. High saline soils are very electrically conductive, and therefore can have a large imaginary component of permittivity. When soil solution electrical conductivity values exceed 2 deciSeimans per meter (dS m^{-1}) the slope of the response curve of the CS616 probe decreases with increasing electrical conductivity, and at values greater than 5 dS m^{-1} the probe output period can become unstable. Electrical conductance in soils is also positively correlated with soil temperature, so as temperatures in the soil rise, attenuation of the pulse signal can occur, which results in an overestimation of the output period and thus water content during soil warming periods.

Conversely, real permittivity of a soil is negatively correlated with soil temperature, so in soils where ε' dominates, an increase in temperature can result in an underestimation of soil moisture as measured by the CS616. In some soils, the two components balance each other and there is no apparent temperature sensitivity in the output period of the probe. In soils which undergo strong diurnal or annual cycling, soil temperature data can be used to correct the water content reflectometer for temperature oscillations.

The output period from the CS616 is a square wave with a frequency that is proportional to the number of reflections per second, which ranges from 14 microseconds in air to 42 microseconds in typical tap water. This output period is what is measured *in situ* by the CS616 probe, and recorded to a datalogger. Volumetric water content of the soil is then derived from a custom calibration curve developed in the laboratory for each probe and soil sample, and empirically related to the output period via regression. The accuracy of the CS616 probe is +/- 2.5 percent volumetric water content using standard calibration with bulk electrical conductivity <0.5 dS/m^{-1}, a soil bulk density of <1.55g/cm^{-3} in a measurement range of 0-50 percent volumetric water content. The resolution and precision of the probe are finer, able to detect changes in water content and repeatedly measure the same change to within 0.1 percent. Probe to probe variability is typically +/- 0.5 percent in dry soil, and +/- 1.5 percent in saturated soil.

2.3 Analytical Approach

Data post-processing was conducted using MatLab® 7.10.0/R2010a computational software (The Mathworks, Inc., 1994-2010), Excel 2010 (Microsoft, 2010), and Minitab® 15.1.30.0. (Minitab, Inc, 2007), and all statistical analyses were conducted using R© 2.11.1/2010 statistics software (The R Foundation for Statistical Computing, 2010). Details are presented separately for each of these hydrologic components below, and data collection and post-processing code is provided in Appendix A.

2.3.1 Analysis of Precipitation

Precipitation totals (mm) and mean and maximum intensities (mm/hr) were derived from 5-minute precipitation recorded at each station. Events were defined as rainfall which occurred within a 24-hour period. In most cases, an event fell within the same calendar day, but in the few cases where an event occurred in the late evening into early morning of the subsequent day, the event day was considered as the day in which most of the precipitation occurred. Mean intensity was calculated as the average of all 5-minute intensities recorded at each station for each event, and maximum intensity was taken as the highest 5-minute intensity value recorded at each station during each event.

Data were first assessed for normality, and both parametric and non-parametric statistical methods were employed where appropriate. Event data were statistically compared for spatial differences ($\alpha = 0.05$) by station, by geomorphic surface (terrace versus wash), and by location (lower, middle, upper basin) within the Yuma Wash watershed. Datasets were truncated to include those events that occurred when at least five out of six stations were operative in order to maximize the number of events that could be compared between stations and simultaneously minimize error associated with missing data. Statistical differences in time ($\alpha = 0.05$) were examined by comparing interannual and interseasonal variability in event precipitation and intensities. Statistical code developed for these analyses is provided in Appendix C. Where not included in the results Section 3.3.1, statistical output from each of these analyses is provided in Appendix D.

2.3.2 Analysis of Soil Moisture

Volumetric water content θ (m^3/m^3) was derived from 15-minute output period data recorded at each probe and an applied laboratory calibration for each probe. Calibration procedures are described in Appendix B. Analysis began by evaluating soil moisture and soil temperature probe performance, and eliminating probes with a large fraction of data out of the expected range of values for either output period or temperature. Remaining data were then truncated to remove data at intervals when soil moisture or soil temperature probes were only periodically malfunctioning. Estimates of temperature corrected versus uncorrected volumetric water content were compared, and differences were analyzed to determine the error in soil moisture estimates associated with soil temperature fluxes.

Fifteen minute volumetric soil moisture θ (m^3/m^3) data were then analyzed for spatial differences by depth, geomorphic surface, cover type, and basin location, and for temporal differences by season and year. Event specific analysis of mean soil moisture θ (m^3/m^3) and event peak magnitude Δθ (m^3/m^3) specifically during wetting periods was conducted next, in the same space-time domains. Because of the complexity introduced by diurnal oscillations in the soil moisture data, the exact 15-minute start time of a soil moisture event was not always identifiable. However, estimates of mean event soil moisture and event peak magnitude were not sensitive to the precise interval within a 24-hour period in which an event began based on the objectives of the study. For consistency, the start time of an event was defined by comparing the diurnal peak 15-minute mean volumetric soil moisture value between two 24-hour periods, until a 24-hour peak value exceeded the previous day's peak value by a user-defined tolerance level. Typically this was 0.01, or one percent. Once an event start time was identified, peak soil moisture was determined by comparing subsequent values sequential to the start time value until the soil moisture value decreased. The end time of an event was defined as either when a 15-minute moisture value was equal to or less than the event start value, or when a subsequent soil moisture event was encountered. Because soil temperature influences were greatest during peak event times, particularly for terrace probes at the near surface, peak magnitude analysis was conducted on temperature corrected data.

Soil moisture events were identified and characterized using an automated post-processing macro developed in Excel (Microsoft, 2010). Program code along with the details of a step-wise procedure for extracting soil moisture event variables from the model is provided in Appendix A. Statistical code developed for these analyses is provided in Appendix C. Where not included in the results Section 3.3.1, statistical output from each of these analyses is provided in Appendix D.

CHAPTER 3

RESULTS

3.1 Precipitation characteristics in Yuma Wash

A bimodal precipitation pattern, high interannual and interseasonal variability, and distinct seasonal precipitation features characteristic of much of the Southwest are reflected in data gathered in the Yuma Wash watershed throughout the study period. Total annual and seasonal precipitation recorded at six stations in Yuma Wash from July 2006 to February 2010 is summarized in Figures 3.1-3.2 and Tables 3.1-3.2, and includes mean annual and seasonal precipitation recorded at the Yuma Proving Grounds station (YPG/DCP1) between 1958-2010 for comparison. YPG/DCP1 station is located approximately 25 km south of the lower Yuma Wash meteorological station (ECOV1) that was deployed for this study.

A total of 70 precipitation events were recorded in Yuma Wash during the study period (Table D1). On average, 46 percent of these events occurred during summer, 35 percent during winter, and 10 and 9 percent in fall and spring, respectively (Table D2). On an annual basis, 16 percent were recorded in 2006 (July-December), 17 percent were recorded in 2007, 37 percent in 2008, 16 percent in 2009, and 14 percent in January and Feburary of 2010 (Table D3). Since 2006 and 2010 represent partial year totals based on the duration of the study period, comparisons of total precipitation between years were not made for those years. Of the years where data were available for twelve months (2007-09), 2008 was the wettest year in Yuma Wash, with a higher mean annual precipitation (125 mm) relative to the historic average reported at the YPG/DCP1 station(93 mm), and 2007 and 2009 were drier than average years, with a mean annual precipitation of 79 mm and 51 mm, respectively. The largest single event recorded

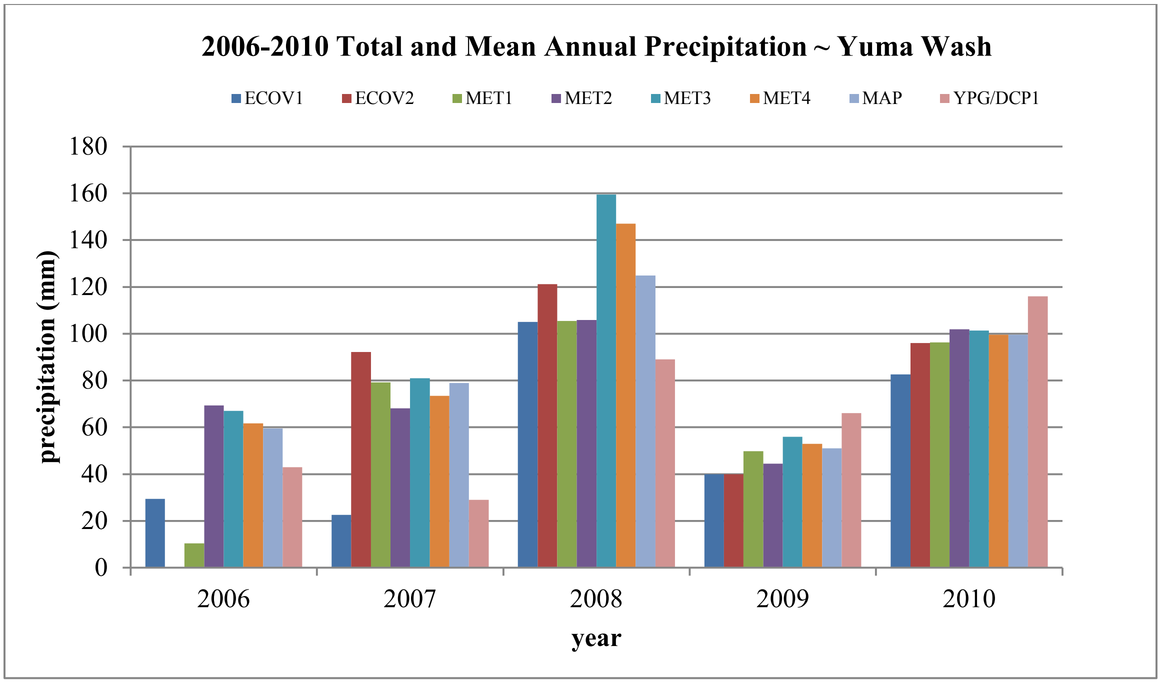


Figure 3.1. Total and mean annual precipitation recorded in Yuma Wash, and at the YPG/DCP1 station on the Yuma Proving Grounds from July 2006 to February 2010. Precipitation values for 2006 and 2010 are therefore partial-year totals. ECOV2 was not fully operative in 2006, MET1 was missing data from July-Sept 2006, and ECOV1 was missing data from September 2007-January 2008.

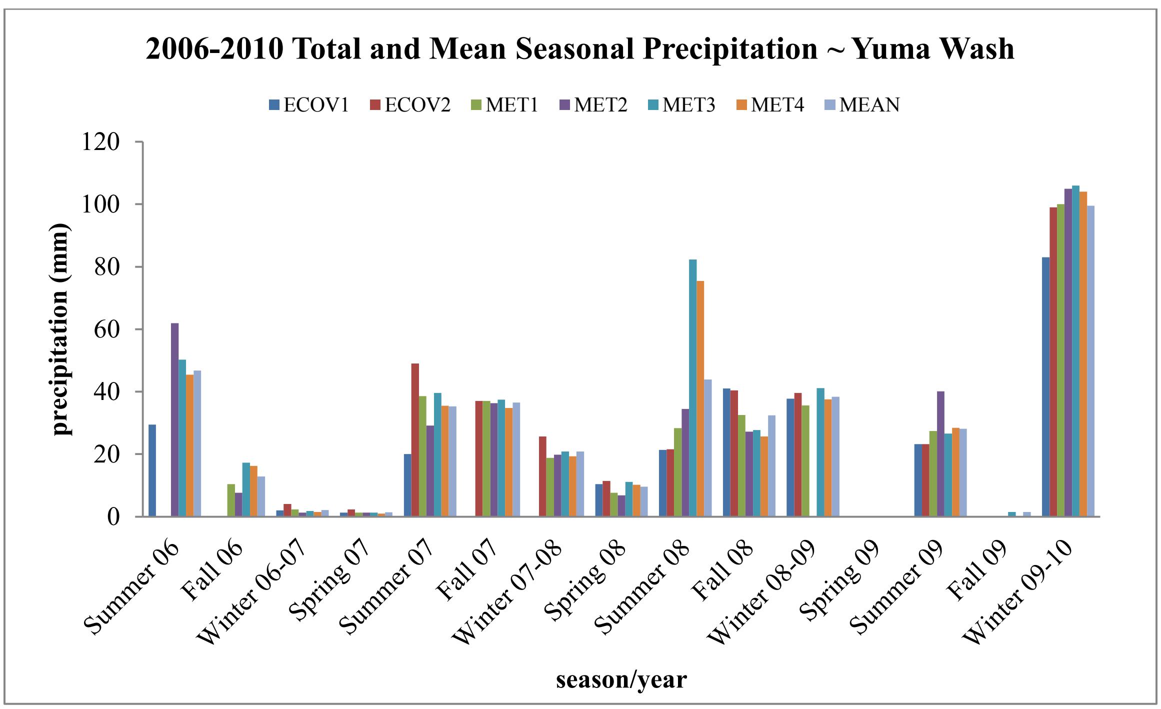


Figure 3.2. Seasonal precipitation recorded in Yuma Wash, from July 2006 to February 2010. MEAN refers to the six station seasonal average.

Table 3.1. Annual precipitation recorded and averaged from six stations in Yuma Wash.

Station	Precipitation (mm)				
	2006*	**2007**	**2008**	**2009**	**2010***
ECOV1/ECOV1R***	29	23***	106	40	83
ECOV2**	--	92	121	40	96
MET1**	10**	79	105	50	96
MET2	69	68	106	44	102
MET3	67	81	160	56	101
MET4	62	73	147	54	100
MAP	57	79	125	51	100
YPG/DCP1	43	29	89	66	116
YPG/DCP1 1958-10 annual mean	93				

MAP refers to mean annual precipitation averaged across all stations where records were complete for the year. * Data were collected from July 2006 to February 2010, therefore precipitation values for 2006 and 2010 are partial year-totals. **MET1 data were missing from July-September 2006. ECOV2 station was not operative in 2006 so precipitation at these stations is not included. ***ECOV1 station was destroyed in a wind storm August 2007 and was not replaced until January 2008.

Table 3.2. Seasonal precipitation averaged from six stations in Yuma Wash for the period of record (July 2006-February 2010), and compared against longer term seasonal averages recorded at the Yuma Proving Grounds meteorological station from 1958-2010.

Year	Winter (mm)	Spring (mm)	Summer (mm)	Fall (mm)
2006 (winter 05-06)	--	--	46	13
2007 (winter 06-07)	2	1	39	37
2008 (winter 07-08)	21	10	43	32
2009 (winter 08-09)	38	--	28	1
2010 (winter 09-10)	104	--	--	--
MSP 2006-10	41	4	39	20
YPG/DCP1 seasonal mean 1958-10	44	5	31	14

for the period of study was in January 2010, where an average of 68 mm of rain fell within a 19 hour period throughout Yuma Wash. Total precipitation for this single event was equivalent to 86 percent of the mean annual precipitation recorded in 2007, over half of the total precipitation recorded in 2008, and roughly 130 percent of the mean annual precipitation recorded in 2009. Total rainfall recorded in Yuma Wash was greater than at the YPG/DCP1 station by 170 percent in 2007, and by 40 percent in 2008.

While variation in total precipitation did not consistently differ by location or by geomorphic surface from year to year or season to season, total precipitation recorded over the period of record was greater in the upper basin by approximately 40 percent relative to the lower basin based on two station averages (446 mm versus 315 mm), greater by 24 percent in the upper basin relative to the mid-basin (446 mm versus 364 mm), and greater by 16 percent in the mid-basin relative to the lower basin (364 mm versus 315 mm). Differences were greatest between all locations in summer, with upper stations reflecting an approximately 2-fold (107 percent) increase in total precipitation relative to the lower stations for the period of record (180 mm versus 87 mm), and a 1.6-fold (60 percent) increase relative to the mid-basin (180 mm versus 114 mm). However, while two station averaging suggested an increase in summer precipitation from lower to upper basin, precipitation in some summers also varied between the two mid-basin and the two lower basin stations. In summer 2006 and summer 2009, recorded precipitation at the wash mid-basin station (MET2) was actually greater relative to the upper basin sites, and in summer 2007, the lower wash station (ECOV2) recorded more precipitation than the upper basin sites.

Fall total precipitation for the period of record also reflected greater precipitation in the upper basin, by nearly a 1.4-fold increase in the upper relative to the lower basin (80 mm versus

59 mm), but data were inconsistent from year to year; in 2008, higher fall precipitation was recorded in the lower basin. Missing data in 2006 and 2007 at the lower and mid-basin stations likely account for some of these differences, but precipitation totals also increased from lower to upper basin in 2008 and 2009, with nearly a 1.4-fold (35 percent) increase from lower to upper basin in 2008, and a 1.25 percent (25 percent) increase in 2009. Much of this variation was due to summer precipitation, which increased nearly 3-fold from lower to upper basin in summer 2008 (260 percent), and 1.3-fold in summer 2009 (25 percent).

When seasonal data were compared between years, interannual variation was least in summer, and greatest in winter. Conversely, summer precipitation was greatest in spatial variability and winter was least. These variations characteristic of Southwest precipitation were reflected in the spatial distribution of annual precipitation in the Yuma Wash watershed. In years where summer precipitation was greater than winter (2007 and 2008), spatial variation in total annual precipitation was greater between stations. And in years where winter precipitation was greater than summer precipitation (2009), or in 2010 when data represent only winter precipitation, spatial variation in annual precipitation was reduced (Figures 3.1-3.2). During 2007, nearly all precipitation was received in Yuma Wash in summer and fall seasons; in 2008, precipitation was received in all seasons with greater fraction occurring in summer and fall; and in 2009, precipitation only occurred during summer and winter seasons (Figure 3.2; Table 3.2).

Mean and maximum annual and seasonal precipitation intensities for all events recorded in Yuma Wash during the study period are presented in Figures 3.3-3.6 and Tables 3.3-3.4. Intensities were generally greatest in summer, averaging 10 mm/hr, followed by fall (7 mm/hr), and winter and spring intensities were relatively lower (3 mm/hr). In 2006 and 2010, partial year records of precipitation precluded comparisons of annual mean intensities against years with full

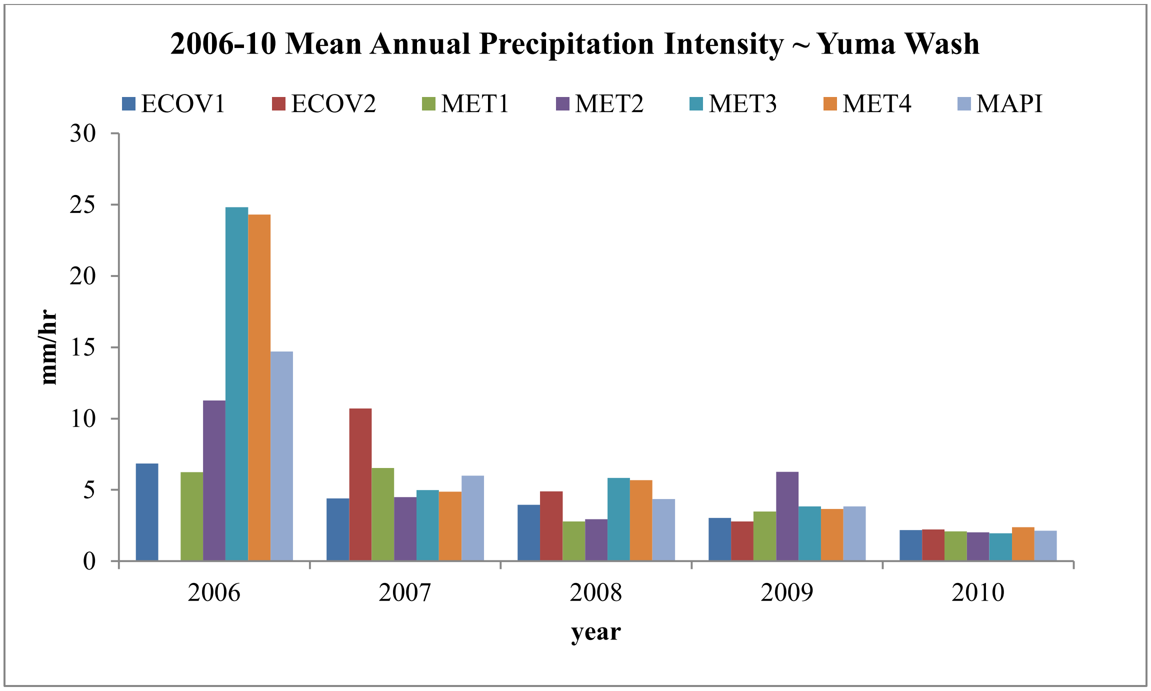


Figure 3.3. Mean annual precipitation intensity for all events (mm/yr) recorded in Yuma Wash. MAPI refers to the six-station average of the mean annual precipitation intensities recorded at each station for each year.

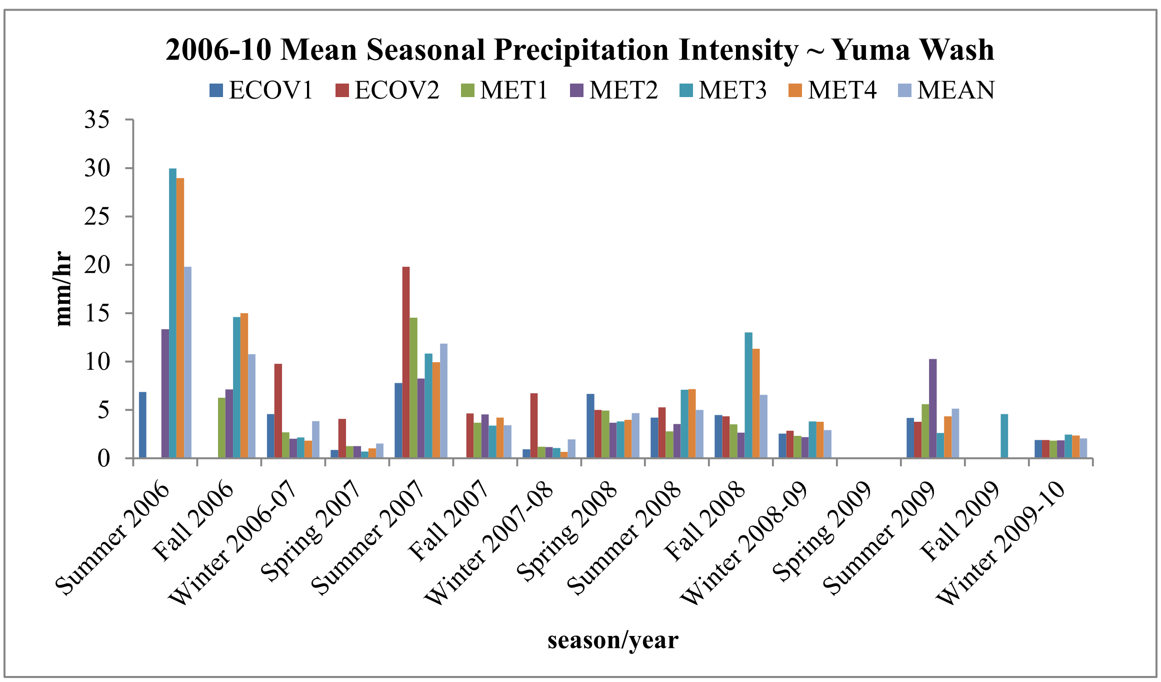


Figure 3.4. Mean precipitation intensity by season and year (mm/hr) recorded in Yuma Wash.

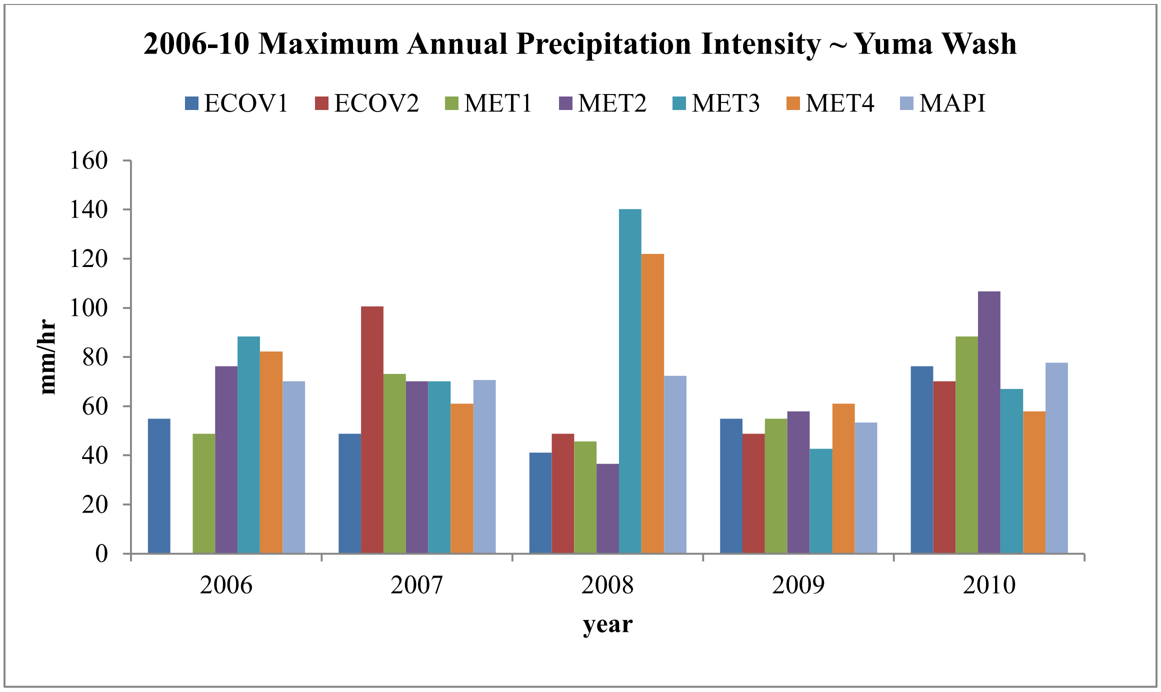


Figure 3.5. Maximum annual precipitation intensity (mm/yr) for all events recorded in Yuma Wash. MMPI refers to the six station mean of the maximum precipitation recorded for each year.

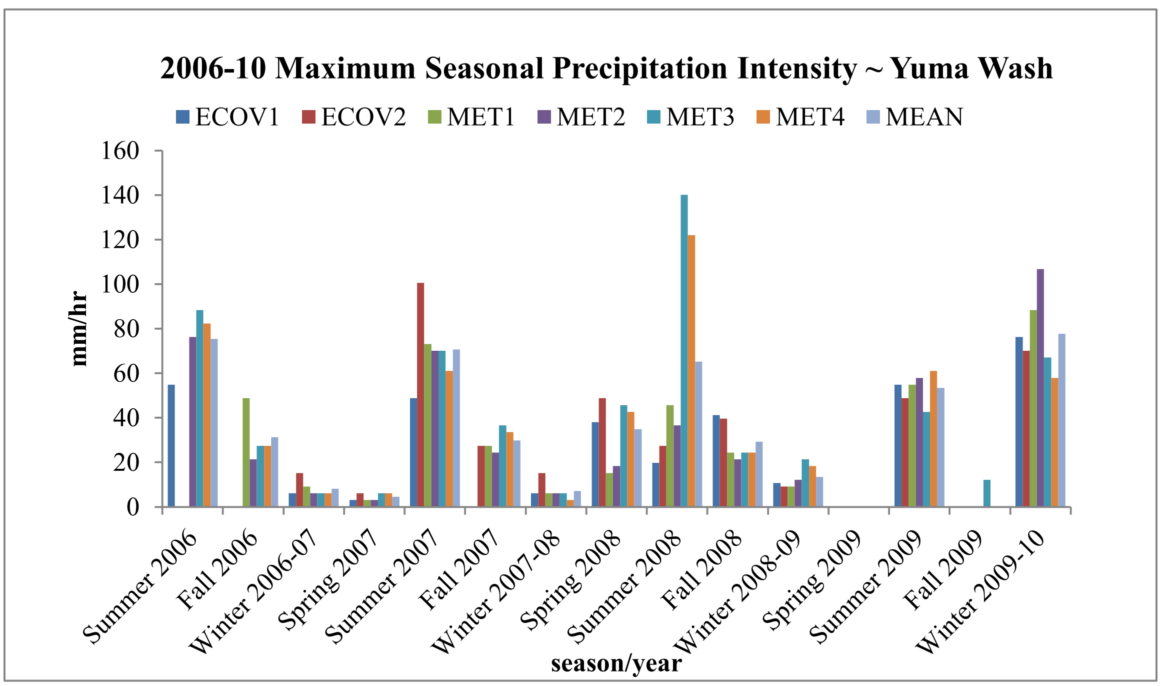


Figure 3.6. Maximum precipitation intensities by season and year (mm/hr) recorded in Yuma Wash.

Table 3.3. Mean and maximum annual precipitation intensity recorded at six stations in Yuma Wash.

Station	Mean and Maximum Precipitation Intensity (mm/hr)									
	2006*		2007		2008		2009		2010*	
	mean	max	mean	max	mean	max	mean	max	mean	max
ECOV1/ECOV1R	7	55	4	49	4	41	3	55	2	76
ECOV2**	--	--	11	101	5	49	3	49	2	70
MET1**	6	49	7	73	3	46	3	55	2	88
MET2	11	76	4	70	3	37	6	58	2	107
MET3	25	88	5	70	6	140	4	43	2	67
MET4	24	82	5	61	6	122	4	61	2	58

*Data were collected from July 2006 to February 2010; therefore precipitation intensities for 2006 and 2010 are partial year-averages. **MET1 data were missing from July-September 2006 due to station malfunction, and ECOV2 station was not operative in 2006. Annual means and maximums were derived from all events recorded in Yuma Wash.

Table 3.4. Seasonal mean and max precipitation intensity averaged from six stations in Yuma Wash for the period of record (July 2006-February 2010).

Year	Winter (mm/hr)		Spring (mm/hr)		Summer (mm/hr)		Fall (mm/hr)	
	mean*	max*	mean*	max*	mean*	max*	mean*	max*
2006 (winter 05-06)	--	--	--	--	20	75	11	31
2007 (winter 06-07)	4	8	2	5	12	71	3	30
2008 (winter 07-08)	2	7	5	35	5	65	7	29
2009 (winter 08-09)	3	13	--	--	5	53	5	12
2010 (winter 09-10)	2	78	--	--	--	--	--	--

*Mean and maximum intensities reported here are averaged across all stations operative within each year.

year records. Since 2006 data represent only summer and fall precipitation, mean annual intensities reflected relatively higher intensity events which occurred in those seasons. In 2010, when only winter precipitation was recorded, mean intensities were generally reflective of the relatively low intensities typical of winter precipitation. For the three years with full year records, mean intensity was higher in 2007 (12 mm/hr) relative to 2008 and 2009 (5 mm/hr), in part because of a greater percentage of precipitation received in summer and fall relative to winter and spring of that year, but also because mean summer and winter intensities were higher in 2007 relative to other years for the period of record. Therefore, mean annual intensity did not necessarily correlate with mean annual precipitation, partially because the average rate of precipitation in any year is dependent on the relative fraction of precipitation received in each season, but also because intensities in each season varied from year to year. Maximum precipitation intensities typically occur during summer and occasionally during fall in the Southwest, and values reported here reflected this trend for all seasons and years except for the largest single event that occurred during the study period in winter 2010. The event delivered 68 mm of rainfall over approximately 19 hours at an average rate of 3-4 mm/hr, but for a brief period, recorded rainfall intensities were between 58-107 mm/hr. Maximum intensities of the magnitude recorded for this event are not generally reported for winter precipitation in the Southwest. In 2007 and 2009, maximum intensities occurred in summer at all stations and were less spatially variable than those recorded in 2008; variability in 2008 can be attributed largely to a few events that occurred in summer, particularly at the upper basin sites. On September 11, 2008, the highest intensity event of the study period recorded a total of 35 mm and 32 mm at MET3 and MET4 stations, respectively, with maximum recorded intensities of 140 mm/hr and 122 mm/hr, respectively (Figure 3.6). No precipitation was recorded during this event at lower basin stations ECOV1 and ECOV2, and only 2 mm and 6 mm were recorded at mid-basin stations MET1 and MET2. At the lower basin stations, highest intensities were recorded in fall and spring of 2008, and for mid-basin in summer. And while higher summer intensities were recorded at the upper basin sites in summer 2006 and 2008, recorded intensities were higher in the lower and mid-basin in summer 2007.

These findings were generally consistent with precipitation trends reported for the Southwest, and speak to the complexity associated with analyzing moisture inputs in arid landscapes. Summer convective storms are typically high in intensity, spatially discontinuous, with low interannual variation in total precipitation relative to other seasons. Winter storms typically deliver low intensity, spatially continuous frontal precipitation, with high interannual variation in total precipitation relative to summer precipitation. Fall events are less frequent, and deliver moderate to high intensity rainfall that is spatially less variable than summer precipitation, and more variable than winter precipitation. Because of limited data, tests for statistical differences in total annual or total seasonal precipitation could not be conducted. However, enough storm events occurred during the study period to allow for an examination of the statistical properties of per event precipitation. Results from these analyses are reported next.

3.1.1 Spatial and temporal analysis of event precipitation

Of the 70 precipitation events recorded throughout the study period, 2 of the 6 meteorological stations were inoperative during 16 of those events. To minimize error associated with missing data, 54 events that occurred when at least five of the six meteorological stations were operative were chosen for statistical analysis. This allowed for an analysis of approximately 80 percent of the recorded precipitation events. Truncating the data sets to only events that occurred when all stations were operative would have reduced the data available for analysis to less than 60 percent of the storms recorded. Table D4 provides a summary of the total number of events included in the analysis for each station and in each season, the number of missing values at each station (i.e. the number of times a station was inoperative during an event that was recorded elsewhere in the basin), and the number of zero values, which represent the number of times a station was operative but did not record precipitation during a storm that was recorded at another station in the basin. Zero values were omitted from the statistical analysis, so n-values shown on all plots represent only the number of non-zero precipitation values recorded at each station for each event included in each analysis.

Total precipitation from the 54 events analyzed from six stations is provided by year and by season in Figures 3.7-3.8 and Tables 3.5-3.6, and illustrates that in general, the distribution of rainfall in time and space is similar to the full data record with 70 events. On average, 40 percent of the 54 events occurred during summer, 43 percent during winter, and 8 and 9 percent in fall and spring, respectively. Event precipitation data are illustrated in Figure 3.9, and summary statistics are provided in Table D5.

Median per event precipitation by station for the period of record ranged from 3-6 mm, and maximum per event precipitation ranged from 62-73 mm. Data from all stations were found to be non-normally distributed (Table D6), and positively (right) skewed (Figures D1-D2). Skewness in this case results from the combination of low frequency, high rainfall events and (relatively) high frequency, low rainfall events typical of this region. Per event precipitation was highly correlated between all stations, with the highest correlations between stations in closest proximity (Figure 3.10; Table D7). Because of the non-normal distribution of the data, non-parametric statistical methods were used to test for significant differences in space and time (α = 0.05), and where appropriate, parametric methods were also employed and results were compared.

Results suggest that spatially, per event precipitation recorded at all stations for the period of record was similar in distribution (Figure 3.9; Table D8), but with greater per event

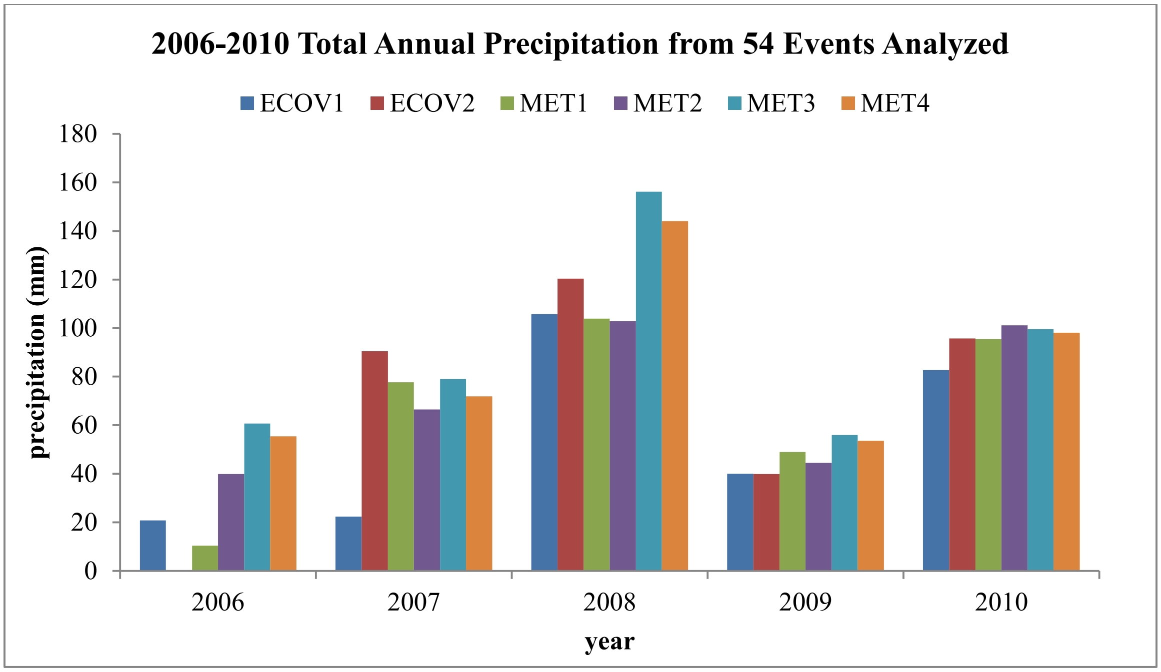


Figure 3.7. Total precipitation (mm) by year and by station from the 54 events selected for statistical analysis.

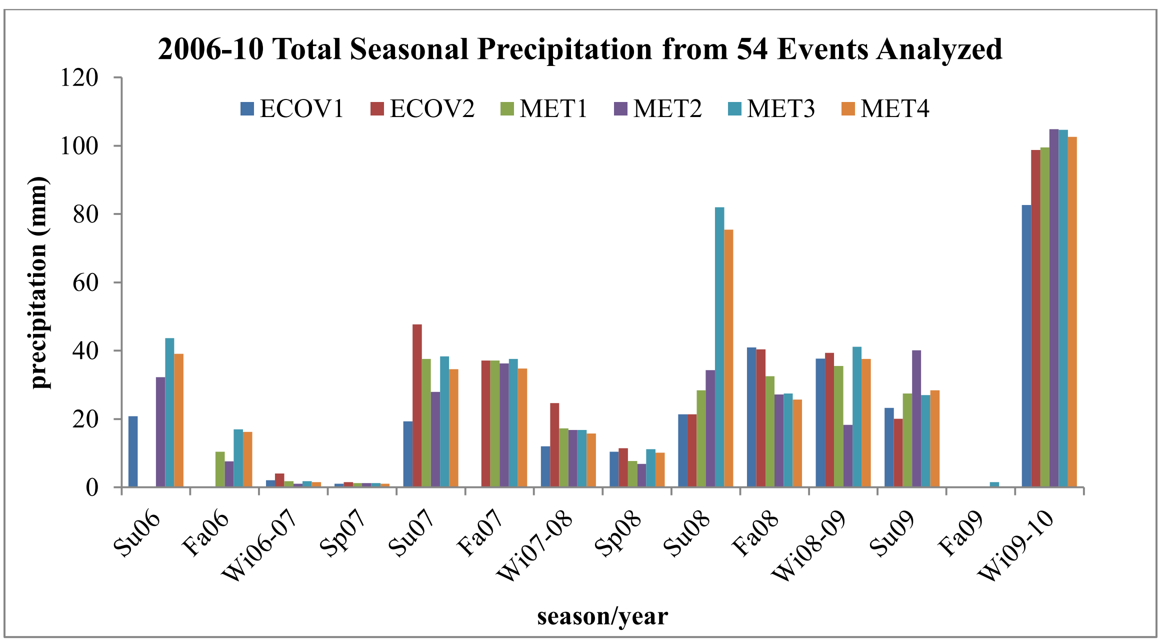


Figure 3.8. Total precipitation (mm) by station and by season-year from the 54 events selected for statistical analysis.

Table 3.5. Total precipitation by year and by station from the 54 events selected for statistical analysis.

Year	Precipitation by Station (mm)					
	ECOV1	ECOV2	MET1	MET2	MET3	MET4
2006	21	--	10	40	61	55
2007	22	90	78	67	79	72
2008	106	120	104	103	156	144
2009	40	40	49	44	56	54
2010	83	96	96	101	100	98

Table 3.6. Total seasonal precipitation by year and by station from the 54 events selected for statistical analysis.

Season/year	Precipitation by Station (mm)					
	ECOV1	ECOV2	MET1	MET2	MET3	MET4
Wi06-07	2	4	2	1	2	2
Wi07-08	12	25	17	17	17	16
Wi08-09	38	39	36	18	41	38
Wi09-10	83	99	100	105	105	103
Sp07	1	2	1	1	1	1
Sp08	10	11	8	7	11	10
Su06	21	--	--	32	44	39
Su07	19	48	38	28	38	35
Su08	21	21	28	34	82	75
Su09	23	20	27	40	18	28
Fa06	0	--	10	8	17	16
Fa07	--	37	37	36	38	35
Fa08	41	40	33	27	27	26
Fa09	0	0	0	0	2	0

precipitation recorded at upper basin sites. Spatial differences were not statistically significant ($\alpha = 0.05$) between any individual stations (Table D9), but when truncated by season, spatial differences were greater during summer and fall relative to winter and spring (Figure 3.11). Summer per event medians were higher in the upper basin relative to the middle and lower basin, but in fall per event medians were higher in the lower basin relative to the middle and upper basin (Table D5). Most seasonal data remained non-normally distributed (Figure D3; Table D10), and correlations remained highest for stations close in proximity (Table D11), with lowest spatial correlations in summer precipitation.

Event data for the period of record were pooled by geomorphic surface and location and spatial differences were reexamined to determine whether statistically significant differences occurred. Data remained non-normally distributed and right-skewed (Figures D4-D5), and did not suggest any significant differences in rank sums of event precipitation between the two geomorphic surfaces instrumented, or any significant differences by basin location (Figures 3.12-3.13; Table D9). By geomorphic surface, medians and IQRs were 5 mm and 2-12 mm on terraces, and 5 mm and 2-13 mm on washes. Differences were greater by location, where per event medians and IQRs in the lower basin were 3 mm and 1-11 mm, respectively, 5 mm and 2-12 mm in the mid-basin, and 6 mm and 2-16 mm in the upper basin.

When data by location were truncated by season, parametric tests suggest differences in event precipitation were significant in summer ($\alpha = 0.10$) between the upper and lower basin, and non-parametric tests suggest rank sums were close to significant ($\alpha = 0.10$) for summer and fall per event precipitation by location (Figure 3.14; Table D9), albeit with opposite seasonal trends. Per event precipitation in summer was higher in the upper basin relative to lower, while fall per event precipitation was higher in the lower basin relative to the upper. Spatial distribution of per event precipitation in winter and spring was less variable.

Comparisons of median per event precipitation by season and year relative to location and geomorphic surface suggest that temporal differences are generally greatest by season, and are generally greater than spatial variability in the Yuma Wash watershed (Figures 3.15-3.16).

Interannual variation notwithstanding, fall events generally delivered higher per event precipitation, with medians of 17 mm, relative to 5 mm in summer, 4 mm in winter, and 1 mm in

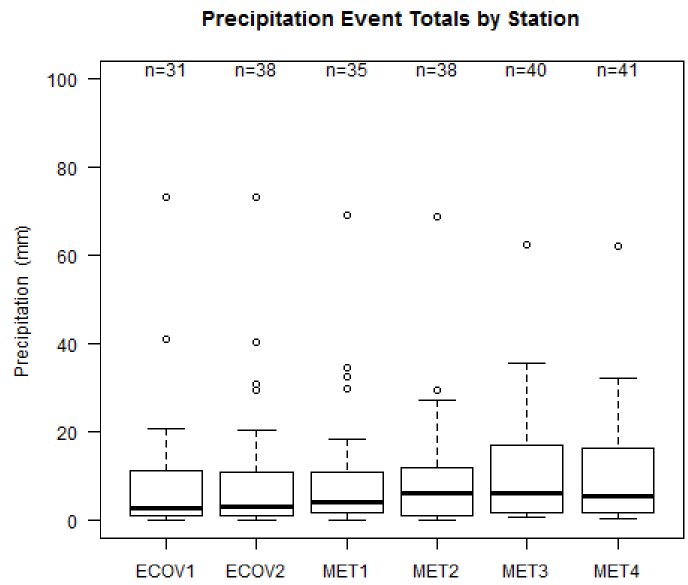


Figure 3.9. Boxplots of precipitation event totals (mm) recorded at six stations for the period of record from July 2006-February 2010 when at least 5 stations were operative.

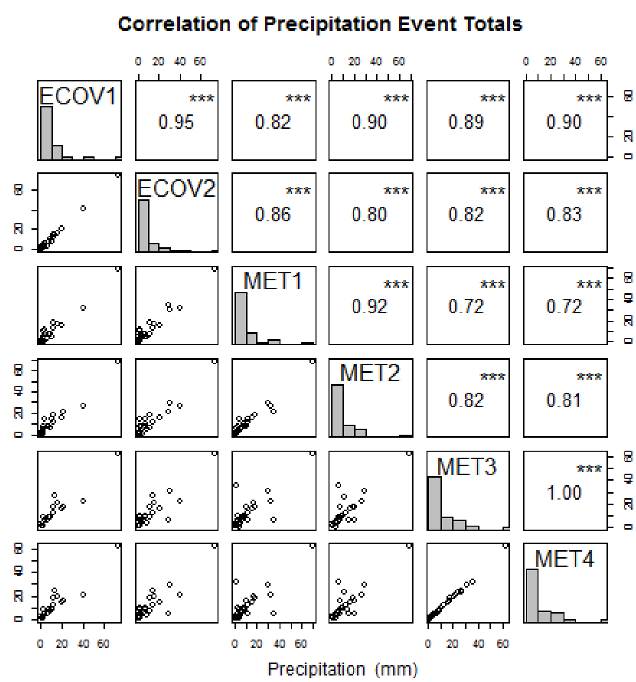


Figure 3.10. Spearman's Rho rank sum correlation of precipitation event totals (mm) recorded at six stations in Yuma Wash for the period of record from July 2006 to February 2010 when at least 5 stations were operative. * indicates (P<=0.001), ** (P<=0.01, *(P<=0.05), · (P<0.1).**

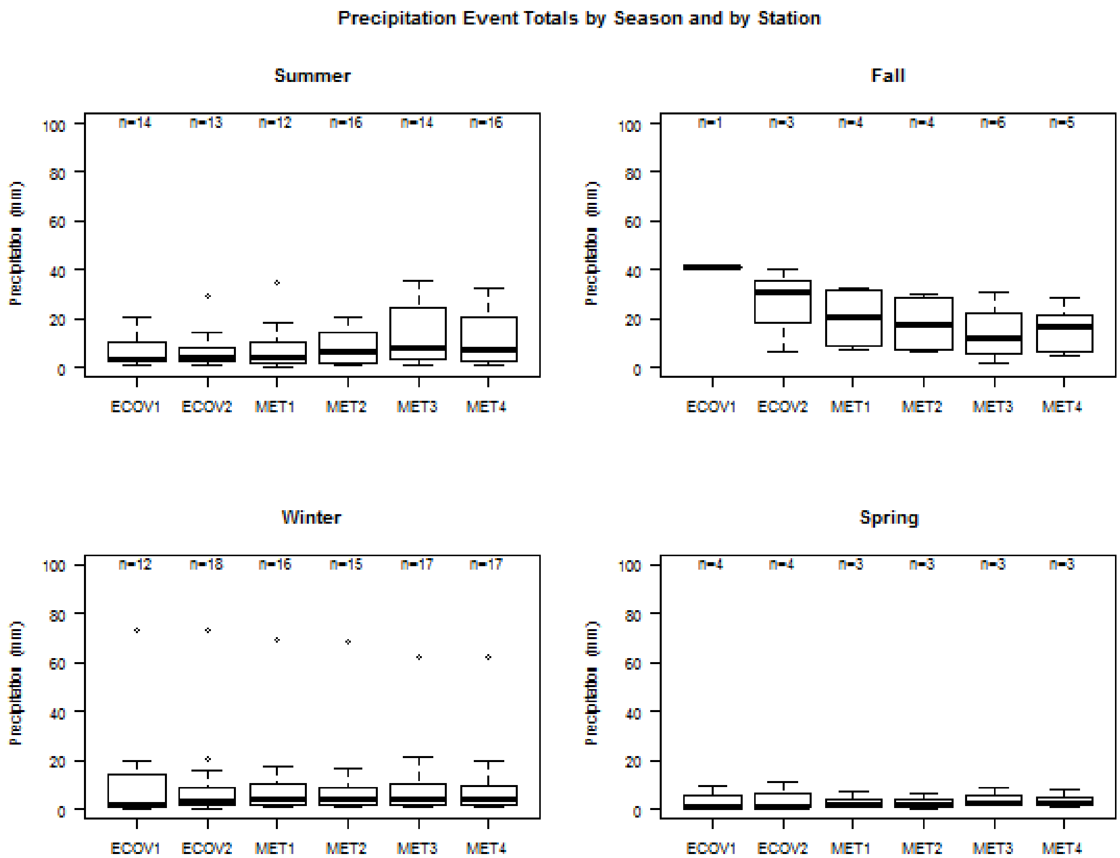


Figure 3.11. Event precipitation recorded in the Yuma Wash watershed by station, truncated by season for the period of record from July 2006-February 2010 when at least 5 stations were operative.

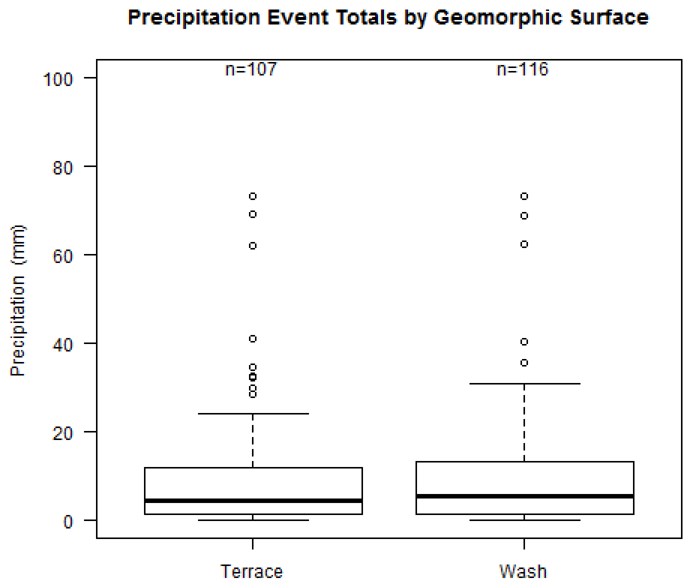


Figure 3.12. Event precipitation pooled by geomorphic surface in the Yuma Wash watershed for the period of record from July 2006-February 2010 when at least five stations were operative.

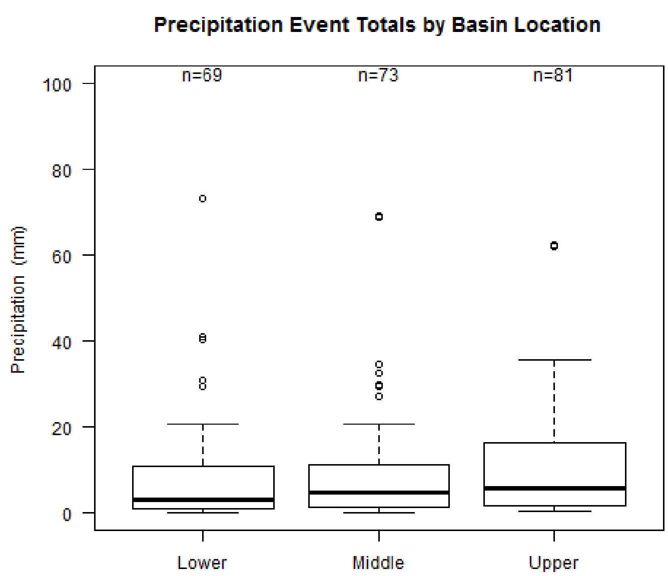


Figure 3.13. Event precipitation pooled by basin location in the Yuma Wash watershed for the period of record from July 2006-February 2010 when at least five stations were operative.

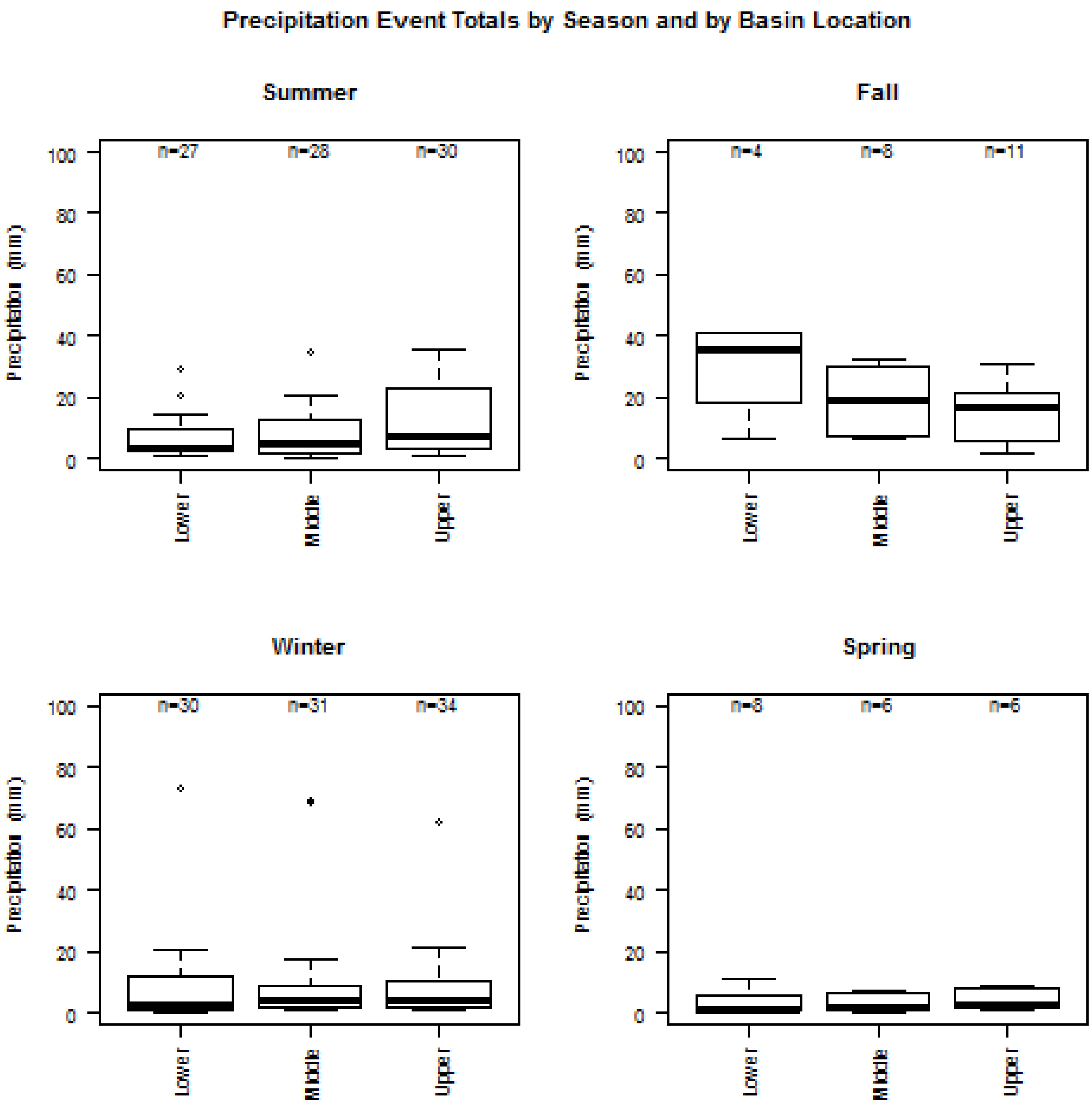


Figure 3.14. Event precipitation recorded in the Yuma Wash watershed pooled by basin location and by season for the period of record from July 2006-February 2010 when at least 5 stations were operative.

spring. Significant differences (α =0.05) in rank sums of per event precipitation were found between all seasons except winter and summer, and differences were most significant between fall and other seasons. Because there is a great deal of variation in seasonal precipitation from year to year, differences between fall and another season may not be significant in all years, and differences between winter and summer precipitation are likely significant in some years. However, too few data existed to make these statistical comparisons between seasons for each year.

While no significant differences were found in per event precipitation at α =0.05 between years with four seasons of records, differences in rank sums were significant at α =0.10 between 2007 and 2009 (Figure 3.17; Table D13), reflecting higher per event precipitation in 2007. Most precipitation in 2007 was received during fall and summer, versus 2009 when precipitation was received primarily in summer and winter, and both fall and summer seasons reflected higher median per event precipitation in 2007 than in 2009.

Comparing the same season in different years, significant differences in rank sums of per event precipitation were found (α =0.05) for summer 2006 and for summer 2007 relative to summers 2008 and 2009, and for winter 2006-07 relative to winters 2007-08 and 2009-10 (Figures 3.17-3.18; Tables D12-D13). Median summer event precipitation was 8 mm in 2007 versus 3 mm in 2008 and 4 mm in 2009. Median winter per event precipitation was 1 mm in 2006-07, versus 10 mm in 2007-08 and 4 mm in 2009-10. While statistical significance in rank sums was not found between fall seasons, median per event precipitation ranged from 25 mm in fall 2008 to 2 mm in 2009. It is likely that variability within each of the fall seasons, along with a limited number of data points available for statistical comparisons using non-parametric methods, constrained this analysis, as differences between years do occur.

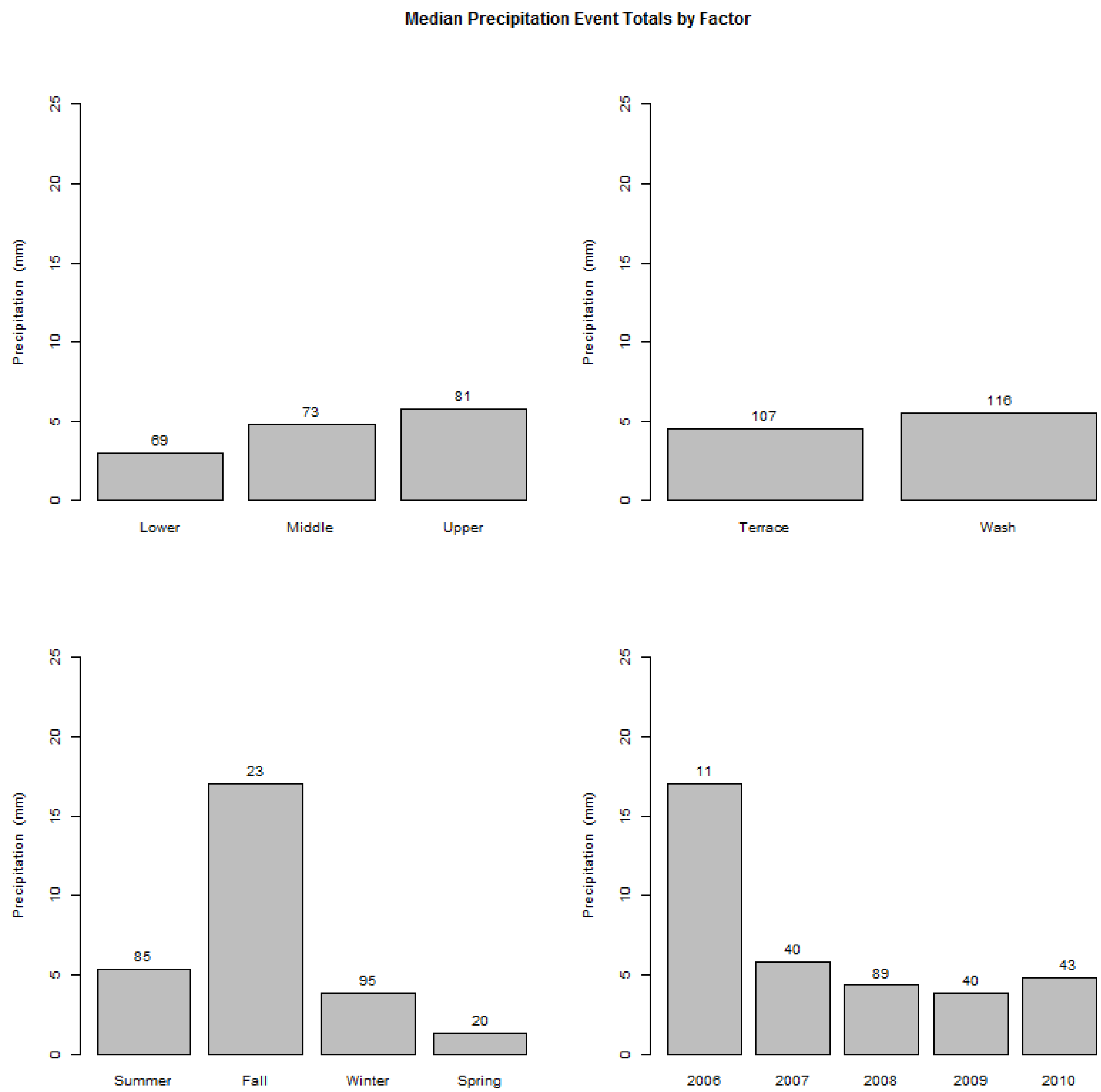


Figure 3.15. Event precipitation medians by location, geomorphic surface, season, and year in the Yuma Wash watershed for the period of record from July 2006-February 2010 when at least 5 stations were operative.

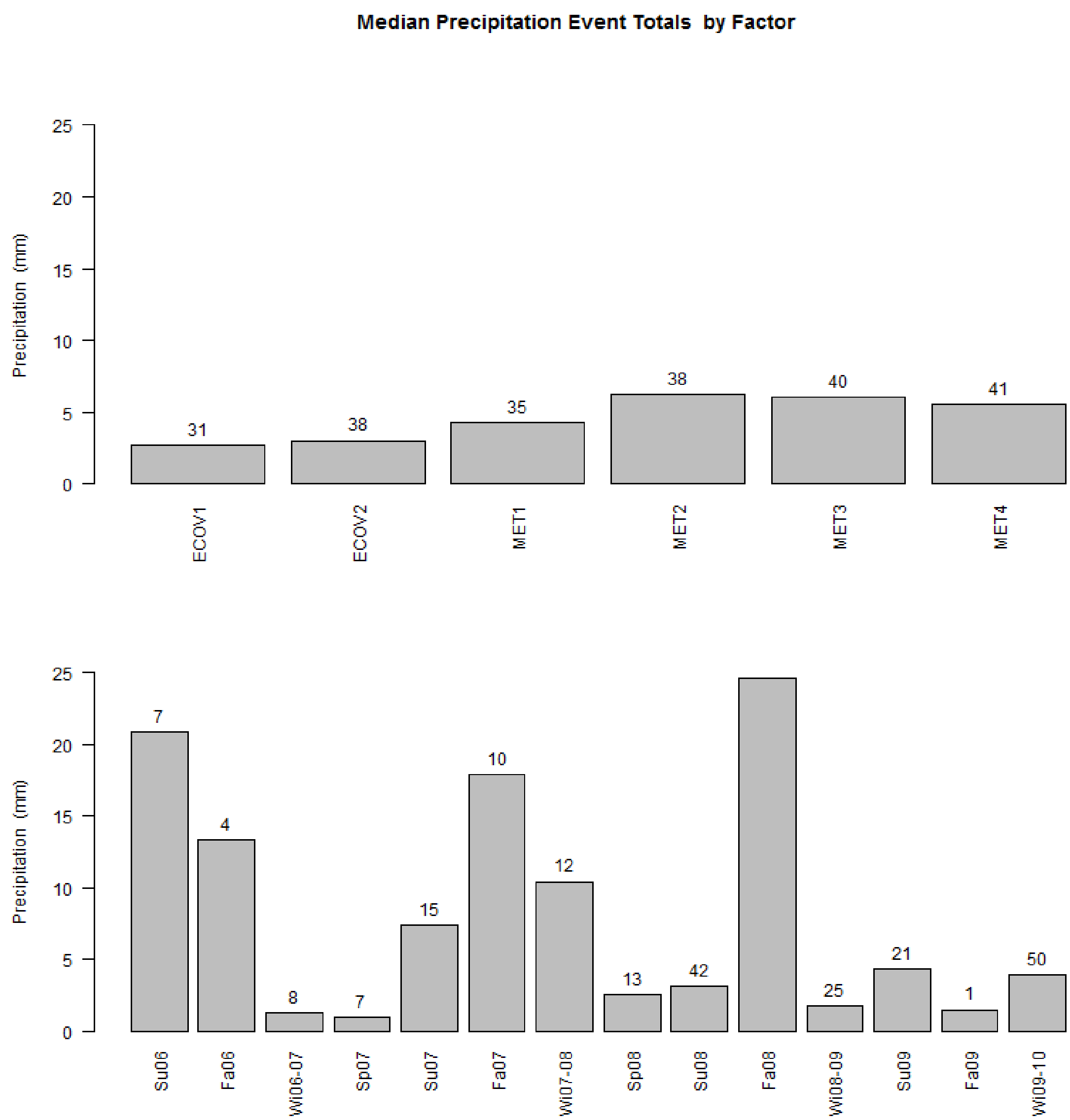


Figure 3.16. Event precipitation medians by station, and by season and year in the Yuma Wash watershed for the period of record from July 2006-February 2010 when at least 5 stations were operative.

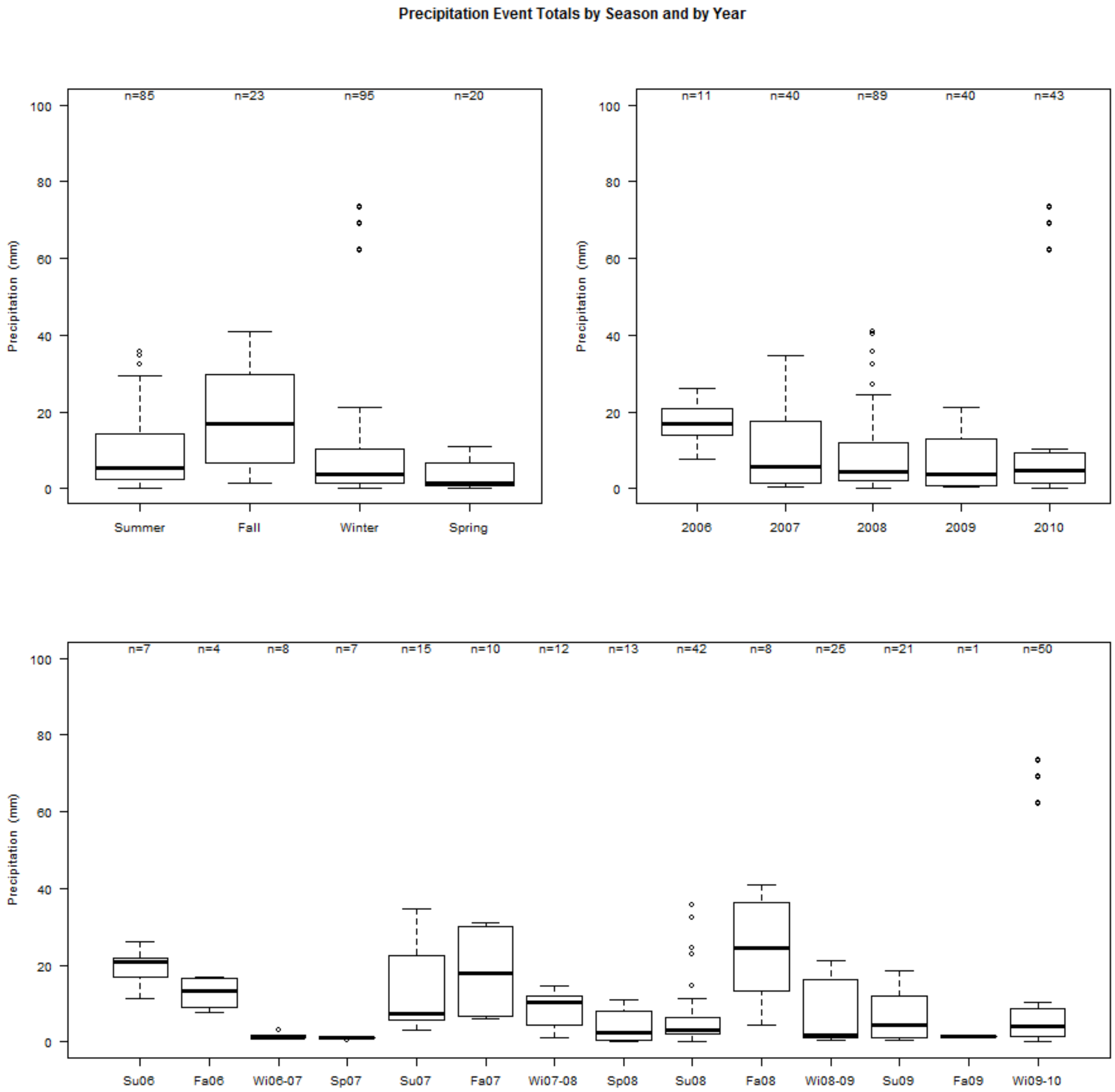


Figure 3.17. Event precipitation recorded in the Yuma Wash watershed pooled by season, by year, and by season-year for the period of record from July 2006-February 2010 when at least 5 stations were operative.

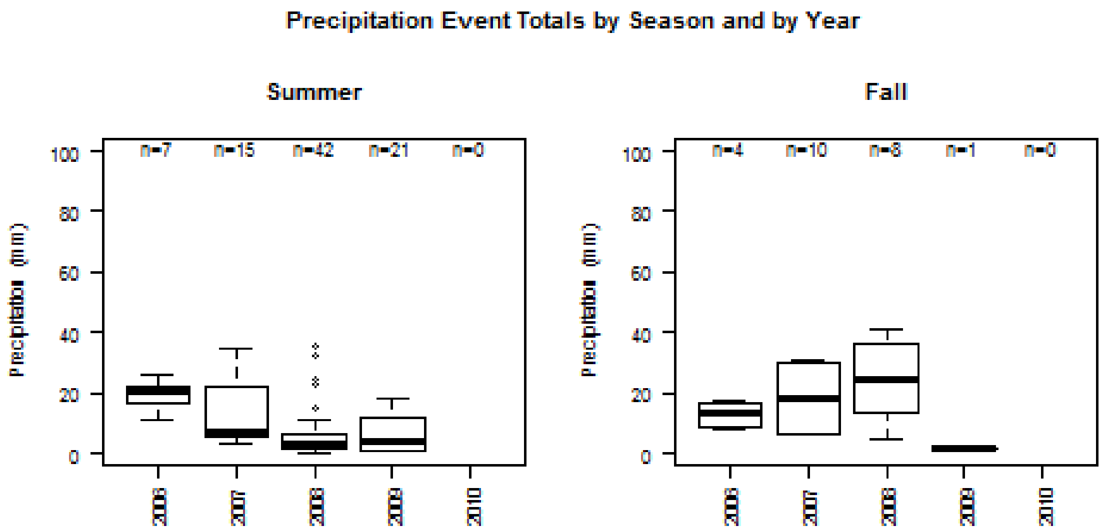


Figure 3.18. Event precipitation recorded in the Yuma Wash watershed pooled by season and year, for the period of record from July 2006-February 2010 when at least 5 stations were operative.

Temporal variation in per event precipitation is not necessarily reflected in the variation in total annual or total seasonal precipitation received. For example, despite significant interannual differences in median event precipitation in summer, interannual variation in the total precipitation received in summer is lower than in any other season (Figures 3.19-3.20; Table 8). Median event precipitation was lower in summer 2008 than in any other summer, yet the highest number of summer events was recorded during 2008. Similarly, while median event precipitation was higher in winter 2008 relative to winter 2007 and winter 2009, and nearly equivalent to winter 2010, total winter precipitation received in 2008 was less than 50 percent of the total received in winter 2009 and less than 20 percent of winter precipitation recorded in 2010 (Figures 33-34). So while a relatively larger number of small events reduce median event precipitation, these events contribute substantially to the total precipitation received in both summer and winter seasons. An analysis of the spatial variation in the rate of precipitation received is provided next.

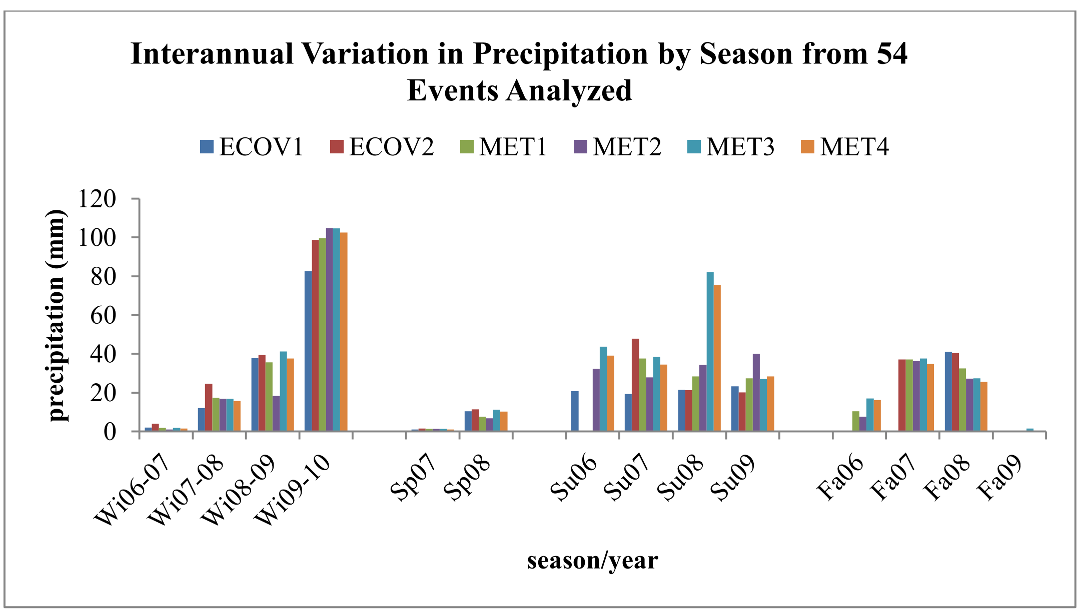


Figure 3.192. Interannual variation in the total seasonal precipitation (mm) received at six stations in each season and year from 54 events analyzed.

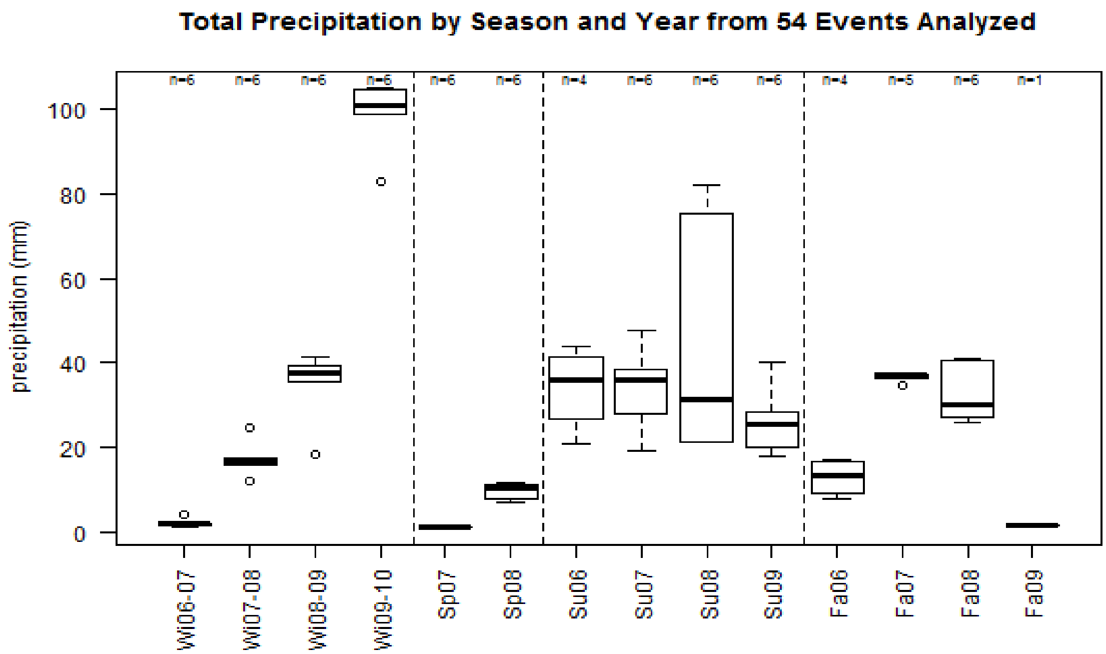


Figure 3.20. Interseasonal variation in the total precipitation (mm) recorded (summed for all events) at six stations in each season and year from 54 events analyzed. N-values in this case represent the number of station totals for each season and year (i.e. n=6 refers to 6 stations).

3.1.2 Spatial and temporal variation in mean and maximum precipitation intensities

Mean and maximum event precipitation intensities are provided in Figures 3.21-3.22 and Tables D15-D16. Medians of the event mean intensities varied from 3-5 mm/hr by station, with the highest event mean intensities ranging from 14-46 mm/hr. Median event maximum intensities ranged from 8-12 mm/hr, with highest maximums that ranged from 76-140 mm/hr by station. Intensity data were also non-normally distributed (Table D17) and positive (right) skewed (Figures D6-D9). Skewness in intensity data results from the combination of relatively low frequency, high intensity rainfall events received primarily during summer and fall seasons, and relatively high frequency, low intensity rainfall events received throughout the year, particularly during winter months. Correlations of mean and maximum event intensities were generally high between stations in closest geographic proximity ($\rho = 0.92$-0.79), and were

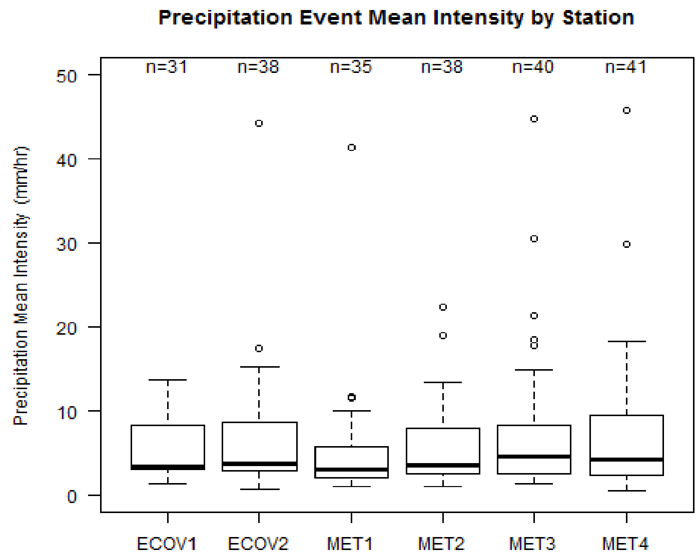


Figure 3.21. Boxplots of mean precipitation intensity (mm/hr) for events recorded in the Yuma Wash watershed during the period of record from July 2006-February 2010 when at least 5 stations were operative.

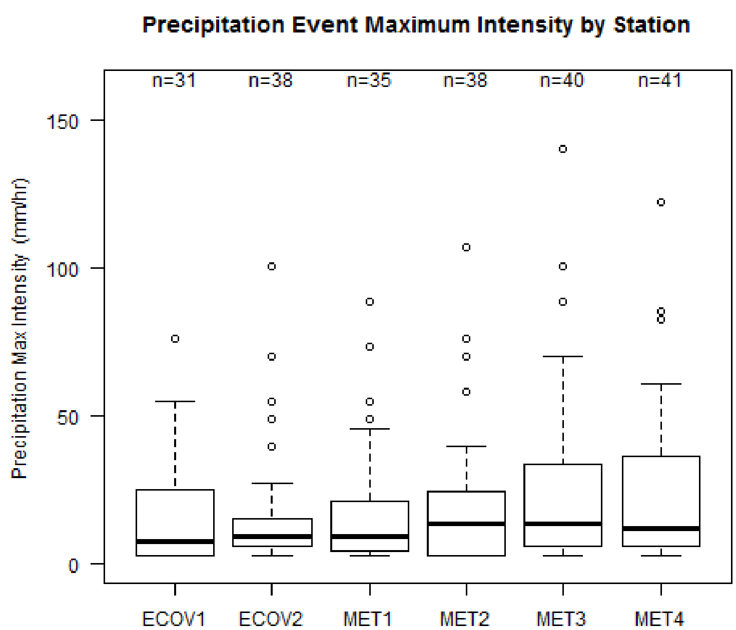


Figure 3.22. Boxplots of maximum precipitation intensity (mm/hr) for events recorded in the Yuma Wash watershed during the period of record from July 2006-February 2010 when at least 5 stations were operative.

moderate to high between stations further apart ($\rho = 0.88\text{-}0.51$) (Figures 3.23-3.24; Tables D18-D19). Intensities recorded at all stations were generally similar in distribution (Tables D20-D21), with generally higher values recorded at the upper basin stations.

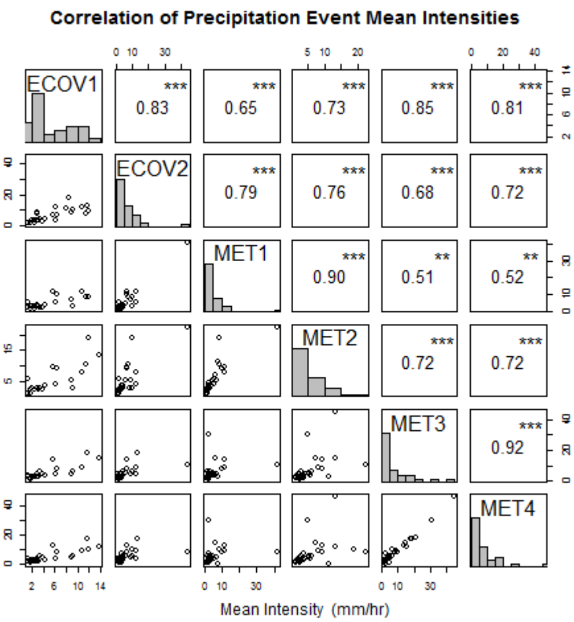


Figure 3.23. Spearman's Rho rank sum correlations of mean precipitation intensity (mm/hr) for events recorded in the Yuma Wash watershed during the period of record from July 2006-February 2010 when at least 5 stations were operative. * indicates (P<=0.001), ** (P<=0.01, *(P<=0.05), ·(P<0.1).**

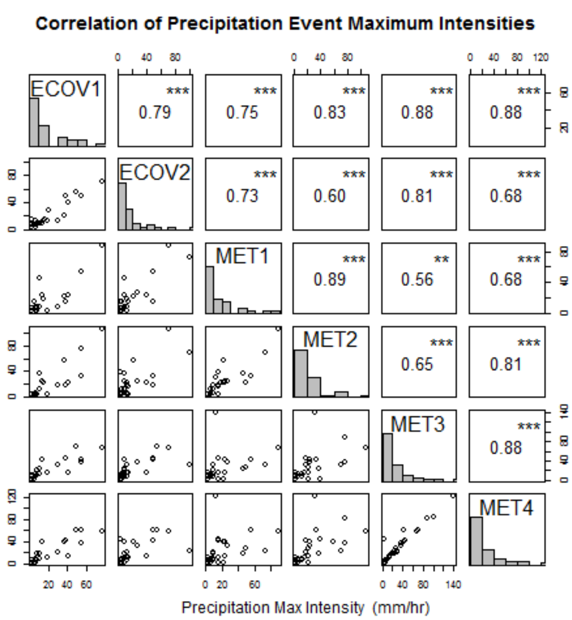


Figure 3.24. Spearman's Rho rank sum correlations of maximum precipitation intensity (mm/hr) for events recorded in the Yuma Wash watershed during the period of record from July 2006-February 2010 when at least 5 stations were operative. * indicates (P<=0.001), ** (P<=0.01, *(P<=0.05),·(P<0.1).**

No statistically significant differences were found in the rate of precipitation received by station using parametric tests, or in rank sums of these rates using non-parametric tests (Table D22). When truncated by season, data in some seasons reflected closer to a normal distribution (Figures 3.25-3.26; Figures D10-D11; Table D23), and reflect spatial variability, particularly for summer maximum intensities, which were generally higher in the upper basin relative to lower and middle basin (Figures 3.25-3.26; Tables D15-D16). Correlations of seasonal mean and maximum precipitation intensities remained relatively high for stations in close proximity ($\rho = 0.83$-0.92 for means and $\rho = 0.79$-0.88 for maximums), and vary from low to high for stations further apart (ρ=0.51-0.85 for means and $\rho = 0.56$-0.88 for maximums) (Tables D24-D25). When pooled by geomorphic surface and by location, data remained non-normally distributed and right skewed (Figures 3.27-3.30; D12-D15). Non-parametric analyses do not suggest any statistically significant relationship between geomorphic surface and the rate of precipitation received, or that intensities varied significantly at α= 0.05 by basin location (Figures 3.27-3.30; Table D22). Medians and IQRs of the maximum intensities ranged from 9 mm/hr and 5-26 mm/hr on terraces, respectively, to 12 mm/hr and 6-27 mm/hr on washes. By location, medians and IQRs of maximum intensities ranged from 9 mm/hr and 6-20 mm/hr in the lower basin, to 12 mm/hr and 3-24 mm/hr in the mid-basin, to 12 mm/hr and 6-37 mm/hr in the upper basin. When data were pooled by season and location, non-parametric and parametric tests suggested significant differences in summer maximum intensities at $\alpha = 0.10$ from lower to upper basin (Figures 3.31-3.32; Table D22). Parametric tests also suggest winter mean precipitation intensity is significantly different at α=0.05 between the lower and middle basin, but because many of the seasonal data remain non-normal in distribution, statistical differences suggested by parametric tests that are not significant using non-parametric equivalents may not be valid.

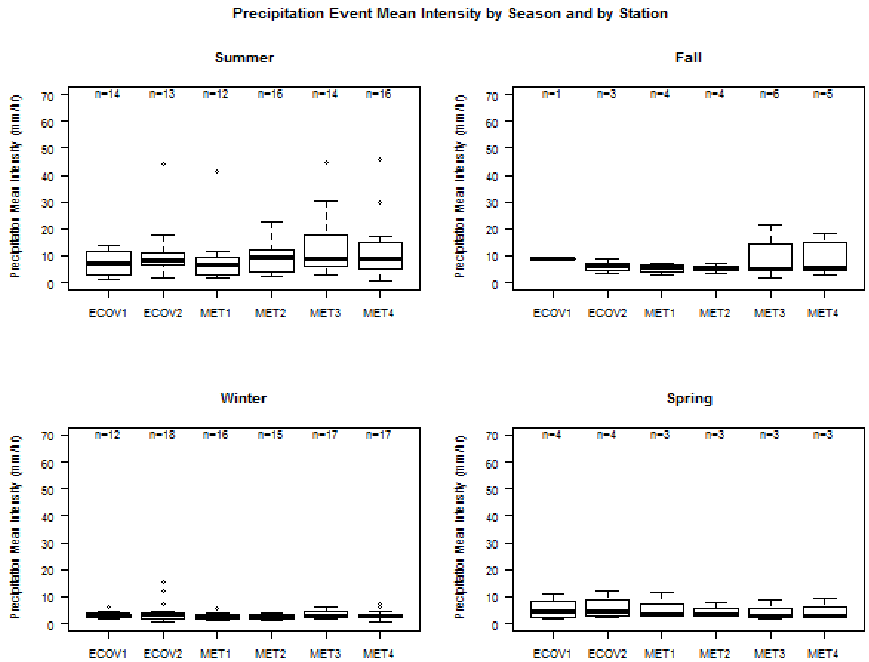


Figure 3.25. Mean precipitation intensity truncated by season for events recorded in the Yuma Wash watershed during the period of record from July 2006-February 2010 when at least 5 stations were operative.

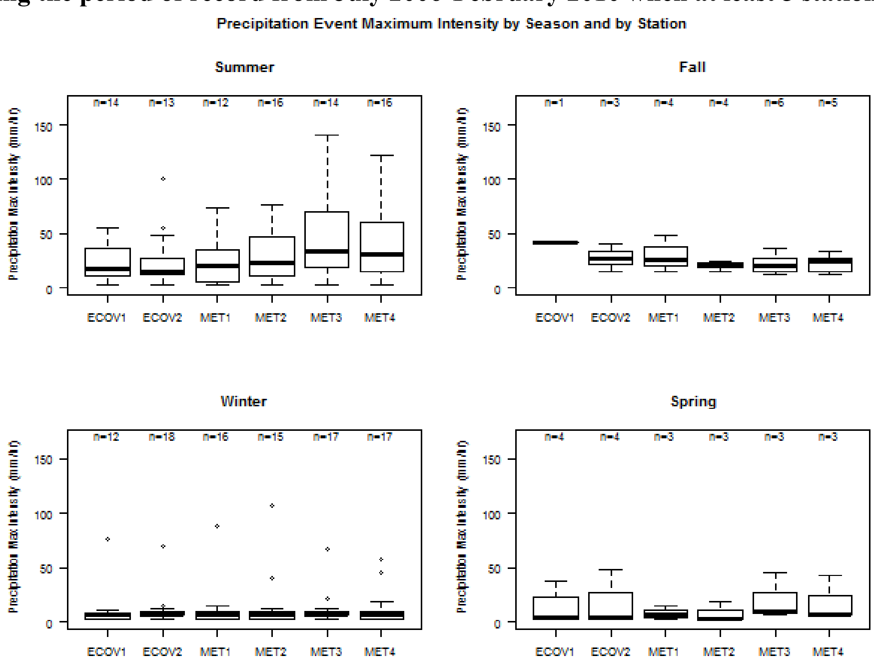


Figure 3.26. Maximum precipitation intensity truncated by season for events recorded in the Yuma Wash watershed during the period of record from July 2006-February 2010 when at least 5 stations were operative.

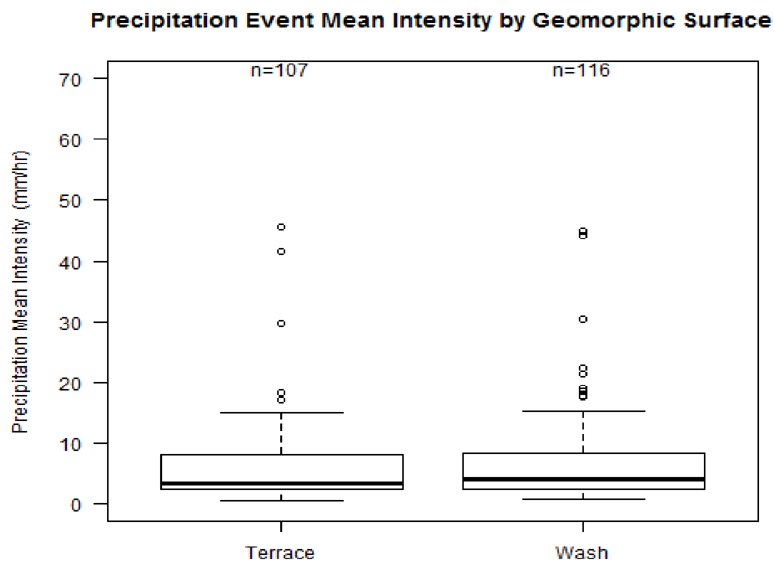


Figure 3.27. Event precipitation mean intensities (mm/hr) pooled by geomorphic surface in the Yuma Wash watershed for the period of record from July 2006-February 2010 when at least five stations were operative.

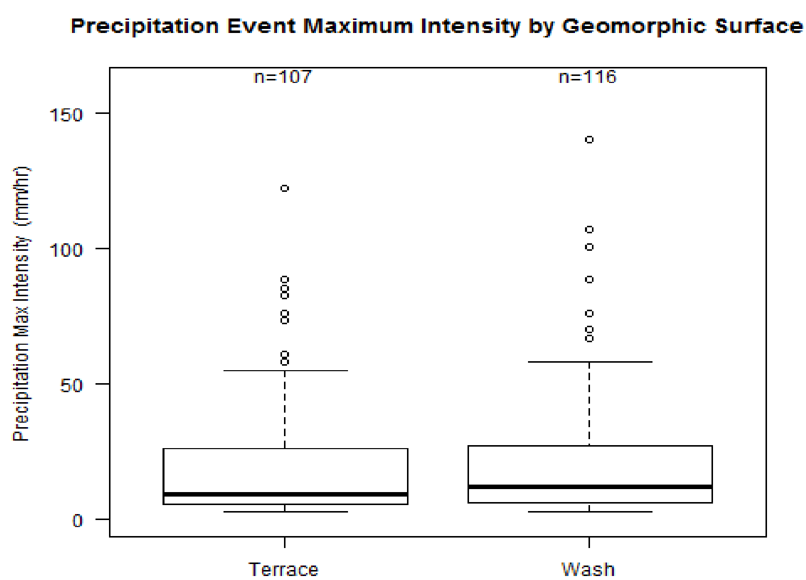


Figure 3.28. Event precipitation maximum intensities (mm/hr) pooled by geomorphic surface in the Yuma Wash watershed for the period of record from July 2006-February 2010 when at least five stations were operative.

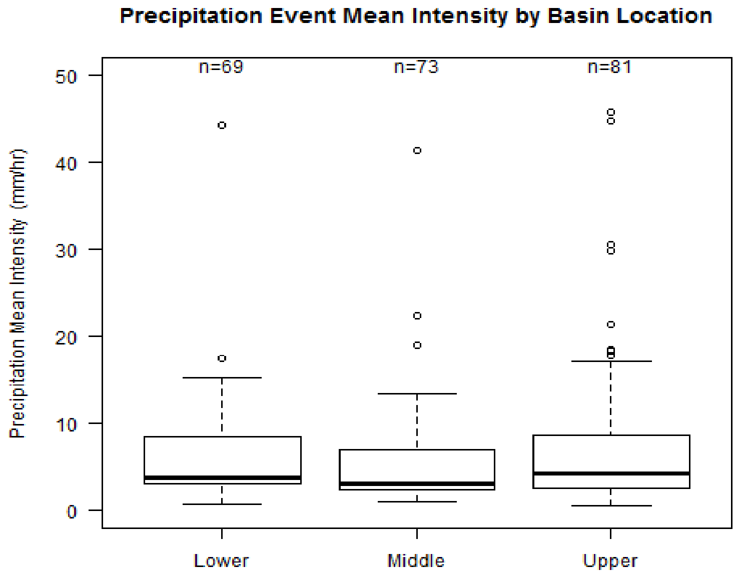


Figure 3.29. Event precipitation mean intensities (mm/hr) pooled by basin location in the Yuma Wash watershed for the period of record from July 2006-February 2010 when at least five stations were operative.

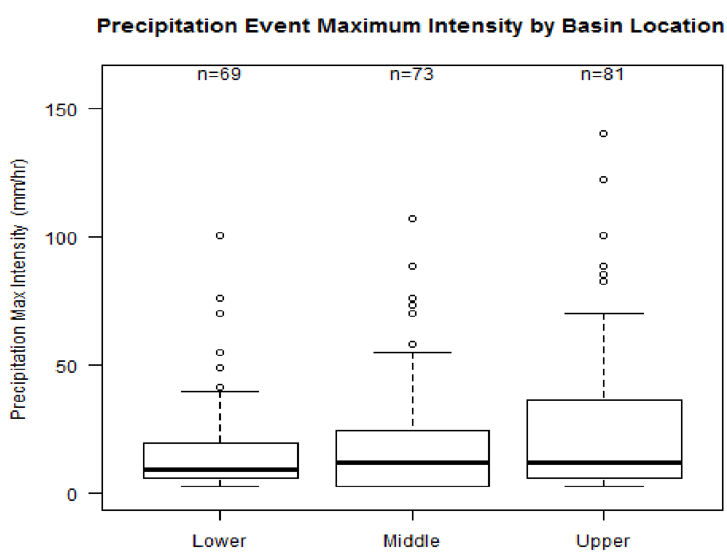


Figure 3.30. Event precipitation maximum intensities (mm/hr) pooled by basin location in the Yuma Wash watershed for the period of record from July 2006-February 2010 when at least five stations were operative.

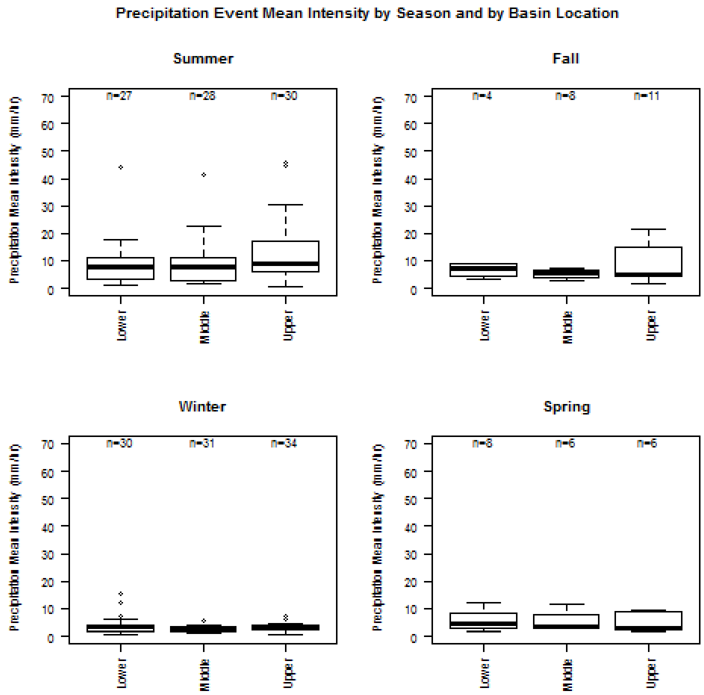


Figure 3.31. Event precipitation mean intensities (mm/hr) by basin location and by season in the Yuma Wash watershed for the period of record from July 2006-February 2010 when at least five stations were operative.

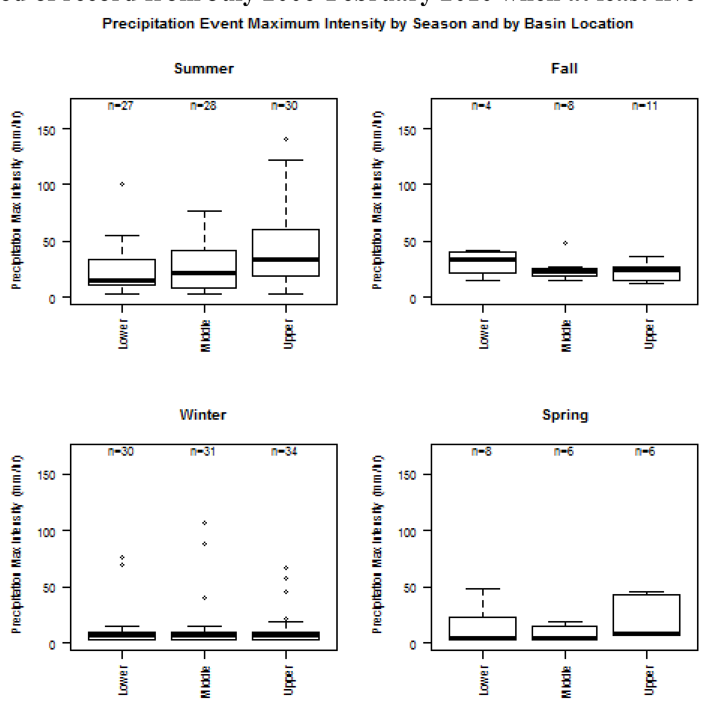


Figure 3.32. Event precipitation maximum intensities (mm/hr) by basin location and by season in the Yuma Wash watershed for the period of record from July 2006-February 2010 when at least five stations were operative.

Comparisons of precipitation intensities by season and year suggest that, like event precipitation, temporal differences in the rate of precipitation received in the Yuma Wash watershed were generally high (Figures 3.33-3.34). Interannual comparisons were first made between the three years with full data records (2007-09). Non-parametric tests suggest significant differences in rank sums for maximum intensities between 2007 relative to 2008 and 2009, but significant differences were not found in mean intensities (Figures 3.33-3.34; Tables D26-D28). Medians and IQRs of the maximum intensities in 2007 were 15 mm/hr and 8-101 mm/hr, respectively, versus 12 mm/hr and 6-21 mm/hr in 2008, and 8 mm/hr and 3-21 mm/hr in 2009. These differences likely reflect the higher fraction of total annual precipitation received in fall and summer of 2007 relative to 2008 and 2009. Significant differences were not found in either mean or maximum intensities between years using parametric tests, and comparisons were not made against years 2006 and 2010 because of partial year datasets represented by those years.

Interannual comparisons of mean precipitation intensities truncated by season resulted in significant differences at either α =0.05 or α =0.10 by year between each of the seasons compared using both parametric and non-parametric indices (Figure 3.35; Tables D26-D28). Significant differences in maximum intensities were found only between springs and between summers in different years using non-parametric and parametric tests; parametric tests suggested that winter 2007-08 and winter 2009-10 also differed significantly at α =0.05 (Figure 3.36; Tables D26- D28). Like event precipitation, mean and maximum intensities were significantly higher in summer 2006 relative to summer 2008 and summer 2009.

The number of data points available for comparisons between different seasons in the same year was very limited, particularly for spring and fall seasons, so additional tests were not

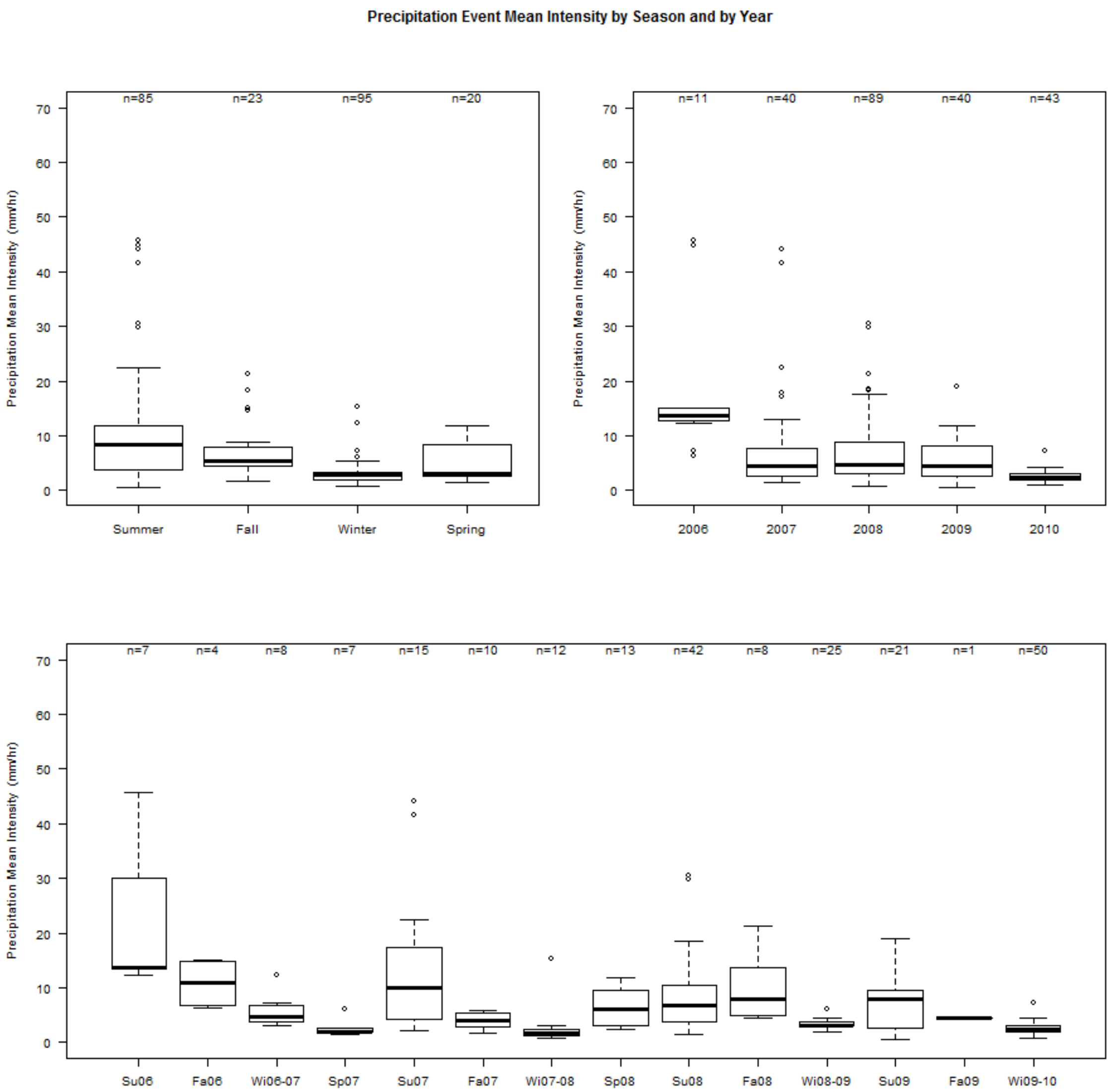


Figure 3.33. Event precipitation mean intensity (mm/hr) recorded in the Yuma Wash watershed pooled by season, by year, and by season-year for the period of record from July 2006-February 2010 when at least 5 stations were operative.

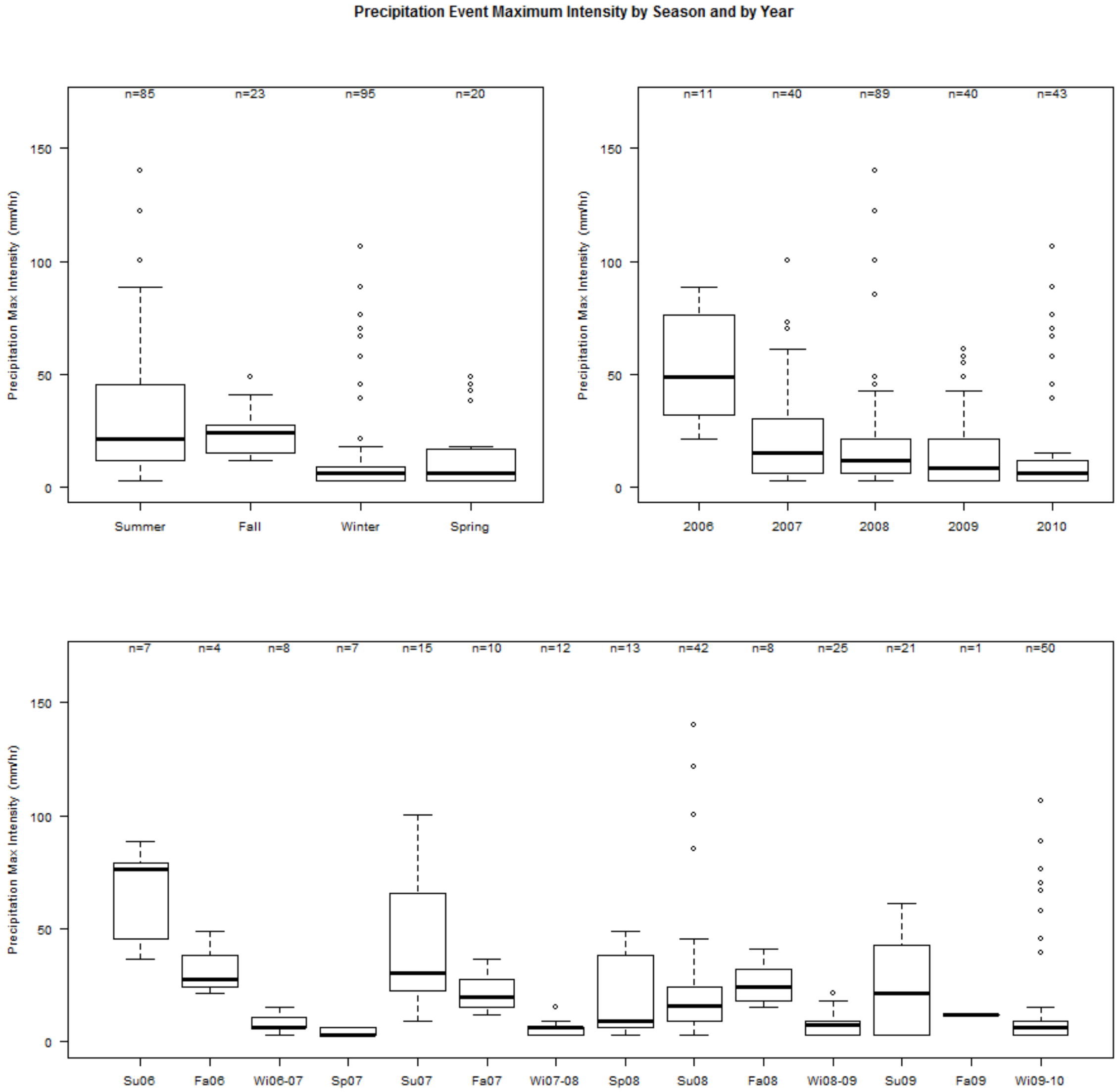


Figure 3.34. Event precipitation maximum intensity (mm/hr) recorded in the Yuma Wash watershed pooled by season, by year, and by season-year for the period of record from July 2006-February 2010 when at least 5 stations were operative.

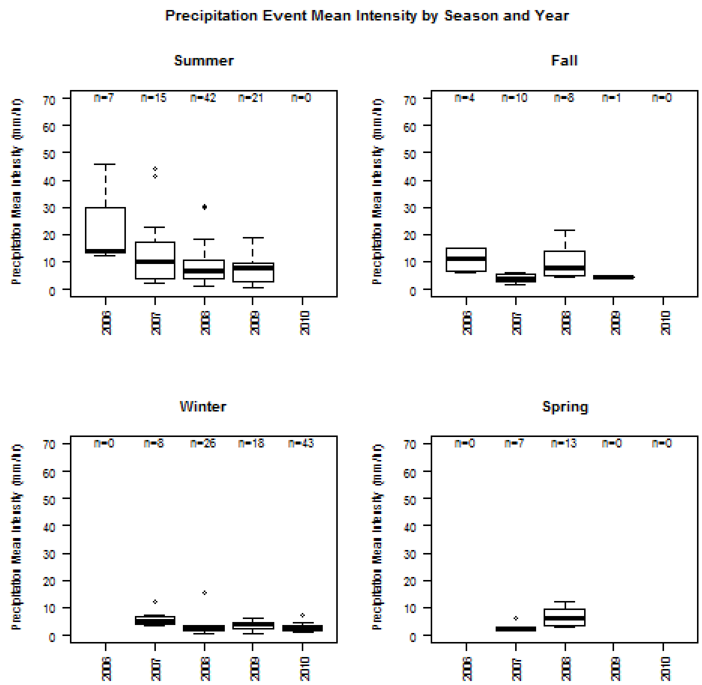


Figure 3.35. Event precipitation mean intensities (mm/hr) by season and by year for the period of record from July 2006-February 2010 when at least 5 stations were operative.

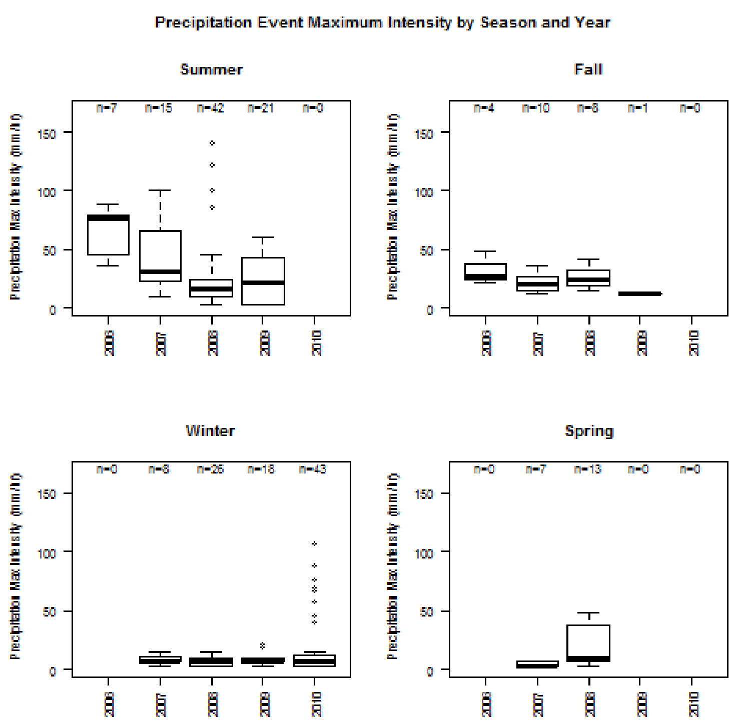


Figure 3.36. Event precipitation maximum intensities (mm/hr) by season and by year for the period of record from July 2006-February 2010 when at least 5 stations were operative.

conducted. Data were instead pooled for each season over the entire period of record and then compared. Statistically significant differences were found between winter versus summer, spring versus summer, and winter versus fall mean and maximum intensities using parametric and non-parametric tests (Figures 3.33-3.34; Table D29).

So while summer and winter per event precipitation was similar, intensities were higher in summer; and fall per event precipitation is higher than summer and winter, but fall intensities are generally lower than in summer and higher than in winter. Based on observation of the medians and variances in each seasonal dataset, most significant differences that were found in intensities when data were pooled over the entire study period would likely be significant if seasons within each year were considered separately, and fall versus summer intensities may also have differed significantly in some years (e.g., 2006 and 2008).

In summary, precipitation totals by year or by season did not provide large enough sample sizes to statistically compare differences, but some general patterns were found. Mean annual precipitation averaged across six stations ranged from 79 mm in 2007, to 125 mm in 2008, and 51 mm in 2009. Mean seasonal precipitation ranged from 41 mm in winter, to 39 mm in summer, 20 mm in fall, and 4 mm in spring. Temporal variation in seasonal precipitation by year was greatest in winter, ranging from 2 mm to 104 mm, followed by fall, ranging from 1 mm to 37 mm, depending on year. Conversely, total summer precipitation was the least variable between years, ranging from 28 mm to 46 mm, but spatial variation was greater in summer than in other seasons and least variable in winter.

Spatial variation in total precipitation was not consistent from year to year or season to season, but for the entire period of record, upper basin stations recorded approximately 40 percent more total precipitation than lower stations, and 24 percent more than the mid-basin

basin stations. Mid-basin stations recorded approximately 16 percent more total precipitation than the lower basin stations. Total summer precipitation reflected the greatest differences, with a roughly 2-fold (107 percent) increase from the lower to the upper basin, and a 1.6-fold (60 percent) increase from the mid- to upper basin, but most of this variation can be attributed to summer 2008. In summer 2007, recorded precipitation was actually higher at one of the lower stations relative to the upper basin, and in summer 2009, higher at one of the mid-basin stations relative to the upper basin. Fall total precipitation for the period of record showed a nearly 1.4-fold (36 percent) increase from the lower to the upper basin, but was also inconsistent from year to year; in 2008, higher fall precipitation was recorded in the lower basin.

Missing data at the lower stations in 2006 and 2007 introduced error that may account for some of the suggested increase in total precipitation from lower to upper basin for the period of record. However, upper stations also recorded more total annual precipitation in 2008 and 2009 relative to the lower basin stations, attributed to a 3-fold increase in summer 2008 (260 percent), and a 1.3-fold increase in summer 2009 (25 percent), which suggests the general increase in total precipitation for the period of record from lower to upper basin resulted from more than missing data.

Per event precipitation totals, and mean and maximum event intensities were also greater in the upper versus lower basin during summer, and differences in rank sums were close to significant ($\alpha = 0.10$) for per event precipitation and significant ($\alpha = 0.10$) for maximum intensities. An opposite trend was found for fall, where per event precipitation and maximum intensities were greater in the lower basin relative to the upper, and differences in rank sums of fall per event precipitation were close to significant ($\alpha = 0.10$). However, temporal variation in fall precipitation between years was greater than between summers, and too few events in fall of some years constrained spatial comparisons.

Correlations in event precipitation were generally higher between stations in closer proximity on different geomorphic surfaces than stations on the same geomorphic surface but further apart. The same was found for mean and maximum intensities, but relative correlations were lower. Statistical differences in rank sums of event precipitation totals, mean and maximum intensities were not found by geomorphic surface.

Significant differences in rank sums of per event precipitation were found between all seasons except winter and summer, and fall per event precipitation was greater than other seasons, with the exception of the single largest event recorded in winter 2010. However, per event precipitation was highly variable from year to year in all seasons, and for summer especially, does not always correlate with variation in total seasonal precipitation. For example, summer 2008 was the wettest of all summers during the period of record, yet median event precipitation was lower than in any other summer. A larger number of smaller events in some summers, offset by fewer events of greater magnitude in others, results in less temporal variation in summer precipitation relative to other seasons.

While non-parametric analysis of precipitation data for this study offered a more valid approach than using parametric tests based on non-normality of data, some power was lost in comparing ranked values rather than actual nominal data. Small sample sizes were restrictive in both parametric and non-parametric analyses, precluding some comparisons, and likely required larger differences in means and medians to detect significant differences. Low frequency precipitation combined with missing data added further constraints to the interpretation of results. Considering these limitations, analyses generally suggest the following with respect to the study questions and hypotheses:

Hypothesis 1:

H_o: The amount and rate of precipitation do not vary significantly by geomorphic surface.

H_a: The amount and rate of precipitation vary significantly by geomorphic surface.

Precipitation does not vary significantly by geomorphic surface. Results do not suggest any consistent differences in total precipitation, per event precipitation, or precipitation intensity by geomorphic surface for the period of record. Missing data notwithstanding, stations paired in the same basin location on different geomorphic surfaces generally recorded similar precipitation. No significant differences were found in rank sums of per event precipitation, or mean or maximum intensities across different geomorphic surfaces. Rejection of the alternative hypothesis is suggested here.

Hypothesis 2:

Ho: The amount and rate of precipitation do not vary significantly by basin location.

Ha: The amount and rate of precipitation vary significantly by basin location.

Precipitation does vary significantly by basin location. Results suggest total summer precipitation for the period of record was greater in the upper basin relative to the lower and mid-basin, more so between the upper and lower sites, albeit differences were not consistent from year to year. Greatest differences were found in summer 2008. Significant differences were found in per event precipitation by location during summer between lower and upper basin using parametric tests ($\alpha = 0.05$), and rank sums were close to significant using non-parametrics

(α =0.10), suggesting per event precipitation may be greater in the upper basin. Significant differences in mean precipitation intensities were not found by location, but significant differences (α =0.05) in rank sums of summer maximum precipitation intensities were found by location, reflecting greater intensities in the upper relative to the lower basin. However, missing data at the lower basin sites in 2006 and 2007 introduce error, and 2008 was the only summer without missing data that reflected greater maximum intensities at both of the upper basin sites relative to the lower and mid-basin. Significant differences in rank sums of maximum intensity were not found by location in other seasons. While some of the findings suggest summer precipitation for the period of record may be greater and/or of a higher intensity in the upper basin relative to the lower basin, limited data due to infrequent rainfall, interannual variation, and missing data add considerable uncertainty to these analyses. Partial acceptance of the alternative hypothesis is suggested.

Hypothesis 3:

H_o: *The amount and rate of precipitation do not vary significantly by season or by year.*

H_a: *The amount and rate of precipitation vary significantly by season or year.*

Precipitation varies significantly by year and by season. Significance tests could not be run on annual or seasonal precipitation totals for the period of record due to small sample size, but variation was high, ranging from 79 mm in 2007, 125 mm in 2008, to 51 mm in 2009. Total seasonal precipitation ranged from an average of 41 mm in winter, 39 mm in summer, 20 mm in fall, to 1 mm in spring. Temporal variation in total seasonal precipitation was highest in winter, ranged from 2 mm to 104 mm depending on year, 1 mm to 37 mm in fall, 1 mm to 10 mm in spring, and lowest in summer, ranging from 28 mm to 46mm.

Significant differences (ρ = 0.10) in rank sums of per event precipitation for years with four seasons of records were found between 2007 and 2009, reflecting higher precipitation received during fall in 2007 relative to 2009. Significant differences were also found between all seasons except winter and summer (ρ = 0.05), and fall per event precipitation was greater than other seasons, with the exception of the single largest event recorded in winter 2010. Per event precipitation was highly variable from year to year for each season also, and particularly in summer, does not always correlate with variation in total seasonal precipitation.

Significant differences were not found in rank sums of mean precipitation intensities between years with four seasons of data records. By season, mean intensities were highest in summer, averaging 10 mm/hr (8 mm/hr median), followed by fall (7 mm/hr mean; 5 mm/hr median), and winter and spring intensities were lowest (3 mm/hr). However, intensities varied from year to year for each season, and significant differences in rank sums were found between most winters, between summer 2006 and other summers, fall 2007 and other falls, and between spring 2008 and other springs (α = 0.05). Between different seasons, differences in mean intensity were significant between all seasons except fall and summer (α = 0.05).

Significant differences were found in rank sums of maximum intensity between years with four seasons of data records in 2007 relative to 2008 and 2009, reflecting a greater fraction of higher intensity rainfall received in fall and summer 2007 (α = 0.05). By season, maximum summer intensities (averaged across stations) ranged from 53-75 mm/hr, depending on year, with a greatest maximum intensity of 140 mm/hr recorded in the upper basin in summer 2008. Winter maxima ranged from a six station average of 8-78 mm/hr depending on year, with an absolute maximum of 107 mm/hr for a brief period during winter 2010. Fall maxima ranged from 12-31 mm/hr depending on year, with a greatest maximum intensity of 49 mm/hr in 2006. Spring maximum intensities ranged from 5-35 mm/hr, albeit the larger intensity refers to only a single event in 2008.

Significant differences in rank sums of maximum intensities were found between all summers except 2008 and 2009, reflecting the greater intensity events received in 2006 and 2007, and between spring 2007 and 2008, reflecting the single event in 2008 of high intensity ($\alpha = 0.05$). However, significant differences in rank sums of maximum intensity were not found for winters or falls in different years. Between different seasons, differences in maximum intensity were significant, with the exception of fall and summer, and spring and winter. Therefore, acceptance of the alternative hypothesis is warranted. Data are generally significantly variable in time between years and seasons.

These findings suggest the precipitation characteristics in Yuma Wash generally reflect regional precipitation patterns typical of the Southwest US. Most precipitation was received during winter and summer seasons, with occasional events occurring in fall, and very little precipitation received in spring. Median per event precipitation was generally highest in fall relative to other seasons, and precipitation intensity was generally highest in summer. Winter precipitation was less spatially variable and generally lower in intensity relative to other seasons, albeit the largest single event, with a brief period of one of the largest maximum intensity rates recorded during the study period, occurred in winter 2010. Maximum intensities were also higher for brief periods during other winter events recorded in Yuma Wash during the study period. With the exception of 2010, interannual variation in per event precipitation was generally low in winter relative to summer and fall, but variation in the total amount of winter precipitation received was high from year to year. Summer precipitation was more spatially variable and higher in intensity than other seasons, and total and per event precipitation was higher from lower to upper basin in summer, which may suggest a relatively greater orographic influence in the upper basin. Temporal variation in per event precipitation was high in summer, but variability in the total amount of summer precipitation received from year to year was low relative to other seasons. Fall precipitation occurred less frequently than summer and winter, but per event precipitation was higher in fall than other seasons, and was generally higher in spatial variation and intensity than winter precipitation, and lower in spatial variation and intensity than summer precipitation. How soil moisture varied in the Yuma Wash watershed was examined next.

3.2 Soil moisture characteristics in Yuma Wash

3.2.1 Temperature correction of soil moisture data

Prior to any statistical analysis of soil moisture, 15-minute soil moisture and temperature data recorded for the entire period of study were examined for probe performance, and temperature influences on soil moisture readings were examined. Each probe is identified by the station where it is deployed, the cover type it is deployed beneath, and its depth within the soil profile. Details for each probe are provided in Tables D30-D31. Five soil moisture and three soil temperature probes illustrating poor performance were identified and eliminated from the study (Figures 3.37-3.38), and are not represented in the data hereafter. Compromised performance in these probes was likely due to either poor soil to probe contact, excessively high soil electrical conductivity around the probe (in the case of the soil moisture sensors), or possibly rodent damage to buried electrical cable. Diurnal and seasonal periodicity is very apparent in the soil temperature data (Figures D16-D22), with wave periods reflective of the daily and annual solar cycles, respectively. Temperature oscillations are greatest at the near surface at 2.5 cm, with

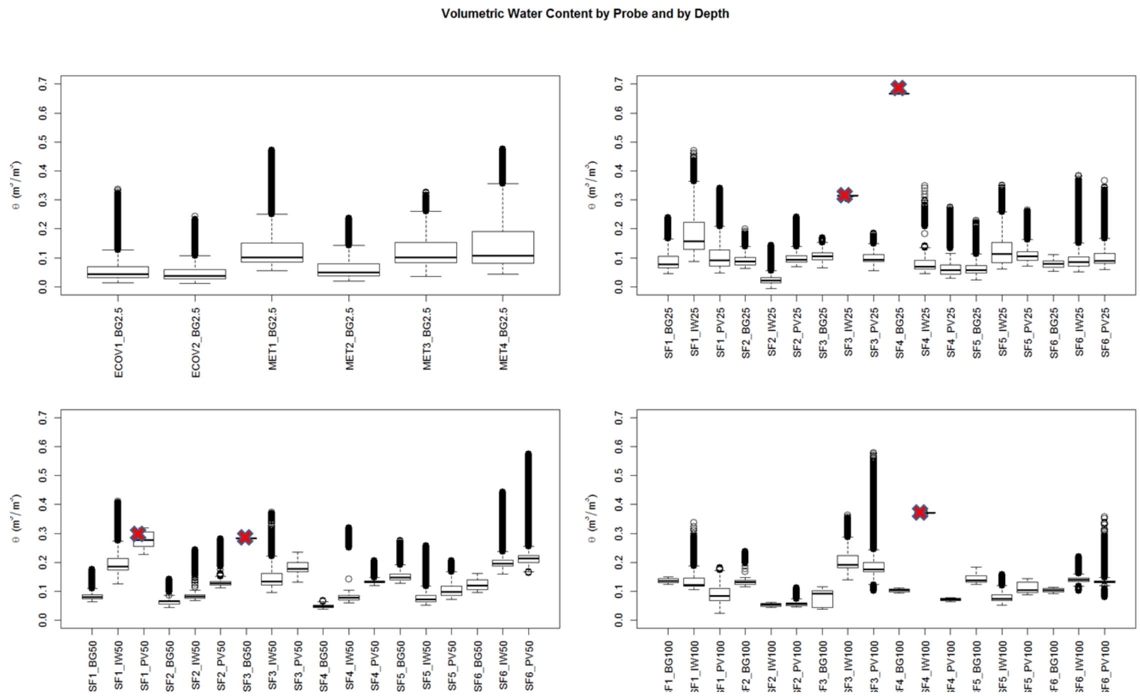


Figure 3.37. Fifteen minute volumetric soil moisture (uncorrected for temperature) estimated for each probe. Probes with poor performance are indicated with a RED X, and were eliminated from the study. PV=Palo verde *(P. microphylla)*, IW-Ironwood *(O. tesota),* BG-bare ground. Probe depths are 25,50, and 100cm.

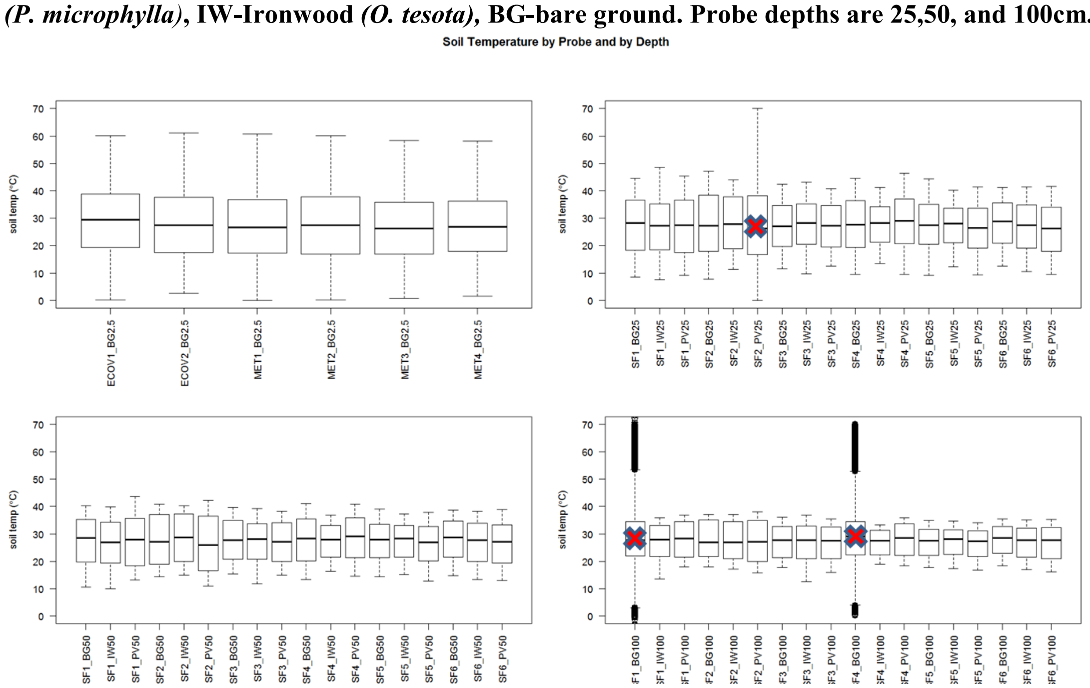


Figure 3.38. Fifteen minute soil temperature recorded at each probe. Probes with poor performance are indicated with a RED X, and were eliminated from the study. PV=Palo verde *(P. microphylla)*, IW-Ironwood *(O. tesota),* BG-bare ground. Probe depths are 25, 50, and 100cm.

amplitude diminishing with depth in the profile. Diurnal variation in temperature is nearly extinguished at 100 cm, but the annual cycle remains very apparent.

The cycling of soil temperature affects the period output reading of the soil moisture probe as discussed in Section 2.2.2. To determine the extent to which soil temperature influenced estimates of soil moisture in Yuma Wash, soil moisture data were temperature corrected to 20^{o}C, the approximate temperature at which laboratory calibrations were developed for each probe (Appendix B). Soil moisture estimates for corrected and uncorrected data for all probes are illustrated in Figures D16-D22. In addition to the five soil moisture probes initially omitted from the study, three additional probes were omitted for the comparative analysis of temperature corrected versus uncorrected soil moisture data, because the three malfunctioning temperature probes could not be used to temperature correct their paired soil moisture probes. A few additional soil temperature probes periodically malfunctioned as well, so those data points were removed for both temperature corrected and uncorrected soil moisture data for the comparison study. Differences between temperature corrected and uncorrected soil moisture were then calculated with all bad data removed, and are provided for each probe in Figure 3.39 and Tables D32-D35. Table D36 and Figures 3.40-3.43 illustrate those differences by geomorphic surface, season, location and cover. Figures 3.44-3.45 show the data graphed as a time series for probes that reflected the largest differences.

Greatest differences occur primarily in select probes beneath terraces (Figure 3.40), predominantly during summer moisture events (Figure 3.41), and at peak event times when soils are wettest (Figures 3.43-3.45). Since temperatures are most extreme in summer and electrical conductivity in soils increases with increasing temperature and increasing soil moisture, this suggests there may be a relatively high imaginary permittivity component in soil moisture

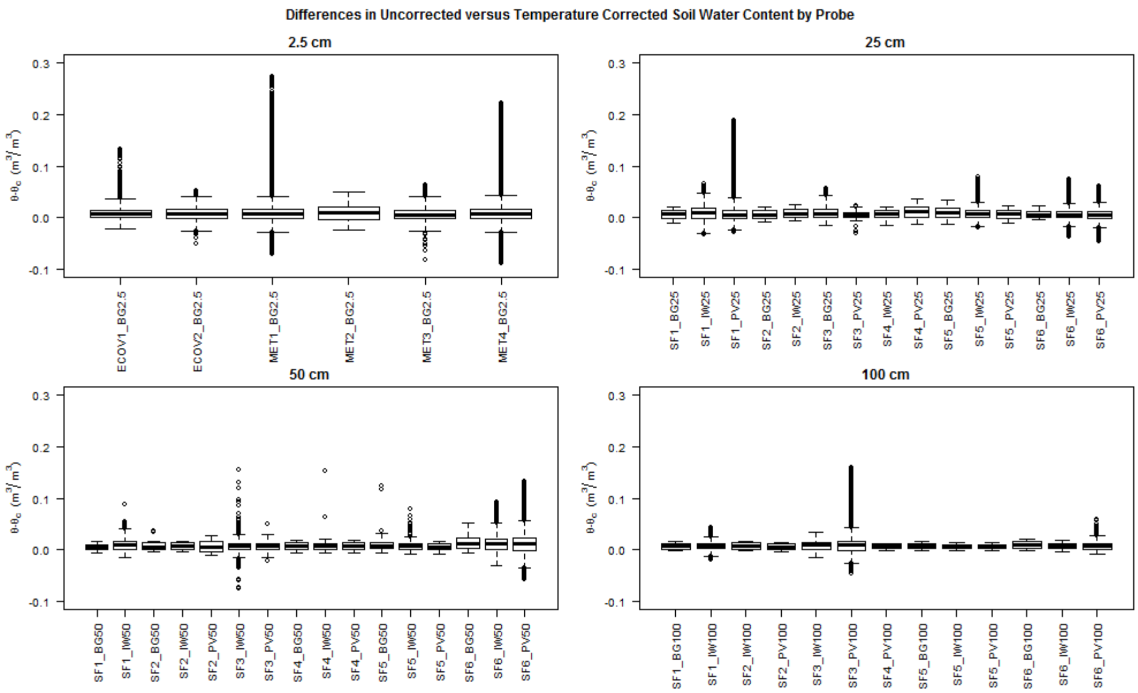


Figure 3.39. Differences in temperature corrected and uncorrected 15-minute soil moisture data by probe for the entire period of record.

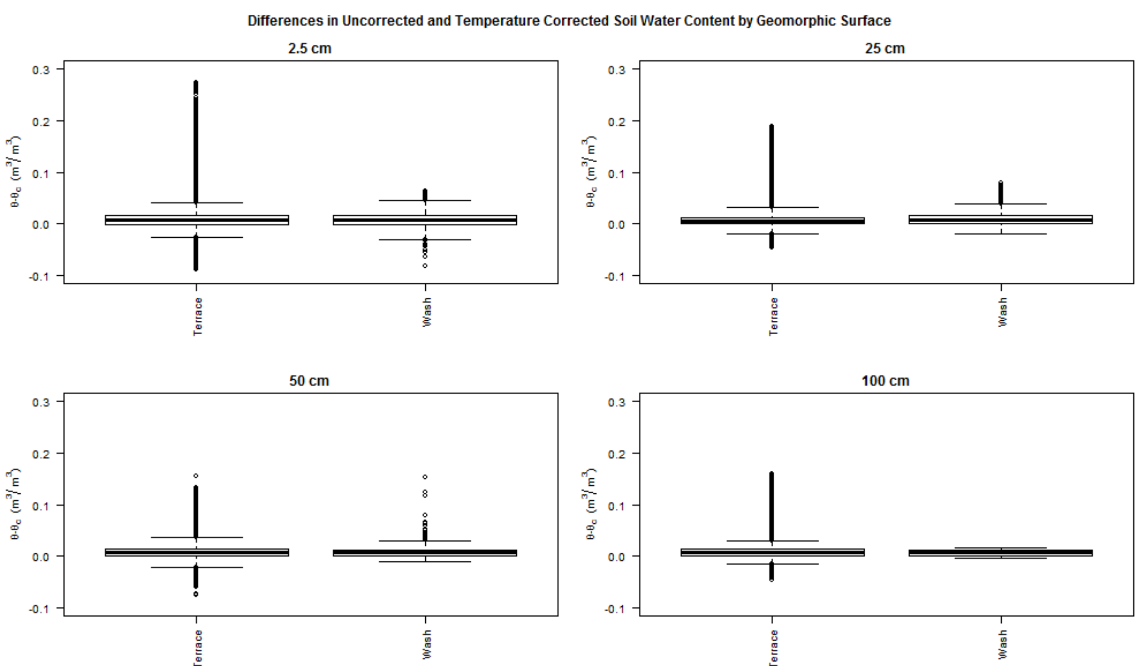


Figure 3.40. Differences in temperature corrected and uncorrected 15-minute soil moisture data pooled by geomorphic surface.

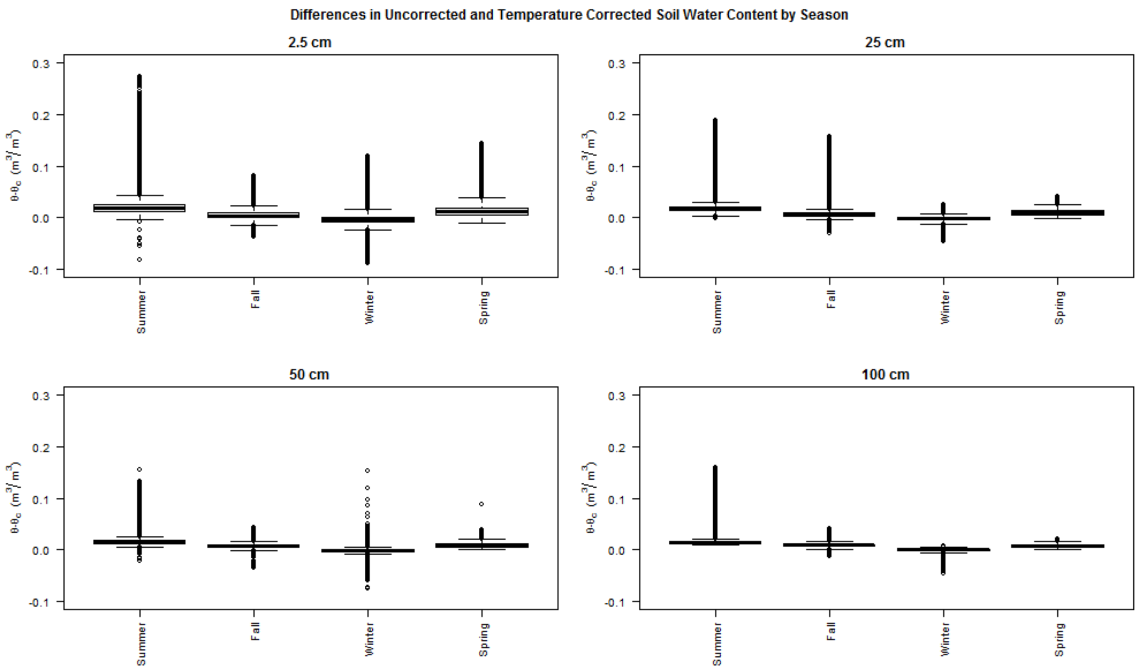


Figure 3.41. Differences in temperature corrected and uncorrected 15-minute soil moisture data pooled by season.

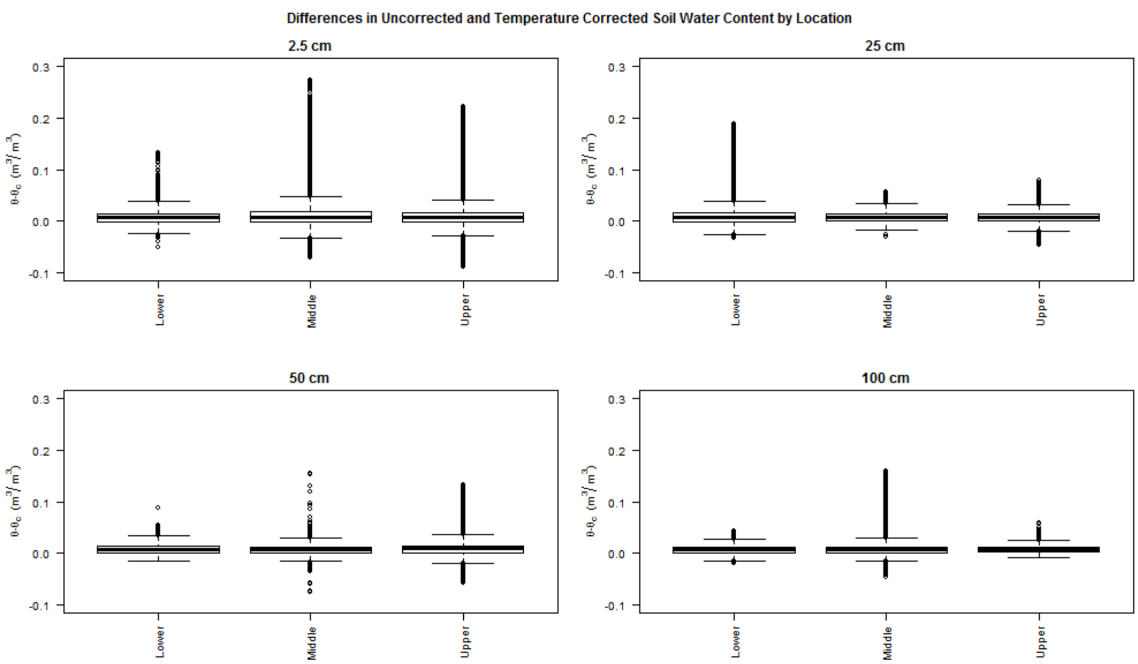


Figure 3.42. Differences in temperature corrected and uncorrected 15-minute soil moisture data by location.

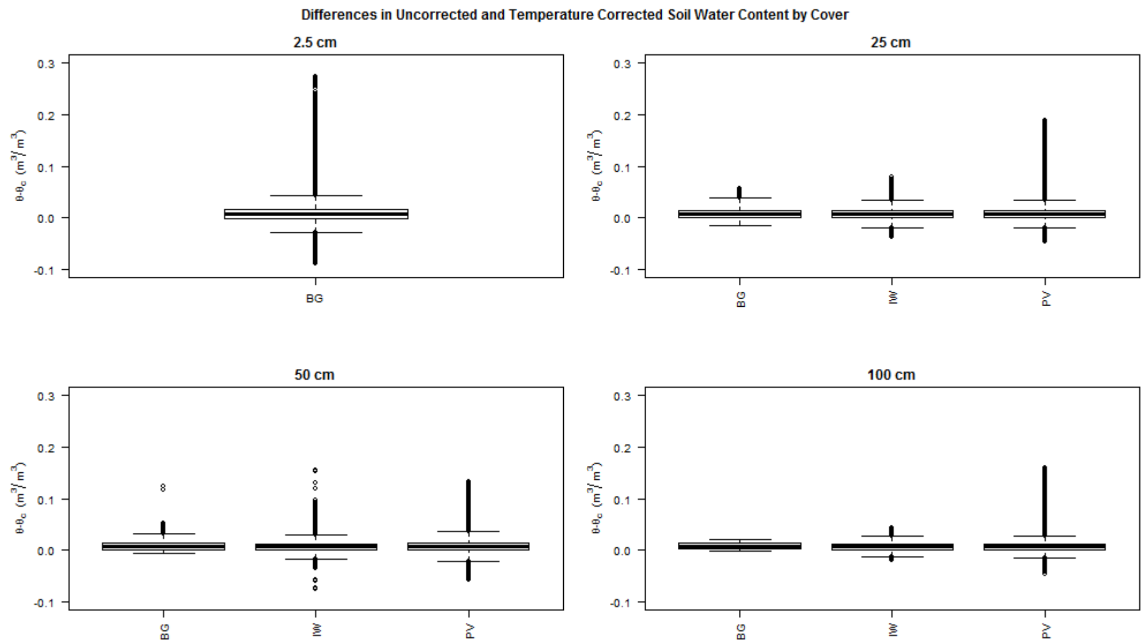


Figure 3.43. Differences in temperature corrected and uncorrected 15-minute soil moisture data by cover.

readings at these probes. Temperature correcting the data smoothed the diurnal and seasonal periodicity in the uncorrected values, and in general, resulted in reduced summer soil moisture estimates, but only by mean and median differences of less than 2 percent at 2.5-50 cm, and less than 1 percent at 100 cm. Differences in median winter soil moisture estimates were +/-0.5 percent or less at 2.5-50 cm, with no change at 100 cm. Mean and median differences in temperature corrected versus uncorrected data were consistently less than 1 percent for all depths when probes were pooled by geomorphic surface, location, or cover. Values for the interquartile range (IQR) were +/- 2 percent for probes at 2.5cm-50cm, +6/-3 percent within 1.5 of the IQR at 2.5 cm +3/-2 at 25-50 cm, with slightly higher values beneath vegetated cover than bare ground (Figure 57). For probes at 100cm, differences are <=2 percent for the IQR, and +2/-1 within 1.5 of the IRQ.

While differences are small for the majority of data, substantial differences in temperature corrected versus uncorrected soil moisture estimates are apparent for a few probes during select wetting events, particularly near peak times and early recession of soil moisture events (Figures 3.44-3.45; Tables D32-D35). Maximum peak differences were found at the three terrace probes beneath bare ground at the near surface (2.5 cm), which ranged from 13-27 percent, and at three terrace probes at 25-50 cm , which ranged from 16 to 19 percent, all occurring during peak times of summer moisture events beneath vegetated cover, where uncorrected soil moisture estimates were higher than corrected values. While using temperature corrected soil moisture data provided a means of potentially reducing these errors associated with soil temperature, there were significant gaps in soil temperature data or periods of malfunctioning in the temperature probes that were not always concurrent with data gaps or periods of malfunctioning in soil moisture probes. Eliminating these data points, coupled with the elimination of several soil moisture and soil temperature probes due to malfunctioning, would have resulted in a significant loss of data for conducting spatial and temporal analyses of soil moisture. And, because the soil temperatures in Yuma Wash are on the upper end of the range of temperatures used to develop the temperature correction algorithm recommended by the manufacturer, it was not clear that correcting the data for temperature influence actually improved the accuracy of all volumetric soil moisture estimates. Because permittivity typically decreases as soil temperature increases, which can result in underestimates of soil moisture, it was expected temperature corrected data would reflect higher estimates of soil moisture in summer and lower estimates in winter. Temperature corrected data showed a generally opposite trend, however, and in some cases, resulted in negative values for estimated soil moisture. Winter soil moisture values generally increased, and summer estimates decreased. Analyses were therefore conducted primarily on uncorrected data, with the aforementioned error variance considered for each probe and depth.

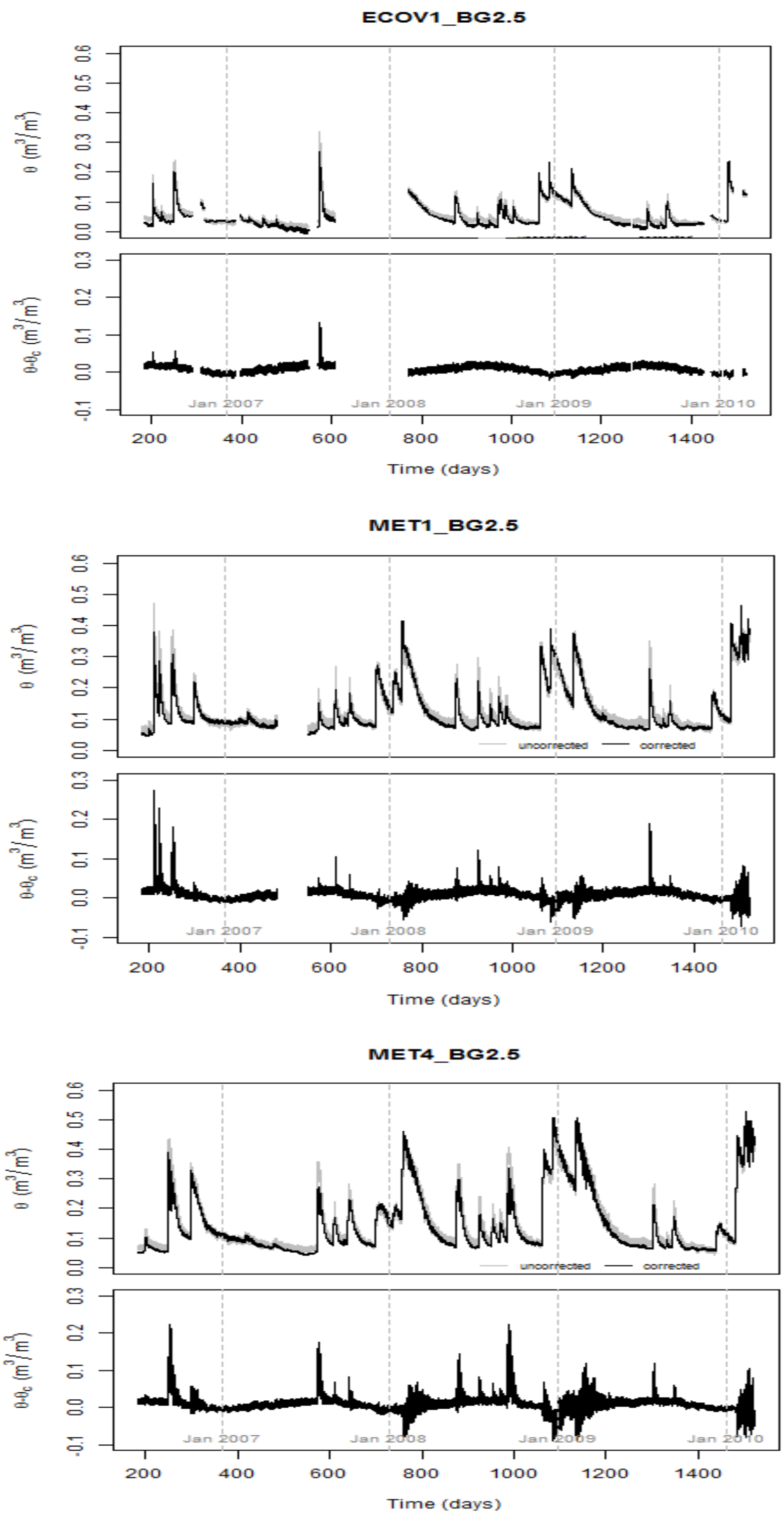


Figure 3.44. Comparison of probes with the greatest differences in 15-minute temperature corrected and uncorrected volumetric soil moisture. Top plots are volumetric soil moisture values recorded from July 2006-February 2010 (Julian Day 182- 1521), and bottom plots illustrate differences in uncorrected-corrected soil moisture.

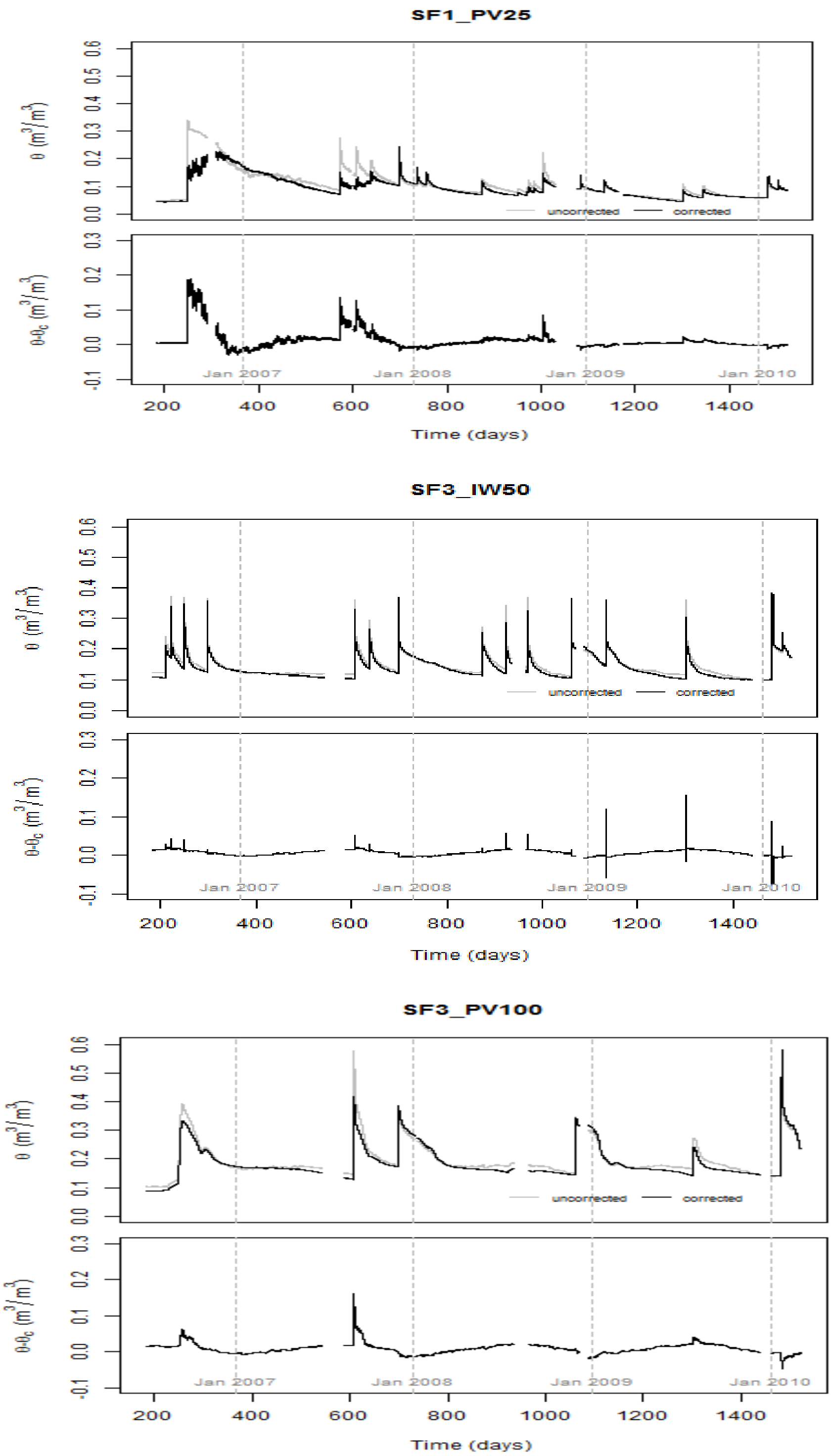


Figure 3.45. Comparison of probes with the greatest differences in 15-minute temperature corrected and uncorrected volumetric soil moisture. Top plots are volumetric soil moisture values recorded from July 2006-February 2010 (Julian Day 182- 1521), and bottom plots illustrate differences in temperature corrected versus uncorrected soil moisture.

3.2.2 *Spatial and temporal analysis of soil moisture*

Mean annual and seasonal volumetric soil moisture (uncorrected for temperature) estimated for each station and depth is summarized in Figures 3.46-3.47 and Tables 3.7-3.8. Values for 2006 and 2010 represent partial year totals based on the duration of the study period (July 2006-February 2010). Higher mean values in 2010 are therefore reflective of only winter months, and 2010 was the wettest winter of the study period. Mean soil moisture pooled by depth and station was generally greater at terrace stations (ECOV1/SF1, MET1/SF3, MET4/SF6) than wash stations (ECOV2/SF2, MET2/SF4, MET4/SF6), and generally increased from lower basin (ECOV2/SF2) to upper basin (MET3/SF5) at all depths for wash stations, and from lower basin (ECOV1/SF1) to upper basin (MET4/SF6) basin at 2.5 cm and 50 cm for terrace stations. When only years with four seasons of records were considered (2007-2009), mean annual soil moisture was generally highest at 50 cm with an average of 13 percent, which varied from 8-18 percent depending on station. At 2.5 cm, mean annual soil moisture averaged 9 percent with a range by station of 4-18 percent, 10 percent with a range of 6-13 percent at 25 cm, and 12 percent with a range of 8-16 percent at 100 cm (Table 3.7). Seasonally, mean soil moisture at 2.5 cm was lowest in spring ranging from 3-10 percent depending on station, and greatest in winter ranging from 7-22 percent. At 25 cm, spatial variation in mean seasonal soil moisture by station ranged from 6-11 percent in spring, to 8-14 percent in winter, at 50 cm from 9-17 percent in spring to 10-20 percent in winter, and at 100 cm, from 8-13 percent in spring to 8-17 percent in winter (Table 3.8).

Temporal variation in mean soil moisture was greater between seasons than years. For years with four seasons of data records (2007-2009), annual differences in mean soil moisture at any station were less than 3 percent at 2.5 cm, and 1 percent or less for any station at 25-100 cm

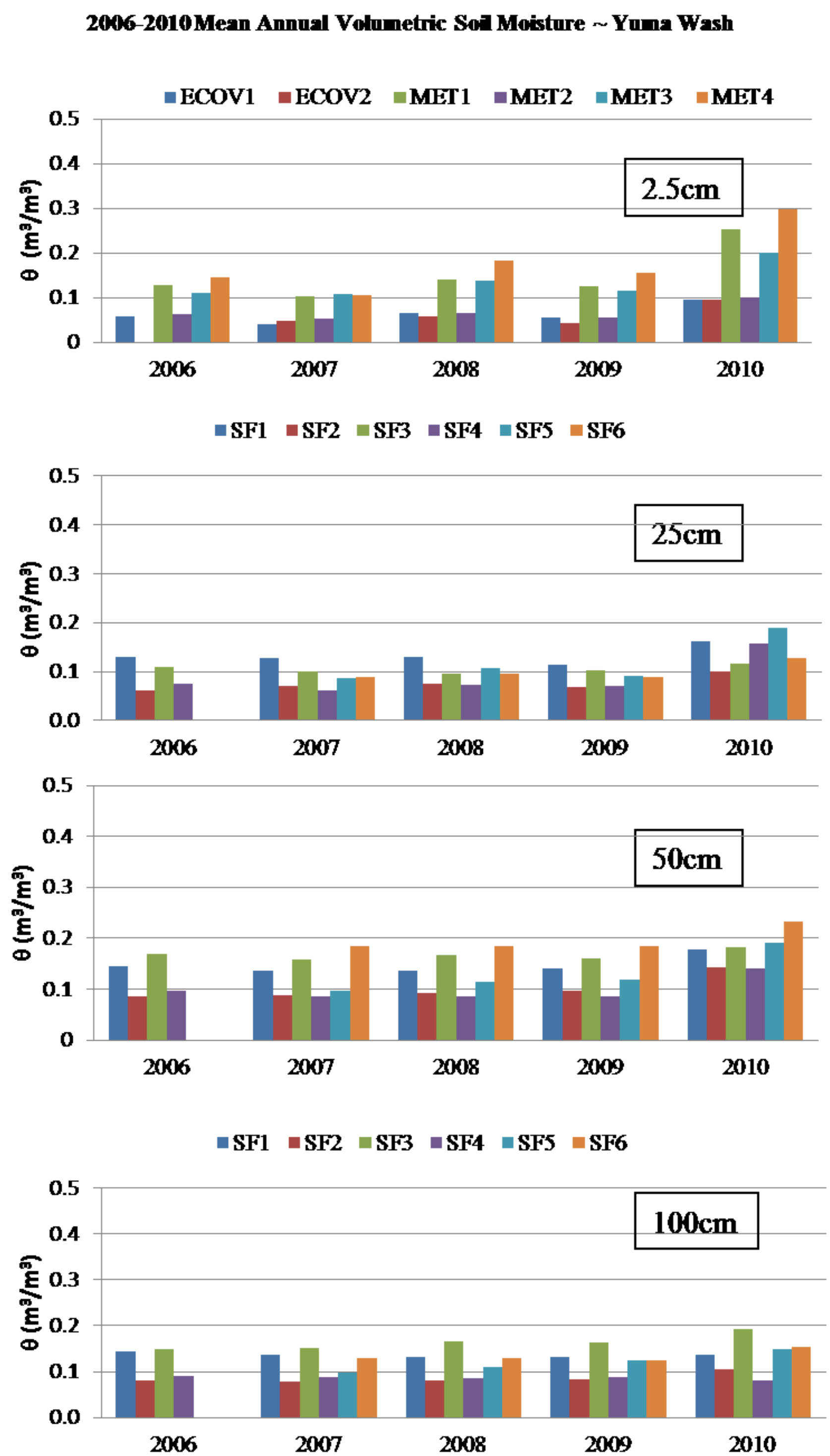


Figure 3.46. Mean annual volumetric soil moisture (m^3/m^3) derived from 15-minute data, uncorrected for temperature at all depths recorded at six stations in Yuma Wash from July 2006-February 2010. 2006 and 2010 are therefore partial year estimates.

Table 3.7. Mean annual volumetric soil moisture by station and by depth derived from fifteen minute data for the period of record July 2006-February 2010. *partial year totals for 2006 and 2010.

2.5cm		**All Stns**	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
	2006*	0.10	0.06	N/A	0.13	0.06	0.11	0.14
	2007	0.07	0.04	0.05	0.10	0.05	0.11	0.11
	2008	0.11	0.07	0.06	0.14	0.06	0.14	0.18
	2009	0.09	0.06	0.04	0.13	0.06	0.12	0.16
	2010*	0.17	0.09	0.09	0.25	0.10	0.20	0.30
25cm		**All Stns**	**SF1**	**SF2**	**SF3**	**SF4**	**SF5**	**SF6**
	2006*	0.09	0.13	0.06	0.11	0.07	N/A	N/A
	2007	0.09	0.13	0.07	0.10	0.06	0.09	0.09
	2008	0.10	0.13	0.07	0.10	0.07	0.10	0.09
	2009	0.09	0.11	0.07	0.10	0.07	0.09	0.09
	2010*	0.14	0.16	0.10	0.12	0.16	0.19	0.13
50cm		**All Stns**	**SF1**	**SF2**	**SF3**	**SF4**	**SF5**	**SF6**
	2006*	0.12	0.14	0.08	0.17	0.10	N/A	N/A
	2007	0.12	0.14	0.09	0.16	0.08	0.10	0.18
	2008	0.13	0.14	0.09	0.17	0.08	0.11	0.18
	2009	0.13	0.14	0.10	0.16	0.08	0.12	0.18
	2010*	0.18	0.18	0.14	0.18	0.14	0.19	0.23
100cm		**All Stns**	**SF1**	**SF2**	**SF3**	**SF4**	**SF5**	**SF6**
	2006*	0.12	0.14	0.08	0.15	0.09	N/A	N/A
	2007	0.11	0.14	0.08	0.15	0.09	0.10	0.13
	2008	0.12	0.13	0.08	0.16	0.09	0.11	0.13
	2009	0.12	0.13	0.08	0.16	0.09	0.12	0.13
	2010*	0.13	0.14	0.10	0.19	0.08	0.15	0.15

*mean annual values are based on partial year totals for 2006 and 2010 and therefore should not be compared against 2007-2009 means.

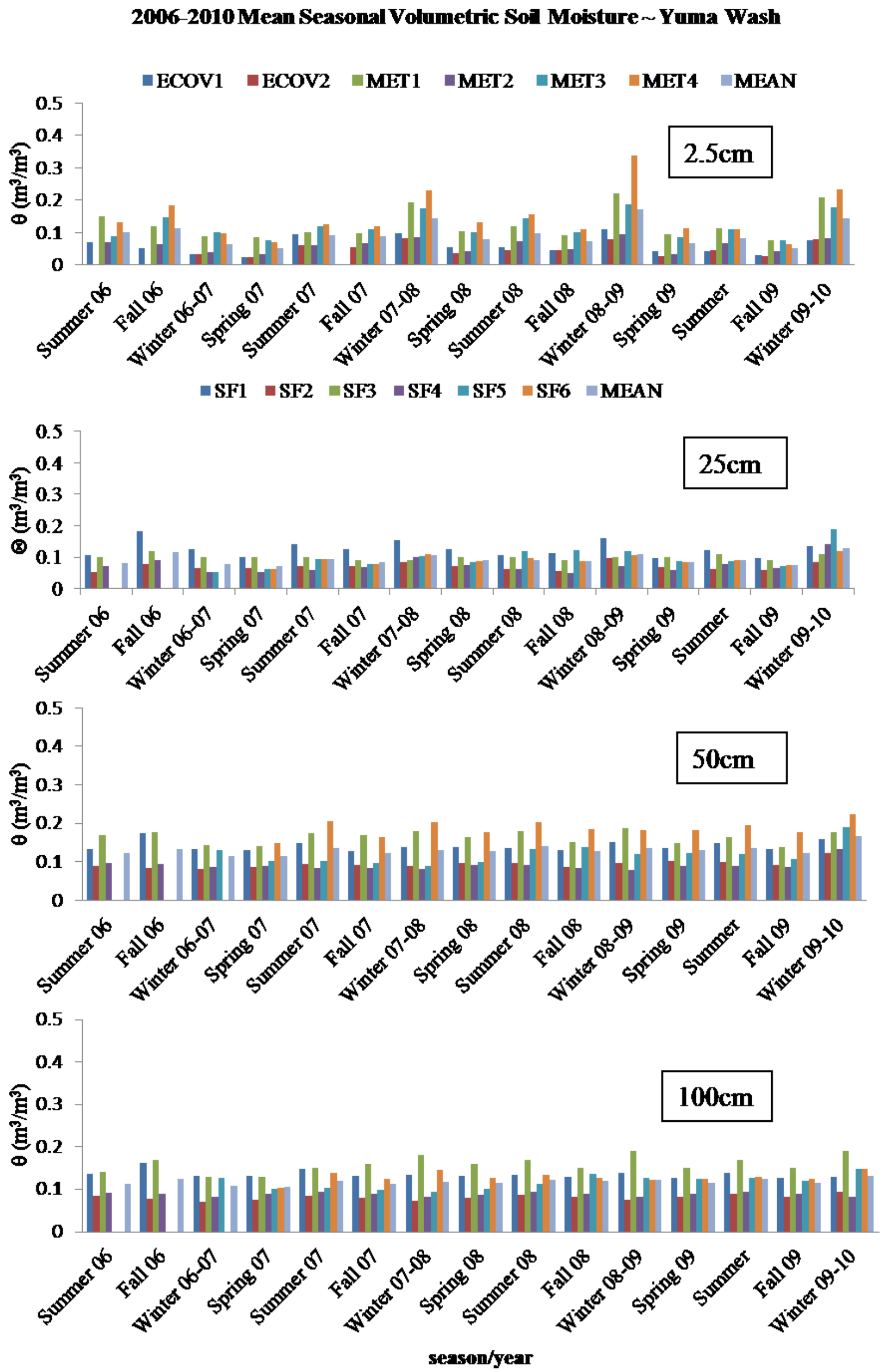


Figure 3.47. Mean seasonal volumetric soil moisture (m^3/m^3) derived from fifteen minute data, uncorrected for temperature at all depths recorded at six stations in Yuma Wash from July 2006-February 2010. 2006 and 2010 are therefore partial year estimates

Table 3.8. Mean seasonal volumetric soil moisture by station and by depth derived from 15-minute data for the period of record July 2006-February 2010.

2.5cm		**All Stns**	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
	summer	0.09	0.06	0.05	0.12	0.07	0.11	0.13
	fall	0.08	0.04	0.04	0.09	0.05	0.11	0.12
	winter	0.10	0.08	0.07	0.18	0.07	0.16	0.22
	spring	0.06	0.04	0.03	0.09	0.03	0.09	0.10
25cm		**All Stns**	**SF1**	**SF2**	**SF3**	**SF4**	**SF5**	**SF6**
	summer	0.09	0.12	0.06	0.10	0.07	0.10	0.09
	fall	0.08	0.13	0.07	0.07	0.07	0.09	0.08
	winter	0.11	0.14	0.08	0.10	0.09	0.11	0.11
	spring	0.08	0.11	0.07	0.09	0.06	0.08	0.08
50cm		**All Stns**	**SF1**	**SF2**	**SF3**	**SF4**	**SF5**	**SF6**
	summer	0.14	0.14	0.09	0.17	0.09	0.12	0.20
	fall	0.13	0.14	0.09	0.16	0.08	0.11	0.17
	winter	0.14	0.14	0.10	0.17	0.09	0.13	0.20
	spring	0.12	0.13	0.09	0.15	0.09	0.11	0.17
100cm		**All Stns**	**SF1**	**SF2**	**SF3**	**SF4**	**SF5**	**SF6**
	summer	0.12	0.14	0.09	0.16	0.09	0.13	0.13
	fall	0.12	0.14	0.08	0.16	0.09	0.12	0.13
	winter	0.12	0.13	0.08	0.17	0.08	0.12	0.14
	spring	0.11	0.13	0.08	0.15	0.09	0.11	0.12

(Table 3.7). Seasonal variation ranged from 2 to 12 percent at 2.5 cm for any terrace station, and from 1 to 7 percent or less for any wash station. At 25 cm, differences in seasonal means at any station ranged from 1-3 percent, from 1-3 percent at 50 cm, and 1-2 percent at 100 cm, with winter soil moisture means generally greater than other seasons (Table 3.8).

Of the 70 precipitation events recorded in the Yuma Wash watershed during the period of study, an average of 58 percent resulted in a detectable soil moisture response at 2.5 cm, compared to 18 percent at 25 cm, 12 percent at 50 cm, and 9 percent at 100 cm (Figure 3.48; Tables D37-D39). Of the soil moisture events recorded at 2.5 cm, the greatest number occurred during summer months (average of 46 percent), with winter events contributing the second

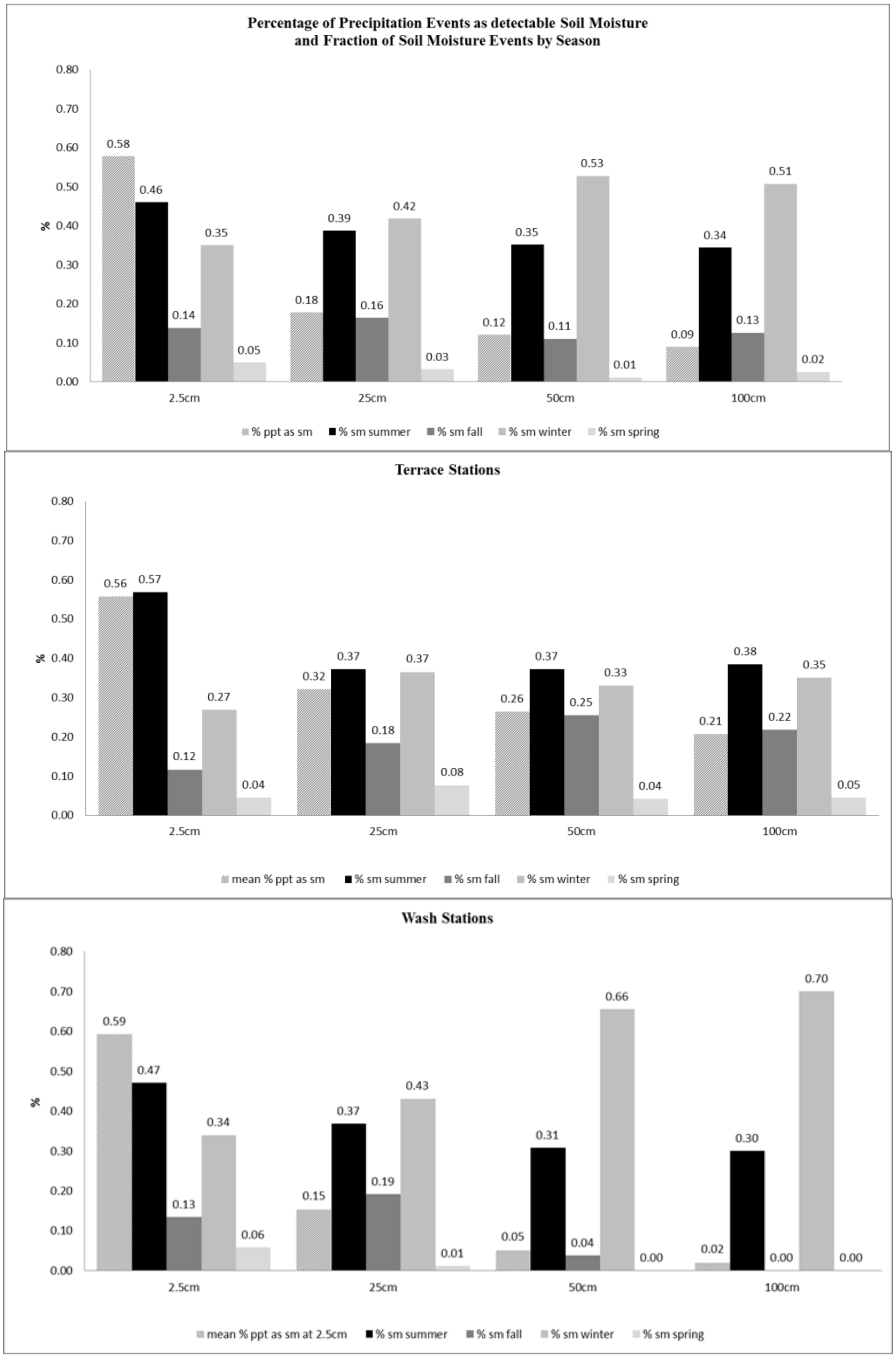


Figure 3.48. Percentage of the 70 precipitation events that resulted in a detectable soil moisture event (column one for each depth) averaged across stations by depth, and the relative percent of those soil moisture events occurring in each season (columns two through five for each depth). Six station averages (top), three station terrace averages (middle), and three station wash averages (bottom). ECOV1 terrace station omitted for terrace averaging due to several missing winter events.

largest fraction (average of 35 percent). At 25-100 cm, the distribution of soil moisture events is predominantly between summer and winter, with what appears to be a higher average percentage of winter events at 100 cm on terraces and 50-100 cm on washes. However, percentages at these depths are based on a very small number of events that occurred, and include no more than a total of 5 events that were recorded at any 50 cm wash probe, and no more than 2 events that were recorded at any 100 cm wash probe for the entire period of record. The single largest event recorded during the study period occurred in January of 2010 (70 mm), resulting in soil moisture responses to at least 100 cm at both wash and terrace stations, which was enough to change the relative fraction of events occurring at 50-100 cm on washes, and 100 cm on terraces from roughly evenly distributed between summer and winter, to predominantly winter.

A larger percentage of precipitation resulted in a soil moisture response on terraces at 25-100 cm relative to washes. Averaged across all locations, approximately 32 percent of precipitation events recorded resulted in a detected soil moisture response at 25 cm on terraces, versus an average of 15 percent on washes. At 50 cm, 26 percent of precipitation events recorded resulted in soil moisture events on terraces, versus only 5 percent on washes. At 100 cm, 21 percent of precipitation events recorded resulted in soil moisture events on terraces, versus only 2 percent on washes. Because few to no events were recorded beneath bare ground on terraces, percentages for this surface were based on events recorded only beneath vegetated cover.

Fifteen minute precipitation and volumetric soil moisture (uncorrected for temperature) recorded at each probe and depth are illustrated for each station by probe and depth as a time series in Figures 3.49-3.54. The number of soil moisture events recorded at each probe for the period of record and by season is illustrated along with the number of precipitation events that

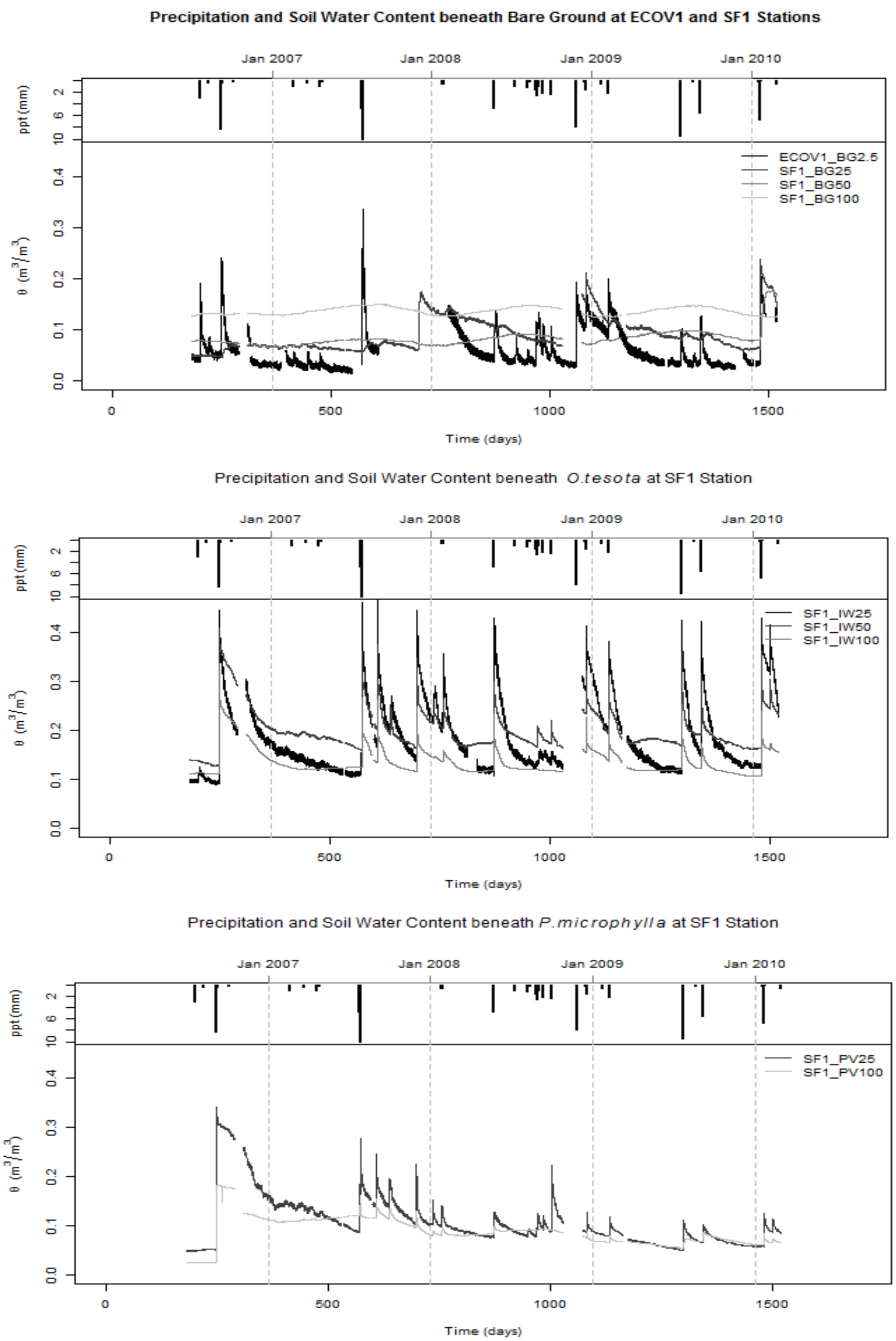


Figure 3.49. Precipitation (mm) recorded at 15-minute intervals at ECOV1 (terrace/lower) station, and volumetric soil moisture (m^3/m^3) recorded at 15-minute intervals at SF1 (terrace/lower) station at each probe and depth beneath three cover types in the Yuma Wash watershed. SF refers to station name, BG, IW, and PV refer to probes emplaced beneath bare ground, *O. tesota* (Ironwood), and *P. microphylla* (Palo verde), respectively.

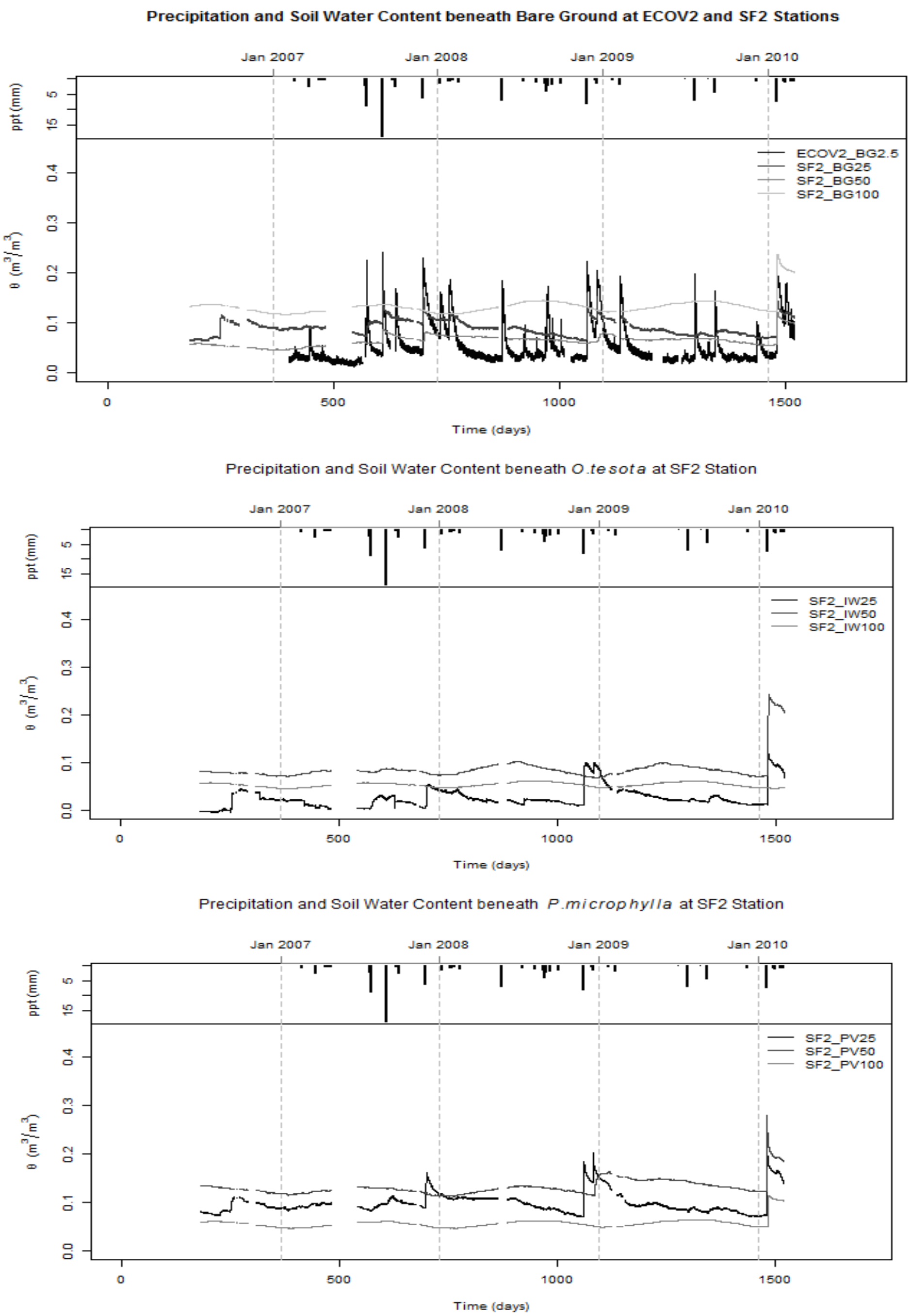


Figure 3.50. Precipitation (mm) recorded at 15-minute intervals at ECOV2 (wash/lower) station, and volumetric soil moisture (m^3/m^3) recorded at 15-minute intervals at SF2 (wash/lower) station at each probe and depth beneath three cover types in the Yuma Wash watershed. SF refers to station name, BG, IW, and PV refer to probes emplaced beneath bare ground, *O. tesota* (Ironwood), and *P. microphylla* (Palo verde), respectively.

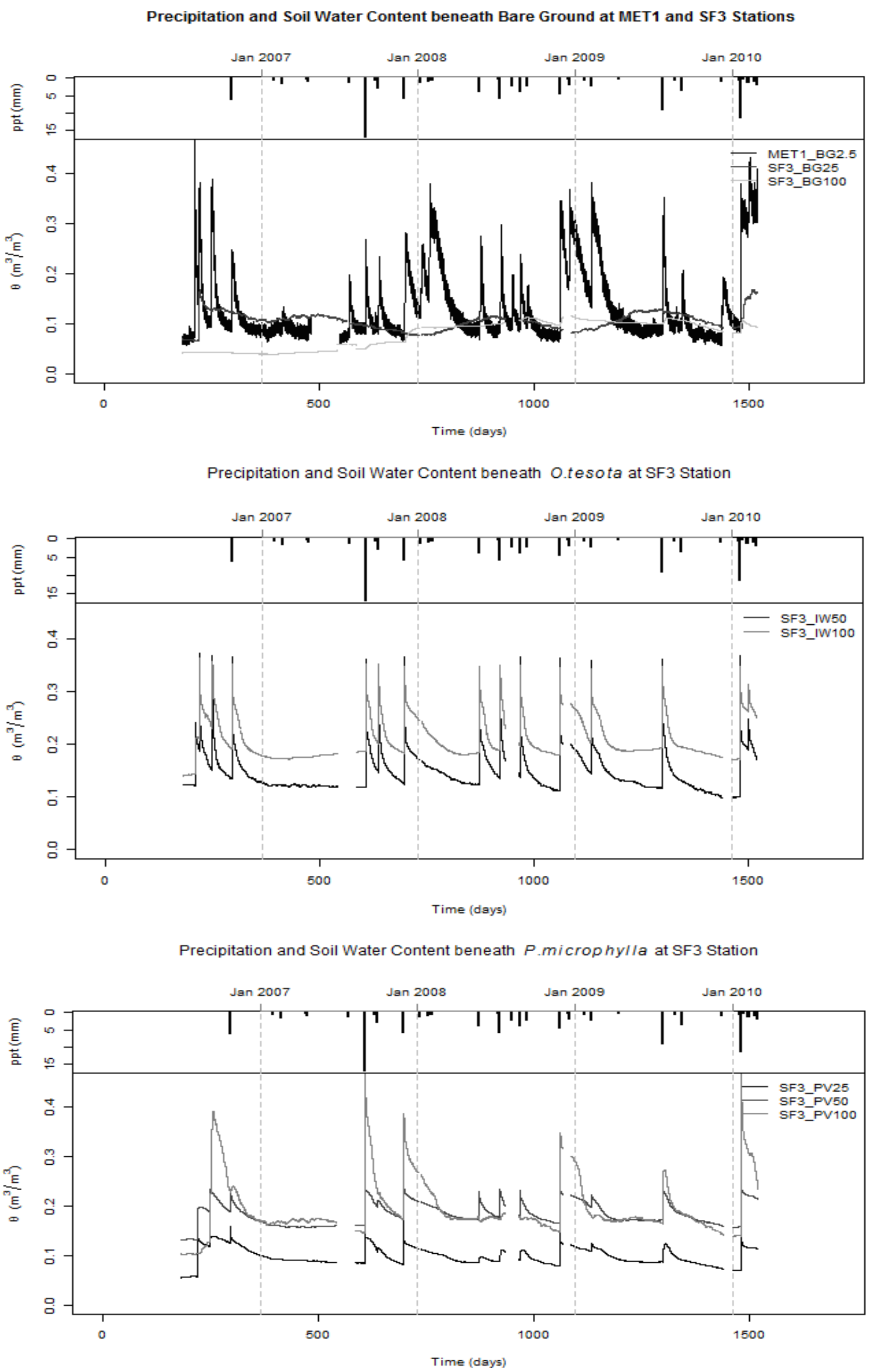


Figure 3.51. Precipitation (mm) recorded at 15-minute intervals at MET1 (terrace/middle) station, and volumetric soil moisture (m^3/m^3) recorded at 15-minute intervals at SF3 (terrace/middle) station at each probe and depth beneath three cover types in the Yuma Wash watershed. SF refers to station name, BG, IW, and PV refer to probes emplaced beneath bare ground, *O. tesota* (Ironwood), and *P. microphylla* (Palo verde), respectively.

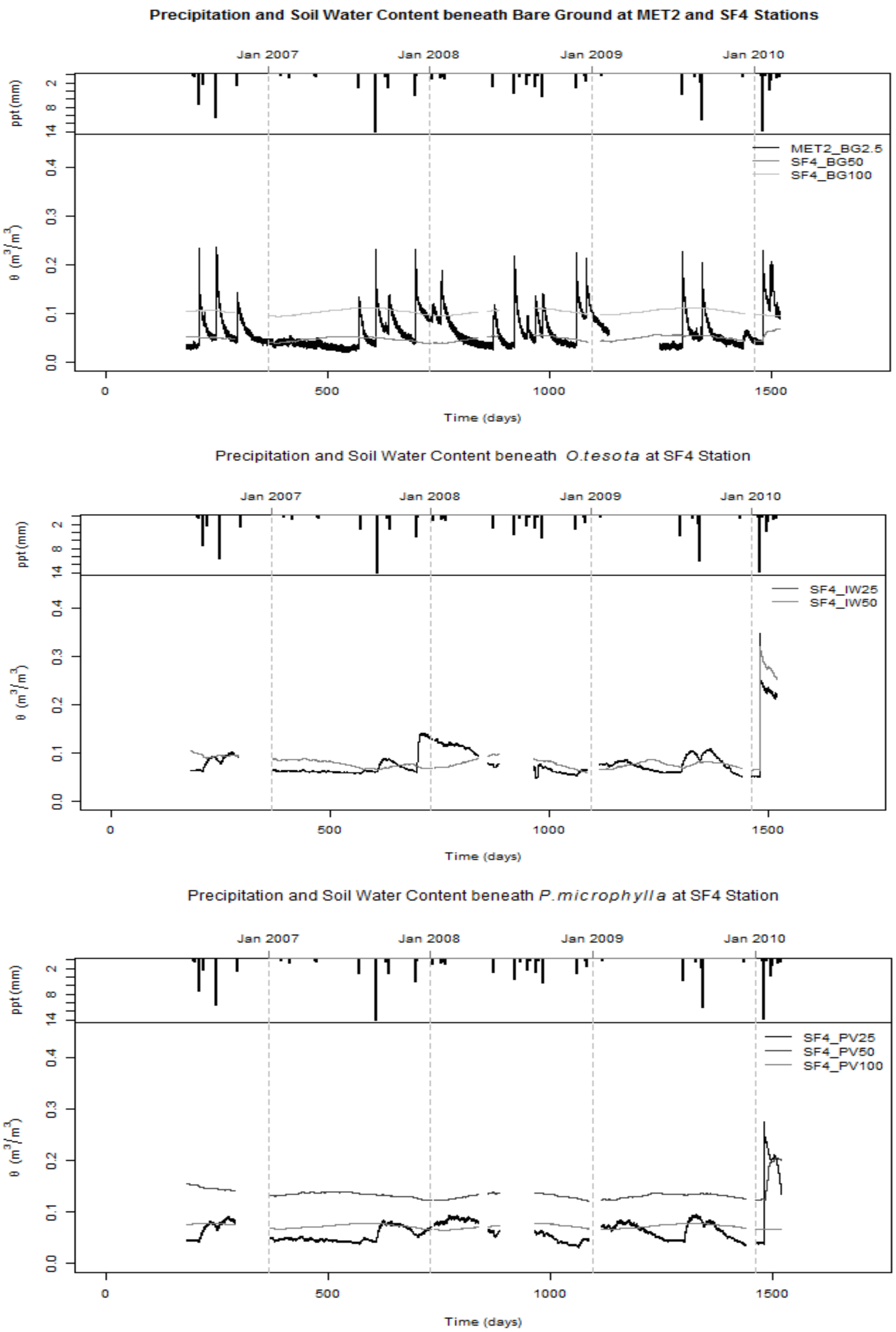


Figure 3.52. Precipitation (mm) recorded at 15-minute intervals at MET2 (wash/middle) station, and volumetric soil moisture (m^3/m^3) recorded at 15-minute intervals at SF4 (wash/middle) station at each probe and depth beneath three cover types in the Yuma Wash watershed. SF refers to station name, BG, IW, and PV refer to probes emplaced beneath bare ground, *O. tesota* (Ironwood), and *P. microphylla* (Palo verde), respectively.

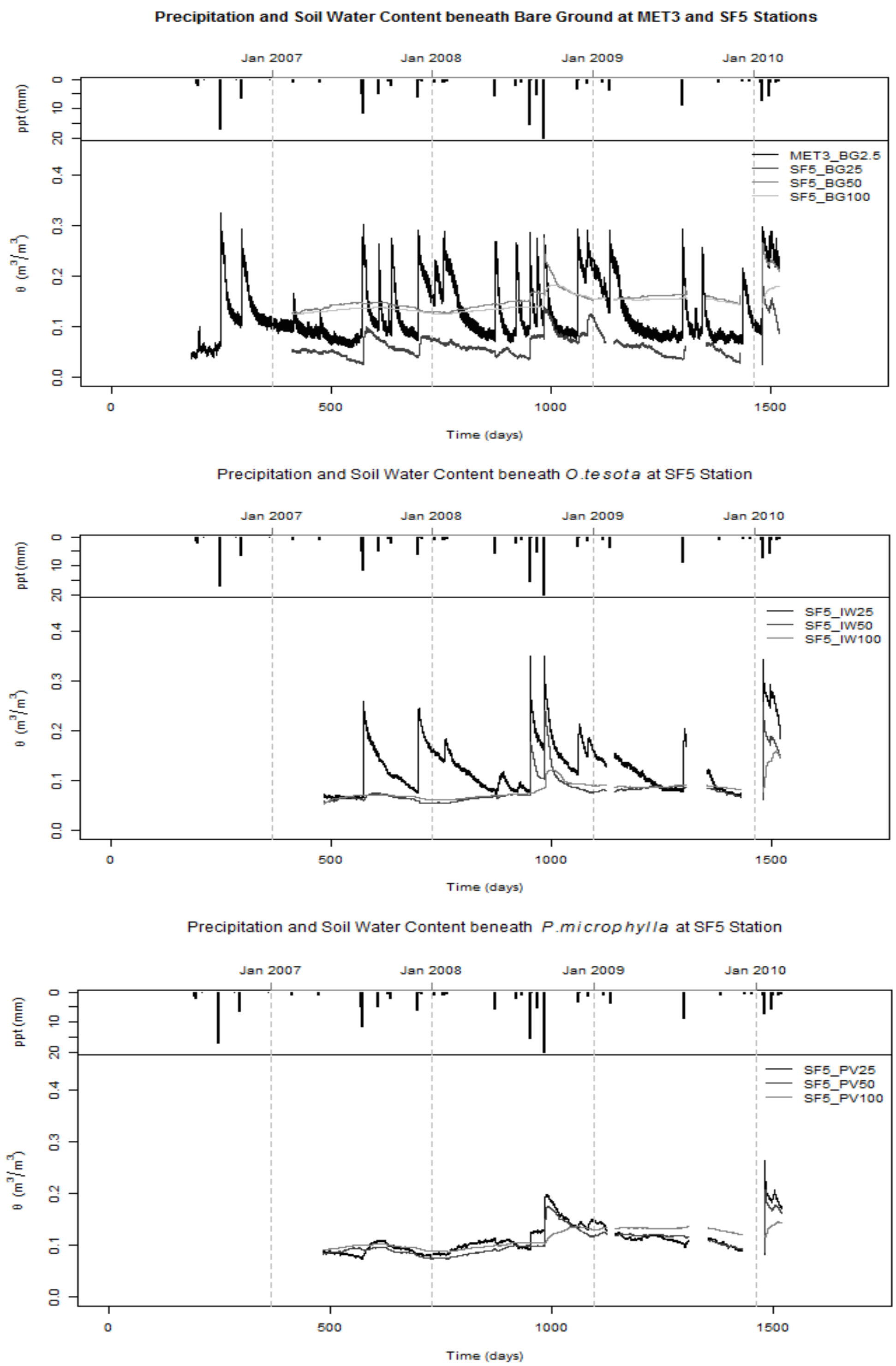


Figure 3.53. Precipitation (mm) recorded at 15-minute intervals at MET3 (wash/upper) station, and volumetric soil moisture (m^3/m^3) recorded at 15-minute intervals at SF5 (wash/upper) station at each probe and depth beneath three cover types in the Yuma Wash watershed. SF refers to station name, BG, IW, and PV refer to probes emplaced beneath bare ground, *O. tesota* (Ironwood), and *P. microphylla* (Palo verde), respectively.

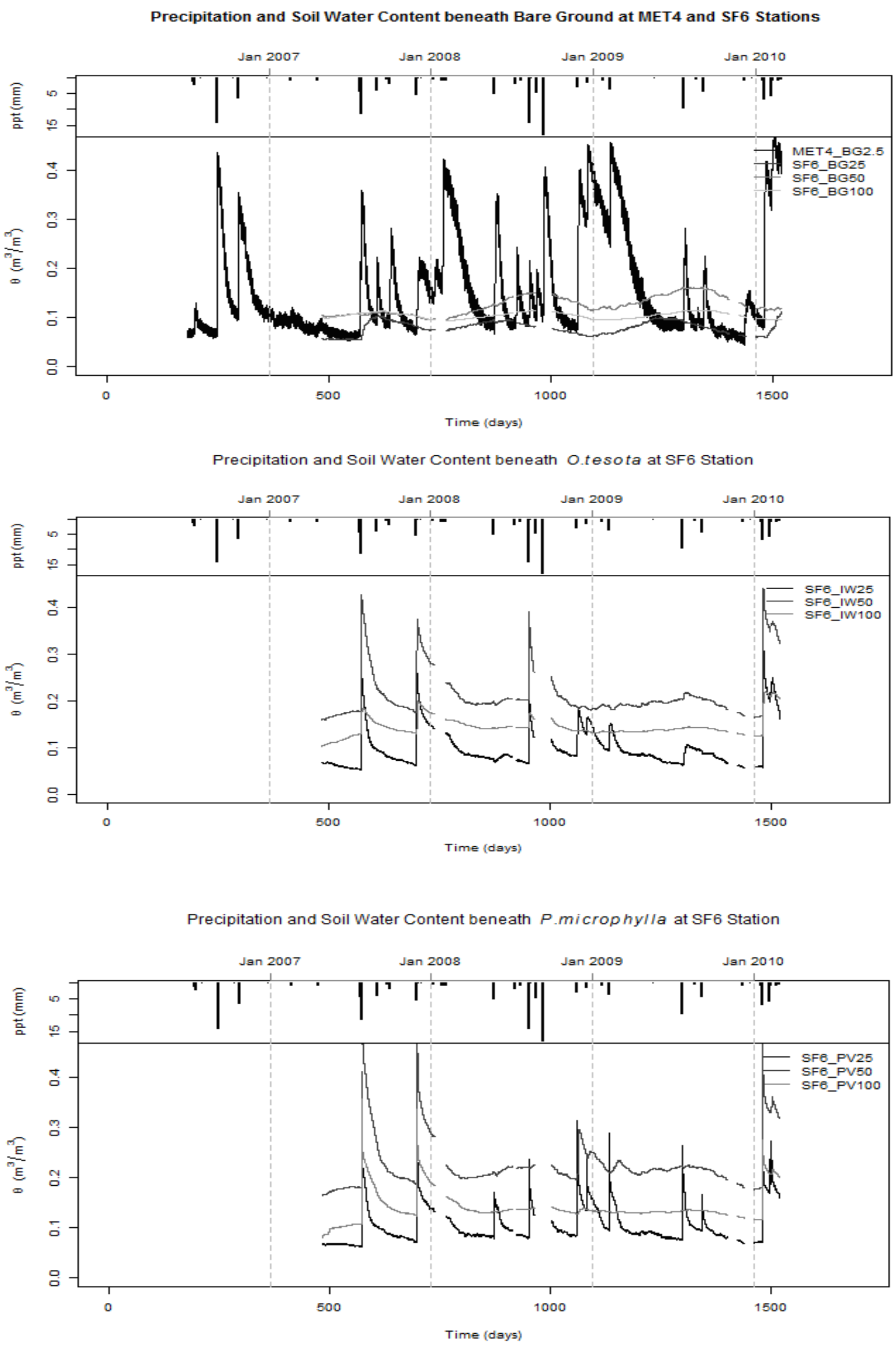


Figure 3.54. Precipitation (mm) recorded at 15-minute intervals at MET4 (terrace/upper) station, and volumetric soil moisture (m^3/m^3) recorded at 15-minute intervals at SF6 (terrace/upper) station at each probe and depth beneath three cover types in the Yuma Wash watershed. SF refers to station name, BG, IW, and PV refer to probes emplaced beneath bare ground, *O. tesota* (Ironwood), and *P. microphylla* (Palo verde), respectively.

occurred at the station associated with each probe in Figures 3.55-3.57. Two general patterns are apparent from these data. First, probes emplaced at 25, 50, and 100 cm beneath *P. microphylla* (PV) and *O. tesota* (IW) on terrace surfaces (Figures 3.49, 3.51, 3.54) tend to respond to precipitation more frequently at depths of 25-100 cm than probes beneath the same vegetation types on wash surfaces (Figures 3.50, 3.52, 3.53). The distinction is not as apparent for probes placed between vegetated cover at 25 cm in the upper basin (SF5_IW25 and SF6_IW25), but the general pattern for all other locations is clear. Second, very few precipitation events recorded during the period of study generated a soil moisture response on terraces at 25-100 cm in probes emplaced beneath bare ground (BG). Relative to soils beneath vegetated cover on terraces, fewer events were recorded beneath bare ground at depths of 25-100 cm at all locations. And in contrast to probes beneath vegetative cover types which recorded a higher number of events on terraces relative to washes, a greater number of events were recorded beneath bare ground on washes than beneath bare ground on terraces.

Differences in soil moisture by geomorphic surface at 2.5 cm do not appear to be related to the number of events recorded on each surface. With the exception of ECOV1 station, where a few events may have been missed due to station inoperation from August 2007 to February 2008, and ECOV2 station, which was inoperative until February 2007, probes beneath bare ground at 2.5 cm on different geomorphic surfaces in the same basin location recorded nearly the same number of events. ECOV1 station at the lower terrace site incurred damage in a wind storm in August 2007, which rendered this station and the near surface soil moisture probe that was wired to it (ECOV1_BG2.5) inoperative during this period. And ECOV2 station in the lower wash initially incurred an electrical fire due to a manufacturing error, which resulted in a delay in operation until February 2007. Since no differences were found in precipitation across

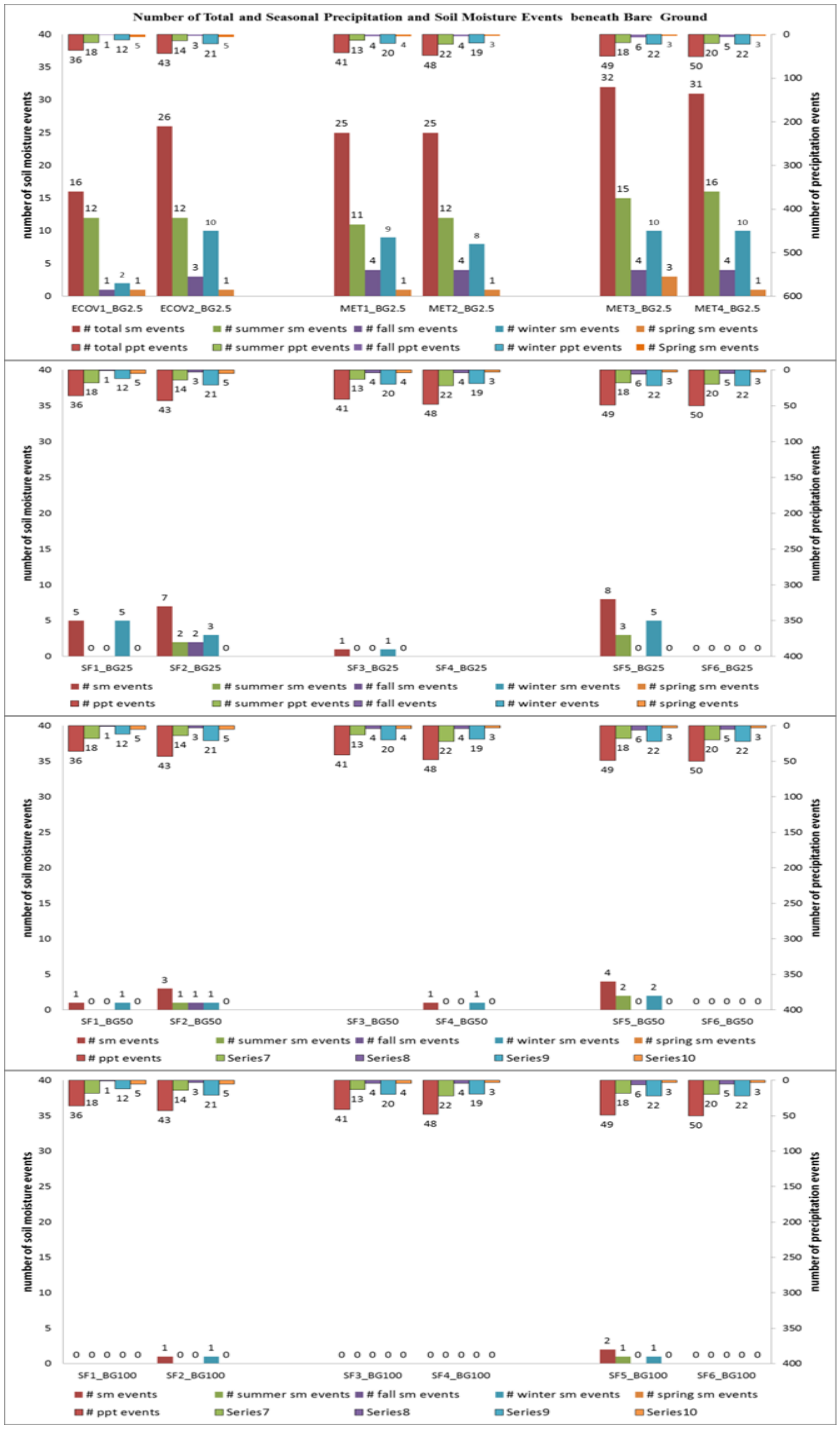


Figure 3.55. Total and seasonal number of recorded precipitation and soil moisture events by depth for all probes beneath bare ground (BG). Depth sequencing of probes is 2.5cm (top) to 100cm (bottom) and station pairs by geomorphic surface are ECOV1-SF1, MET1-SF3, and MET4-SF6 (terraces), and ECOV2-SF2, MET2-SF4, MET3-SF5 (washes). Zero values for a probe indicate probe was functioning but no soil moisture events were detected. Probes with no values were eliminated from the study due to malfunctioning.

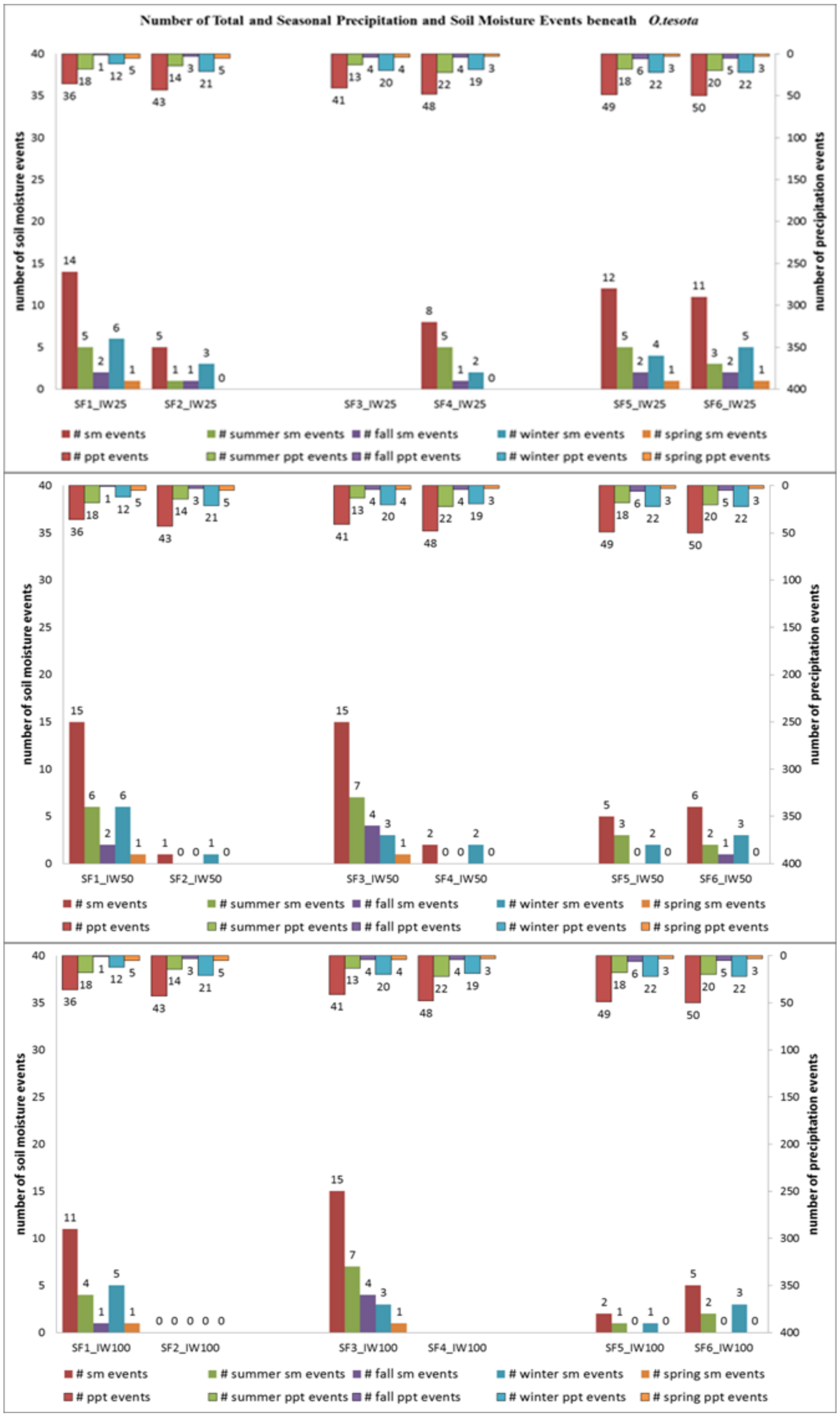


Figure 3.56. Total and seasonal number of recorded precipitation and soil moisture events by depth for all probes beneath *O. tesota* (IW). Depth sequencing of probes is 2.5cm (top) to 100cm (bottom) and station pairs by geomorphic surface are ECOV1-SF1, MET1-SF3, and MET4-SF6 (terraces), and ECOV2-SF2, MET2-SF4, MET3-SF5 (washes). Zero values for a probe indicate probe was functioning but no soil moisture events were detected. Probes with no values were eliminated from the study due to malfunctioning.

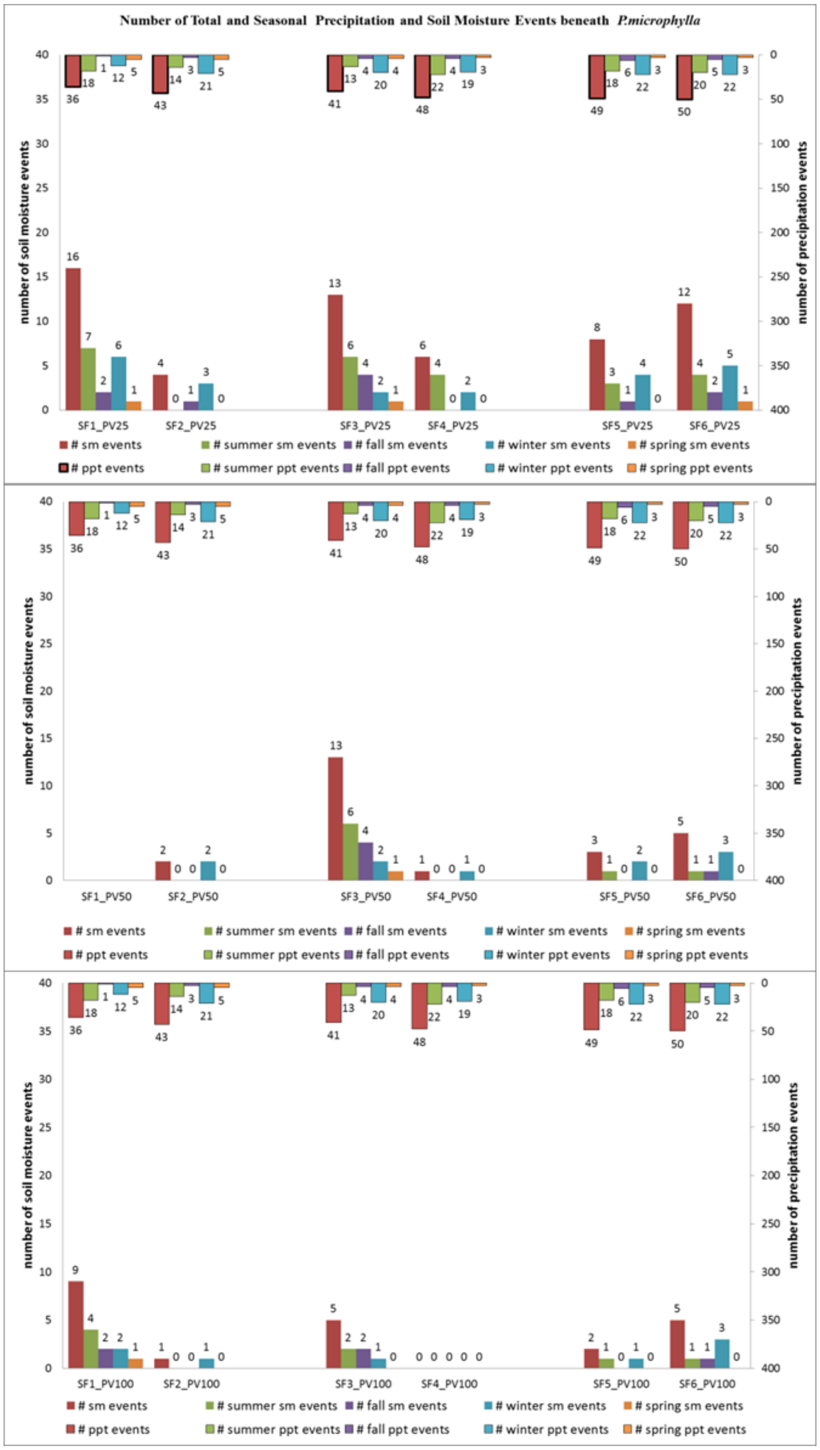


Figure 3.57. Total and seasonal number of recorded precipitation and soil moisture events by depth for all probes beneath *P. microphylla* (PV). Depth sequencing of probes is 25cm (top) to 100cm (bottom) and station pairs by geomorphic surface are ECOV1-SF1, MET1-SF3, and MET4-SF6 (terraces), and ECOV2-SF2, MET2-SF4, MET3-SF5 (washes). Zero values for a probe indicate probe was functioning but no soil moisture events were detected. Probes with no values were eliminated from the study due to malfunctioning.

different geomorphic surfaces, differences in soil moisture beneath bare ground at the near surface likely have more to do with soil characteristics on these different geomorphic surfaces than the amount or number of precipitation or soil moisture events recorded.

At 25-100 cm, differences in the number of events recorded varied based on geomorphic surface and cover type. At 25 cm beneath *O. tesota,* differences in the number of events recorded on terraces relative to washes were highest in the lower basin (n=14 and n=5, respectively). It is likely that a greater number of events were also recorded at 25 cm beneath *O. tesota* at the midbasin terrace station relative to *O. tesota* at the midbasin wash station (n=8) considering the number of events recorded at this probe at 50 and 100 cm, but midbasin terrace probe SF3_IW25 was omitted from the study because of malfunctioning so comparisons could not be made. In the upper basin, the number of events recorded beneath *O. tesota* was similar on terraces versus washes (n=11 and n=12, respectively). At 25 cm beneath *P. microphylla*, differences in the number of events recorded on terraces relative to washes were also highest in the lower basin (n=16 and n=4, respectively), next in the middle basin (n=13 and n=6), and least in the upper basin (n=12 and n=8, respectively). Beneath bare ground at 25 cm, differences in the number of events recorded on terraces relative to washes showed the opposite trend by location and by geomorphic surface. Differences were greatest in the upper basin (n=0 on terraces and n=8 on washes, respectively), and least in the lower basin (n=5 on terraces and n=7 on washes, respectively). The mid-basin bare ground wash probe at 25 cm was eliminated due to malfunction, so comparisons could not be made, but the terrace mid-basin probe beneath bare ground only recorded 1 event, so it is likely the wash probe recorded a higher number of events than the terrace mid-basin probe. Lower terrace 25 cm probe beneath bare ground (SF1_BG25) was the only probe to record more than a single event at 25-100 cm beneath bare ground on any terrace during the study period.

Lower terrace SF1 station was the first site where instrumentation was deployed, and installation of the probes beneath bare ground at this station caused some local disturbance of the surface soil in the area immediately down gradient of the probe insertion point, disturbing much of the Av horizon and desert pavement stones characteristic of this surface (Figure 3.58). Although the probes at 25-100 cm were emplaced directly beneath an intact surface of soil and stone pavement, as seen in the lower center of Figure 3.58, disturbance of the Av horizon may have led to increased infiltration and lateral subsurface flow at this particular probe. However, the depth of the vesicular horizon beneath pavement stones at this site was also noted during field installation as less than the other two terrace sites (5 cm versus 6-8 cm at the mid- and upper basin terrace sites, respectively), which also could have resulted in greater infiltration to 25 cm relative to other sites. Since the near surface probe at 2.5 cm beneath bare ground was wired to a separate meteorological station (ECOV1) in the vicinity, but located up gradient of the disturbed pavement surface by several meters, soil moisture readings at this probe were not

Figure 3.58. Terrace surface disturbance at SF1 station and evidence of erosion and surface pooling following a storm event. SF1_BG25-BG100 probes were emplaced beneath intact soil and desert pavement in lower center of photo.

likely affected by any localized damage to pavement. Greater care was taken at subsequent stations to preserve the surface characteristics of the soil when excavating soil pits to install probes at 25-100 cm, particularly on terraces.

At 50 cm, differences in the number of events recorded beneath *O. tesota* on terraces versus washes were also highest in the lower basin (n=15 and n=1, respectively), then midbasin (n=15 and n=2, respectively), and least in the upper basin stations (n=6 and n=5, respectively). Beneath *P. microphylla* at 50 cm, differences in the number of events recorded on terraces relative to washes was highest in the midbasin (n=13 and n=1, respectively) stations, and differences were least in the upper basin (n=5 and n=3, respectively). Lower basin station probe at 50 cm beneath *P. microphylla* was eliminated due to malfunctioning, so comparisons could not be made between lower basin stations. The smaller number of events recorded at 50-100 cm on upper terrace sites beneath vegetated cover may have resulted from soil compaction and/or concretions observed at this station. Beneath bare ground at 50 cm, differences were greatest in the upper basin (n=0 on terraces and n=4 on washes), and next in the lower basin (n=1 on terraces and n=3 on washes). The mid-basin terrace probe beneath 50 cm bare ground was eliminated so comparisons could not be made, albeit the mid-basin wash probe recorded only n=1 event.

At 100 cm, differences beneath *O. tesota* on terraces versus washes were highest in the lower basin (n=11 and n=0, respectively), and least in the upper basin (n=5 and n=2, respectively). It is also likely that a greater number of events were recorded beneath *O. tesota* at the midbasin terrace station (n=15) relative to the midbasin wash station, but the latter probe (SF4_IW100) was omitted from the study because of malfunctioning, so comparisons could not be made. At 100 cm beneath *P. microphylla*, the number of events recorded on terraces relative to washes was also highest in the lower basin (n=9 and n=1, respectively), next in the midbasin (n=5, n=0, respectively), and least in the upper basin (n=5 and n=2, respectively). Beneath bare ground at 100 cm, differences in the number of events recorded on terraces versus washes were highest in the upper basin (n=0 on terraces and and n=2 on washes), next in the lower basin (n=0 on terraces and n=1 on washes), and no events were recorded on either surface at 100 cm beneath bare ground at the midbasin stations (n=0 and n=0).

Comparing the number of events recorded on each geomorphic surface by cover type, differences were consistently greater beneath vegetated cover relative to bare ground on terraces, whereas no consistent differences were found in the number of events recorded beneath vegetated cover versus bare ground on washes. At 25 cm on terraces, more events were recorded beneath *P. microphylla* (n=12-16) and *O. tesota* (n=11-14) relative to bare ground (n=0-5). At 25 cm on washes, a higher number of events were recorded beneath *O. tesota* (n=12) in the upper basin relative to *P. microphylla* (n=8) or bare ground (n=8), but in the lower basin, a higher number of events were recorded beneath bare ground (n=7) relative to *O. tesota* (n=5) or *P. microphylla* (n=4). Mid-basin wash probe beneath bare ground at 25 cm was eliminated, so comparisons could not be made between vegetated and unvegetated cover for this location.

A greater number of events were also recorded at 50 cm beneath terrace *O. tesota* (n=6-15) and *P. microphylla* (n=5-13) relative to bare ground (n=0-1), while differences in the number of events recorded by cover beneath wash stations were very small (n=1-4 for bare ground versus n=1-3 for *P. microphylla* and n=1-5 for *O. tesota*). The number of events recorded at 100 cm beneath *O. tesota* (n=5-15) and *P. microphylla* (n=5-9) was also higher relative to bare ground (n=0) on terraces, and there were few to no differences in the number of events recorded at wash stations by cover type (i.e., all recorded n=0-2 events).

Comparing the number of events recorded by basin location, a greater number of soil moisture events were recorded at 2.5 cm in the upper basin relative to the mid-basin and lower basin on both surfaces, albeit it is difficult to determine how much of this discrepancy is real due to missing data at the lower basin probes. However, at 25-100 cm, the number of events recorded at wash station probes was also greater in the upper basin relative to the middle and lower basin, more so beneath vegetated cover than bare ground. Beneath *O. tesota* at 25 cm on washes, the highest number of events were recorded in the upper basin (n=12), versus n=8 midbasin, and n=5 in the lower basin. Beneath *P. microphylla* at 25 cm on washes, the highest number of events were also recorded in the upper basin (n=8), versus midbasin (n=6) and lower basin (n=4). Beneath bare ground, the number of events in the upper basin (n=8) was greater than in the lower basin, but only by a single event (n=7). At 50-100 cm, the same increasing pattern from lower to upper basin was found. So it may be that at least some of the difference between lower and upper soil moisture in the top meter of soil in washes can be attributed to differences in number of events recorded.

On terraces, differences in the number of events recorded also varied by location and by cover type, but an increasing trend from lower to upper basin was not found. Beneath *O. tesota* and *P. microphylla*, a higher number of events were recorded at the lower and mid-basin stations relative to the upper basin, especially at depths of 50-100 cm. And beneath bare ground, a greater number of events was recorded at the lower site relative to the upper. This may have resulted from localized effects of damaged pavement surface at this site, but also may have resulted from differences in soil characteristics at the near surface, which were not quantified in this study.

To further investigate these differences, statistical properties of soil moisture for the period of record were examined by depth, geomorphic surface, location, and cover type in the spatial domain, and by year and by season in the temporal domain. For significance tests, weekly means averaged from 15-minute data were used with the aim of reducing the detection of small differences as statistically significant when working with large datasets. Fifteen-minute soil moisture data recorded at each probe are shown in Figure 3.59. Summary statistics by probe

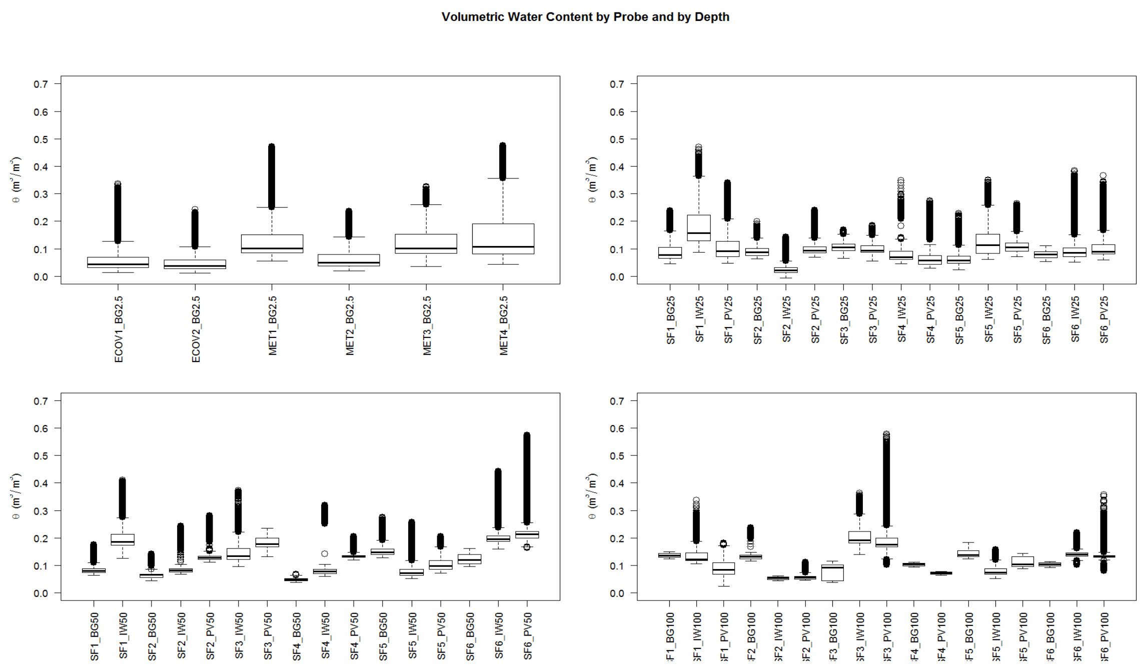


Figure 3.59. Fifteen minute volumetric soil moisture recorded at all probes (bad probes eliminated and not shown here) at 2.5, 25, 50, and 100 cm depths. ECOV1-MET4 are station names for probes emplaced at 2.5cm. SF1-SF6 are station names for probes emplaced at 25-100 cm. PV, IW, and BG denote cover types: PV-Palo verde *(P. microphylla)*, IW-Ironwood *(O. tesota),* and BG-bare ground.

are provided in Tables D40-D41, for bivariate pooling in Tables D42-D45, and for trivariate pooling in Tables D46-D48. Data from most probes were non-normally distributed and right-skewed (Figures D49-D68), reflecting the response of soils to low frequency rainfall substantial enough to infiltrate into the top one meter of soil. This warranted the use of non-parametric statistical tests for investigating differences.

Probe to probe variation in Figure 3.59 illustrates the generally higher soil moisture values at probes beneath vegetated cover on terraces (SF1,SF3,SF6) versus probes beneath vegetated cover beneath washes (SF2,SF4,SF5) at all depths, and the generally lower values recorded at terrace probes beneath bare ground (BG) relative to terrace probes beneath *P. microphylla* (PV) and *O. tesota* (IW). Data pooled by depth illustrate that soil moisture was higher at 50 cm relative to other depths (Figure 3.60; Table 3.9). Bivariate pooling by depth and by geomorphic surface illustrates that the increase in soil moisture at 50 cm relative to other depths is more apparent at terrace probes than wash probes, and terrace probes have higher median values with greater variability in soil moisture relative to wash probes at all depths, more so at depths of 50-100 cm (Figure 3.61; Table 3.10). When pooled by depth and cover type (Figure 3.62; Table 3.11), median soil moisture was similar beneath vegetated and bare ground cover at 25 and 100 cm and higher beneath vegetated species at 50 cm, and variance in soil moisture beneath both vegetated species is higher than beneath bare ground at all depths of 25-100 cm. When pooled by location (Figure 77; Table 3.12), median soil moisture appeared to increase from lower to upper basin at all depths except 25 cm.

Non-parametric tests suggest differences in ranks sums of weekly soil moisture (averaged from fifteen minute data) were generally significant by cover type, geomorphic surface, basin location, and depth ($\alpha = 0.05$) (Tables D49-D51). Bivariate analysis by depth and each of these other factors resulted in differences at 2.5 cm that were most significant by location, and were greatest between the lower and upper basin (Figure 3.63; Table D51). Differences at 25-100 cm were most significant by geomorphic surface, with generally higher soil moisture values on

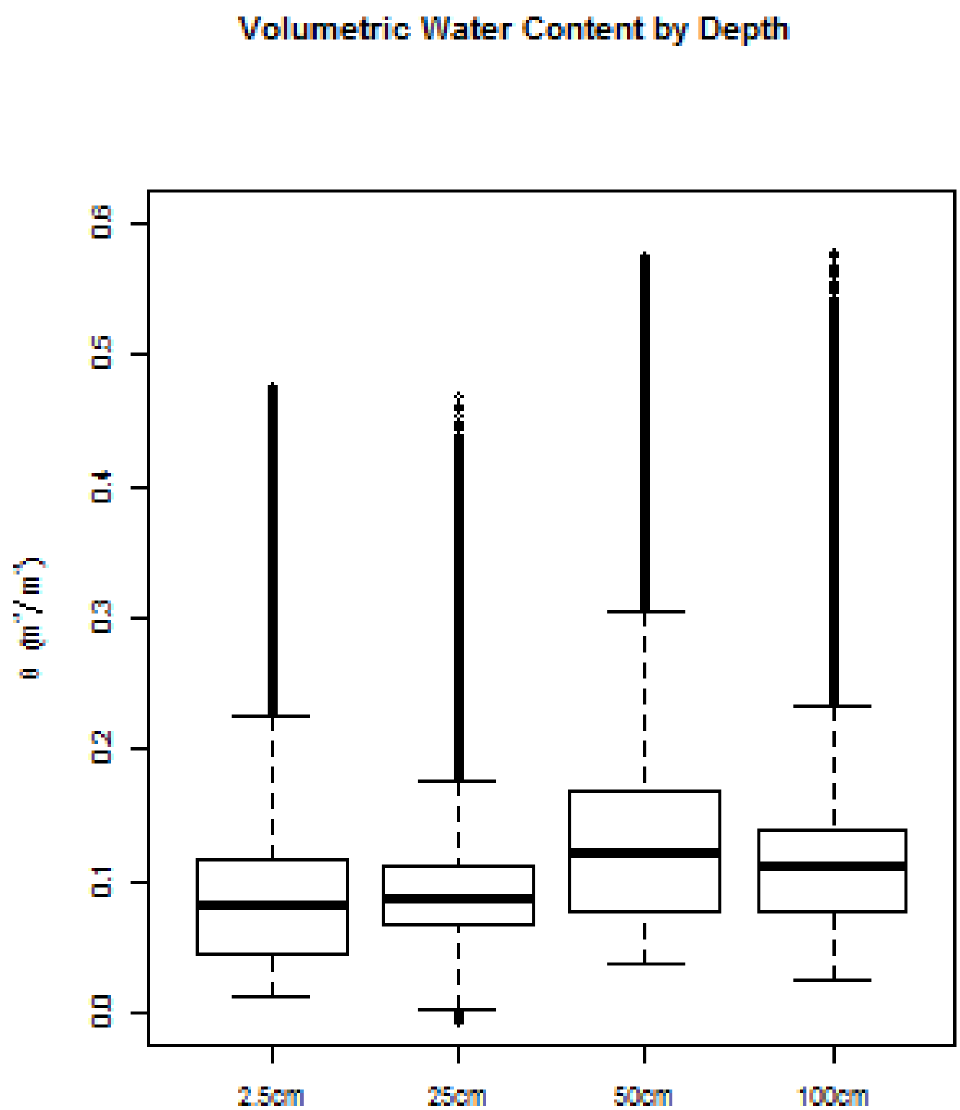


Figure 3.60. Fifteen minute volumetric soil moisture by depth recorded at all stations in the Yuma Wash watershed.

Table 3.9. Fifteen minute volumetric soil moisture by depth in the Yuma Wash watershed.

Depth	θ m^3/m^3				
	Median	Min	Max	Q1	Q3
2.5 cm	0.08	0.01	0.47	0.05	0.12
25 cm	0.09	0.002	0.46	0.07	0.11
50 cm	0.13	0.04	0.53	0.08	0.17
100 cm	0.12	0.03	0.58	0.08	0.14

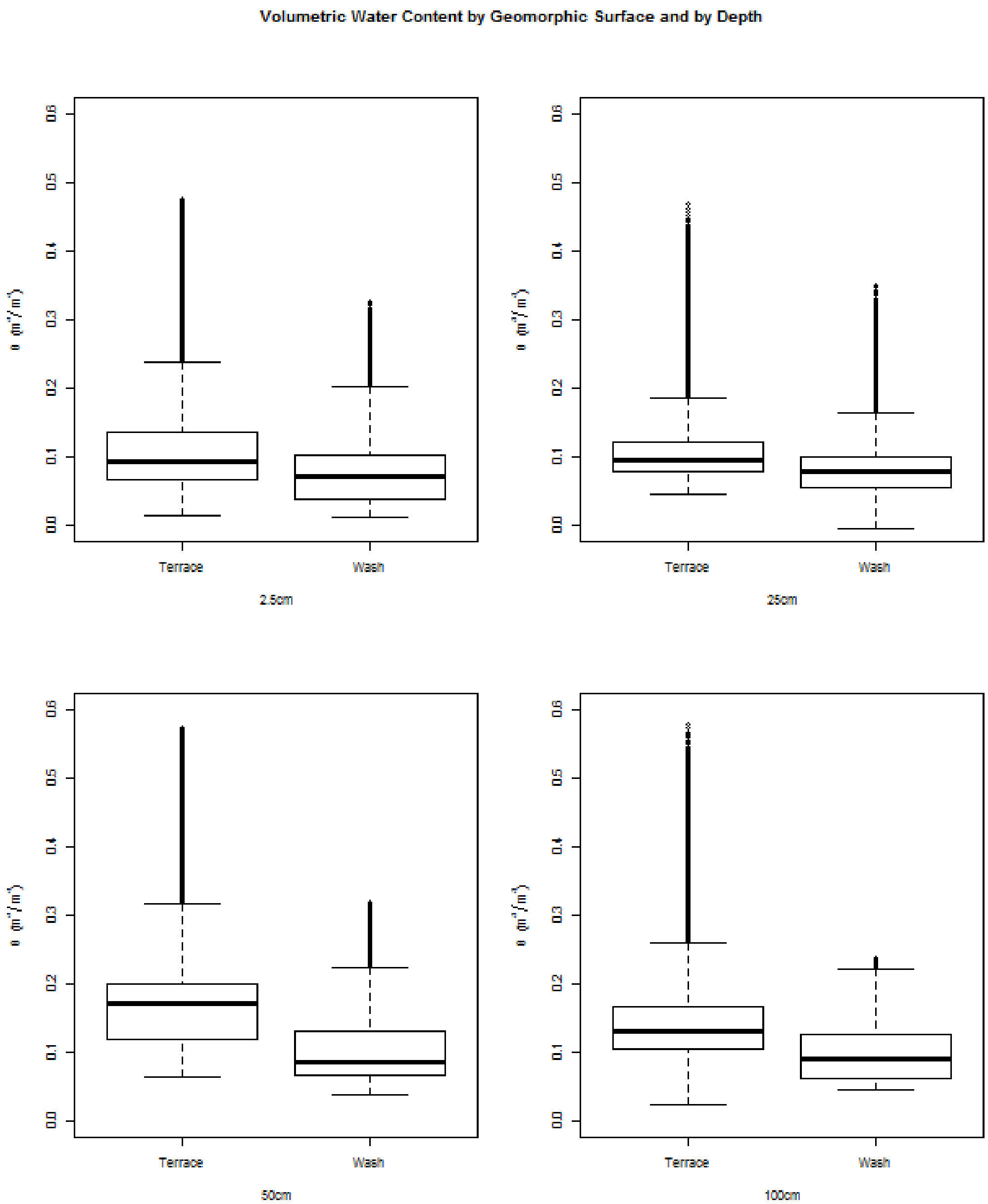


Figure 3.61. Fifteen minute volumetric soil moisture by depth and geomorphic surface in the Yuma Wash watershed.

Table 3.10. Fifteen minute volumetric soil moisture by depth and geomorphic surface in the Yuma Wash watershed.

Depth	θ m^3/m^3 (Terrace)					θ m^3/m^3 (Wash)				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	0.09	0.01	0.48	0.07	0.13	0.07	0.01	0.33	0.04	0.10
25 cm	0.09	0.05	0.47	0.08	0.12	0.08	0.005	0.35	0.06	0.10
50 cm	0.17	0.07	0.57	0.12	0.20	0.09	0.04	0.32	0.07	0.13
100 cm	0.13	0.02	0.58	0.11	0.17	0.09	0.05	0.24	0.06	0.13

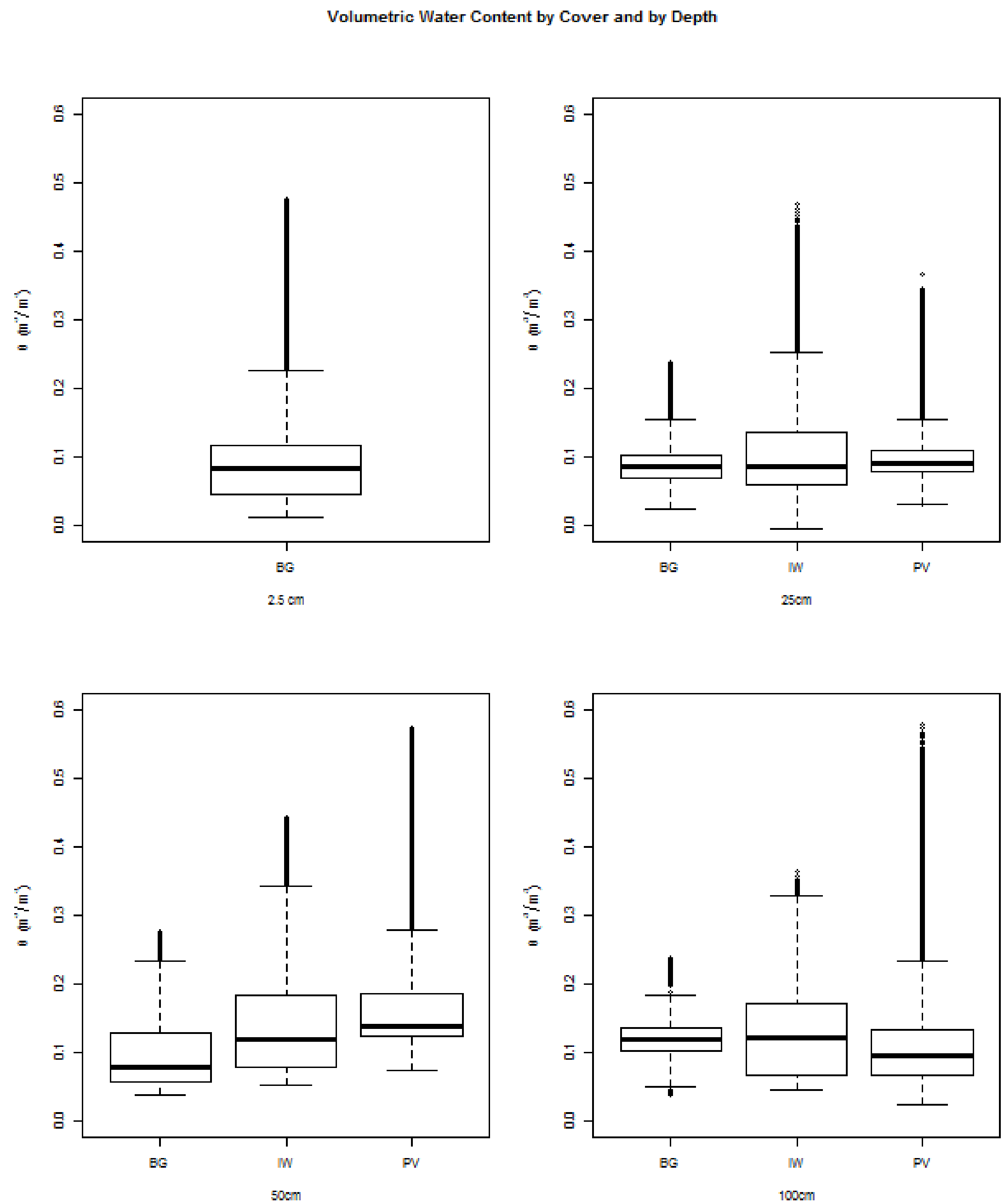


Figure 3.62. Fifteen minute volumetric soil moisture by depth and by cover type in the Yuma Wash watershed.

Table 3.11. Fifteen minute volumetric soil moisture by depth and by cover type in the Yuma Wash Watershed.

Depth	θ m^{-3}/m^{-3} (BG)				
	Median	Min	Max	Q1	Q3
2.5 cm	0.08	0.01	48	0.05	0.12
25 cm	0.09	0.02	0.24	0.07	0.10
50 cm	0.08	0.04	0.28	0.06	0.13
100 cm	0.12	0.04	0.24	0.10	0.14
	θ m^{-3}/m^{-3} (IW)				
	Median	Min	Max	Q1	Q3
2.5 cm	N/A	N/A	N/A	N/A	N/A
25 cm	0.09	0.005	0.47	0.06	0.14
50 cm	0.12	0.05	0.44	0.08	0.18
100 cm	0.12	0.04	0.36	0.07	0.17
	θ m^{-3}/m^{-3} (PV)				
	Median	Min	Max	Q1	Q3
2.5 cm	N/A	N/A	N/A	N/A	N/A
25 cm	0.09	0.03	0.37	0.08	0.11
50 cm	0.14	0.07	0.57	0.12	0.19
100 cm	0.10	0.02	0.58	0.07	0.13

terraces relative to washes (Figure 3.61; Table D49). By cover type, differences were most significant at 50 cm between all cover types (Figure 3.62; Table D50). Trivariate pooling by depth, geomorphic surface, and cover further revealed that on terraces, soil moisture was generally greater and more variable beneath *P. microphylla* and *O. tesota* relative to bare ground (Figure 3.64; Tables 3.13 D49). Greatest differences on terraces were found between *O. tesota* and bare ground at 25-100 cm, followed by *P. microphylla* and bare ground at 50-100 cm (Figures 3.49, 3.51, 3.54; Table D52). Differences between *O. tesota* and bare ground on terraces ranged from median differences of 4 percent and IQR differences of 2-7 percent at 25 cm, to 9 percent median differences and 7-8 percent IQR differences at 50 cm, to 4 percent median and 3-6 percent IQR differences at 100 cm. Differences between *P. microphylla* and bare ground on terraces ranged from less than 1 percent median and IQR differences at 25 cm, to

11 percent with a 10 percent IQR difference at 50 cm, to 2 percent with 4 percent IQR differences at 100 cm.

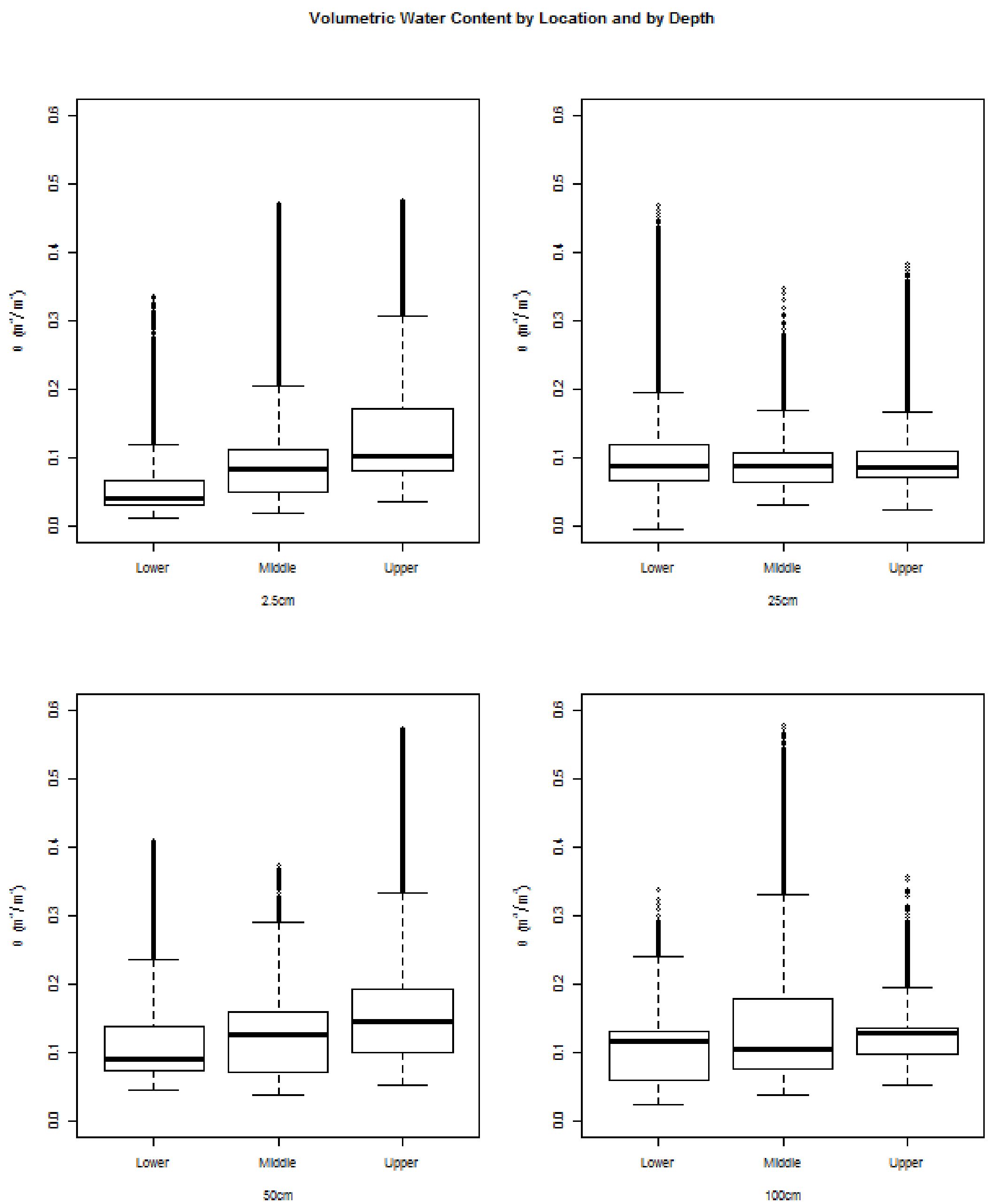


Figure 3.63. Fifteen minute volumetric soil moisture by depth and location in the Yuma Wash watershed.

Table 3.12. Fifteen minute volumetric soil moisture by depth and by location in the Yuma Wash Watershed.

Depth	θ m^{-3}/m^{-3} (Lower)				
	Median	Min	Max	Q1	Q3
2.5 cm	0.04	0.01	0.34	0.03	0.07
25 cm	0.09	0.005	0.47	0.07	0.12
50 cm	0.09	0.04	0.41	0.07	0.14
100 cm	0.12	0.02	0.34	0.06	0.13
	θ m^{-3}/m^{-3} (Middle)				
	Median	Min	Max	Q1	Q3
2.5 cm	0.08	0.02	0.47	0.05	0.11
25 cm	0.09	0.03	0.35	0.07	0.11
50 cm	0.13	0.04	0.37	0.07	0.16
100 cm	0.11	0.02	0.58	0.08	0.18
	θ m^{-3}/m^{-3} (Upper)				
	Median	Min	Max	Q1	Q3
2.5 cm	0.10	0.04	0.47	0.08	0.17
25 cm	0.09	0.02	0.38	0.07	0.11
50 cm	0.14	0.05	0.57	0.10	0.19
100 cm	0.13	0.05	0.36	0.10	0.14

With the exception of differences between *P. microphylla* and bare ground at 25 cm on terraces, each of these differences exceeded the median and IQR error variance associated with soil temperature influences for each depth, cover type, and geomorphic surface. Coupled with the number of events recorded beneath each cover type on each geomorphic surface, these results suggest that, generally, probes on terraces beneath bare ground received less moisture than probes beneath *O. tesota* (at 25-100 cm) and *P. microphylla* (at 50-100 cm) on the same geomorphic surface.

At 25 cm on terraces, differences remained the most significant between *O. tesota* and bare ground, but between *P. microphylla* and bare ground, statistical differences were less significant than between *P. microphylla* and *O. tesota*. However, this was more likely reflective of differences in measured soil moisture at the lower terrace site, where soil moisture medians beneath *O. tesota* were greater by 7 percent relative to *P. microphylla*, coupled with an increase in the number of events recorded beneath the lower terrace bare ground probe at 25 cm. Soil

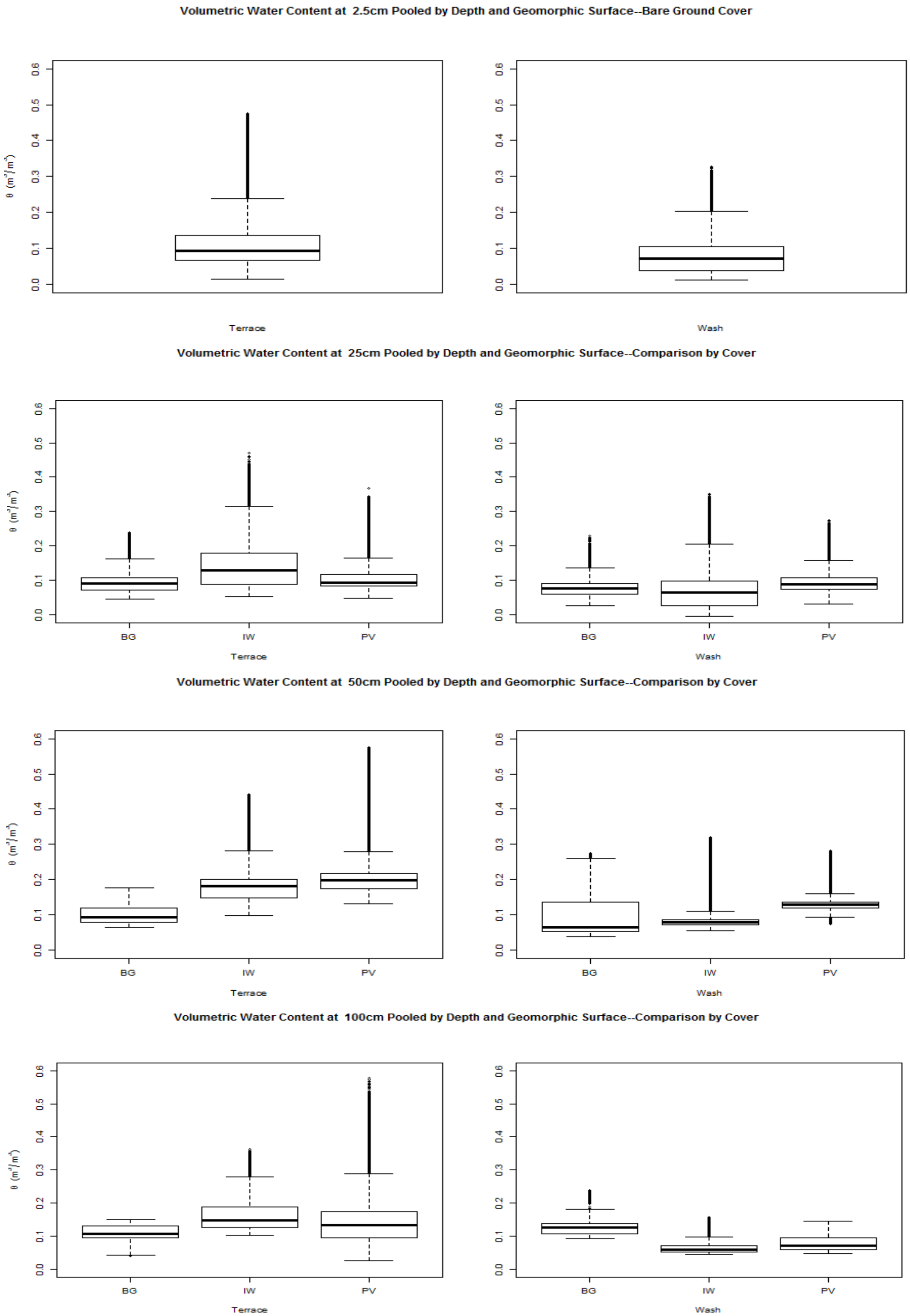


Figure 3.64. Fifteen minute volumetric soil moisture pooled by depth, geomorphic surface, and cover in the Yuma Wash watershed.

Table 3.13. Fifteen minute volumetric soil moisture by depth, geomorphic surface, and cover. Cover types are BG=bare ground, PV=Palo verde (*P. microphylla*), and IW=Ironwood (*O. tesota*).

Depth	θ m^{-3}/m^{-3}					θ m^{-3}/m^{-3}				
	BG Terrace					BG Wash				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	0.09	0.01	0.48	0.07	0.14	0.07	0.01	0.33	0.04	0.10
25 cm	0.09	0.05	0.24	0.07	0.11	0.08	0.02	0.23	0.06	0.09
50 cm	0.09	0.07	0.18	0.08	0.12	0.07	0.04	0.28	0.05	0.14
100 cm	0.11	0.04	0.15	0.10	0.13	0.13	0.09	0.24	0.11	0.14
	IW Terrace					IW Wash				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
25 cm	0.13	0.05	0.47	0.09	0.18	0.06	0.005	0.35	0.03	0.10
50 cm	0.18	0.10	0.44	0.15	0.20	0.08	0.05	0.32	0.07	0.09
100 cm	0.15	0.10	0.36	0.13	0.19	0.06	0.05	0.16	0.05	0.07
	PV Terrace					PV Wash				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
25 cm	0.09	0.05	0.37	0.08	0.12	0.09	0.03	0.27	0.07	0.11
50 cm	0.20	0.13	0.57	0.17	0.22	0.13	0.07	0.28	0.12	0.13
100 cm	0.13	0.03	0.58	0.10	0.17	0.07	0.05	0.14	0.06	0.09

moisture comparisons could not be made at the mid-basin site due to the elimination of the terrace probe at 25 cm beneath *O. tesota*, but differences were not significant beneath these two species at the upper basin sites.

On washes, soil moisture estimates at probes beneath vegetated cover were not consistently higher than beneath bare ground, and at depths of 100 cm, median soil moisture was actually lower beneath vegetated cover than beneath bare ground (Figures 3.50, 3.52, 3.53). Particularly at depths of 50-100 cm on washes, where few events were recorded, differences in soil moisture are likely more reflective of differences in baseline values rather than actual response to wetting events that occurred during the study period. Differences in rank sums between cover types were significant on washes, but generally less so than on terraces, and inconsistently across depths for different cover types and locations. When data from all wash locations were pooled, statistical differences in rank sums were greater between *P. microphylla* and *O. tesota* than between either species and bare ground at 25-50 cm; at 100 cm, differences were greater between *O. tesota* and bare ground, and *P. microphylla* and bare ground, relative to differences between the two species (Table D52).

Comparing the same cover type across different geomorphic surfaces, soil moisture beneath *P. microphylla* and *O. tesota* on terraces was higher and more variable relative to soil moisture beneath the same species on washes, with the exception of *P. microphylla* at 25 cm (Figures 3.65-3.70; Table D52). For *O. tesota*, median differences were 7 percent with IQR differences of 6-8 percent at 25 cm, 10 percent with IQR differences of 8-11 percent at 50 cm, and 9 percent with IQR differences of 8-12 percent at 100 cm. For *P. microphylla*, differences were less than 1 percent for medians and the IQR range at 25 cm, but at 50 cm, medians differed by 7 percent and IQR values by 5-9 percent, and at 100 cm, medians differed by 6 percent and IQR values by 4-8 percent.

Statistical tests showed significant differences in rank sums between all cover types across different geomorphic surfaces, but the greatest differences were found between *O. tesota* on terraces and *O. tesota* on washes at all depths, and next between *P. microphylla* on terraces and *P. microphylla* on washes at 50-100 cm (Table D52). In each of these cases, median and IQR differences exceeded the error variance associated with soil temperature influences for these cover types and geomorphic surfaces. Baseline soil moisture was also generally higher by 1-5 percent beneath *O. tesota* on terraces relative to washes, and between 2-6 percent beneath *P. microphylla* on terraces relative to washes depending on depth. Coupled with a greater number of soil moisture events recorded beneath these species on terraces relative to washes, these results suggest that soils beneath vegetated surfaces on terraces likely received greater moisture from storm events than probes beneath the same species on washes during the study period.

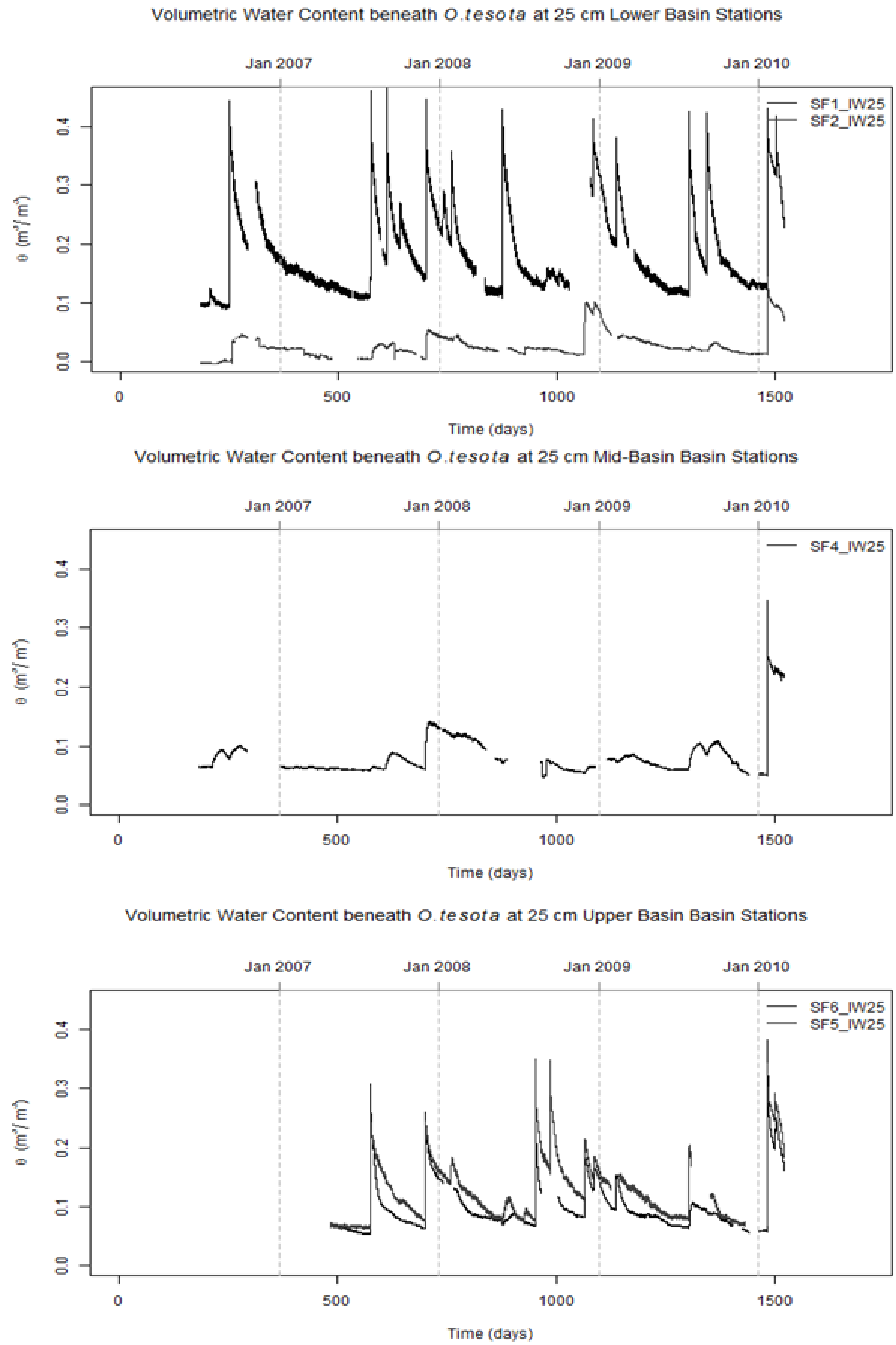


Figure 3.65. Fifteen minute volumetric soil moisture time series data comparing probes at 25 cm beneath *O. tesota* (Ironwood, IW), at three basin locations across two geomorphic surfaces. SF1,SF3, and SF6 are terrace sites, and SF2,SF4, and SF5 are wash sites.

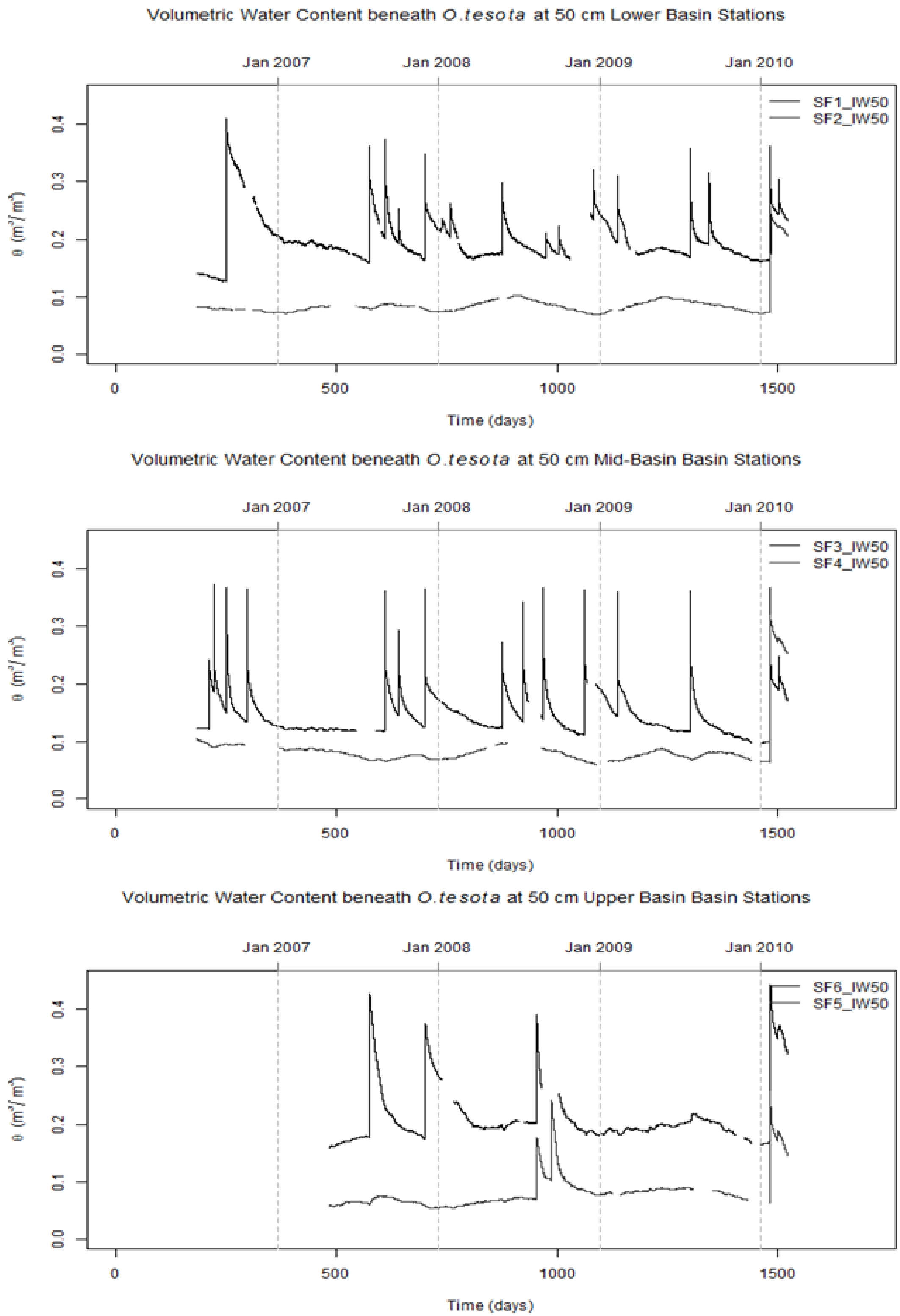


Figure 3.66. Fifteen minute volumetric soil moisture time series data comparing probes at 50 cm beneath *O. tesota* (Ironwood, IW), at three basin locations across two geomorphic surfaces. SF1,SF3, and SF6 are terrace sites, and SF2,SF4, and SF5 are wash sites.

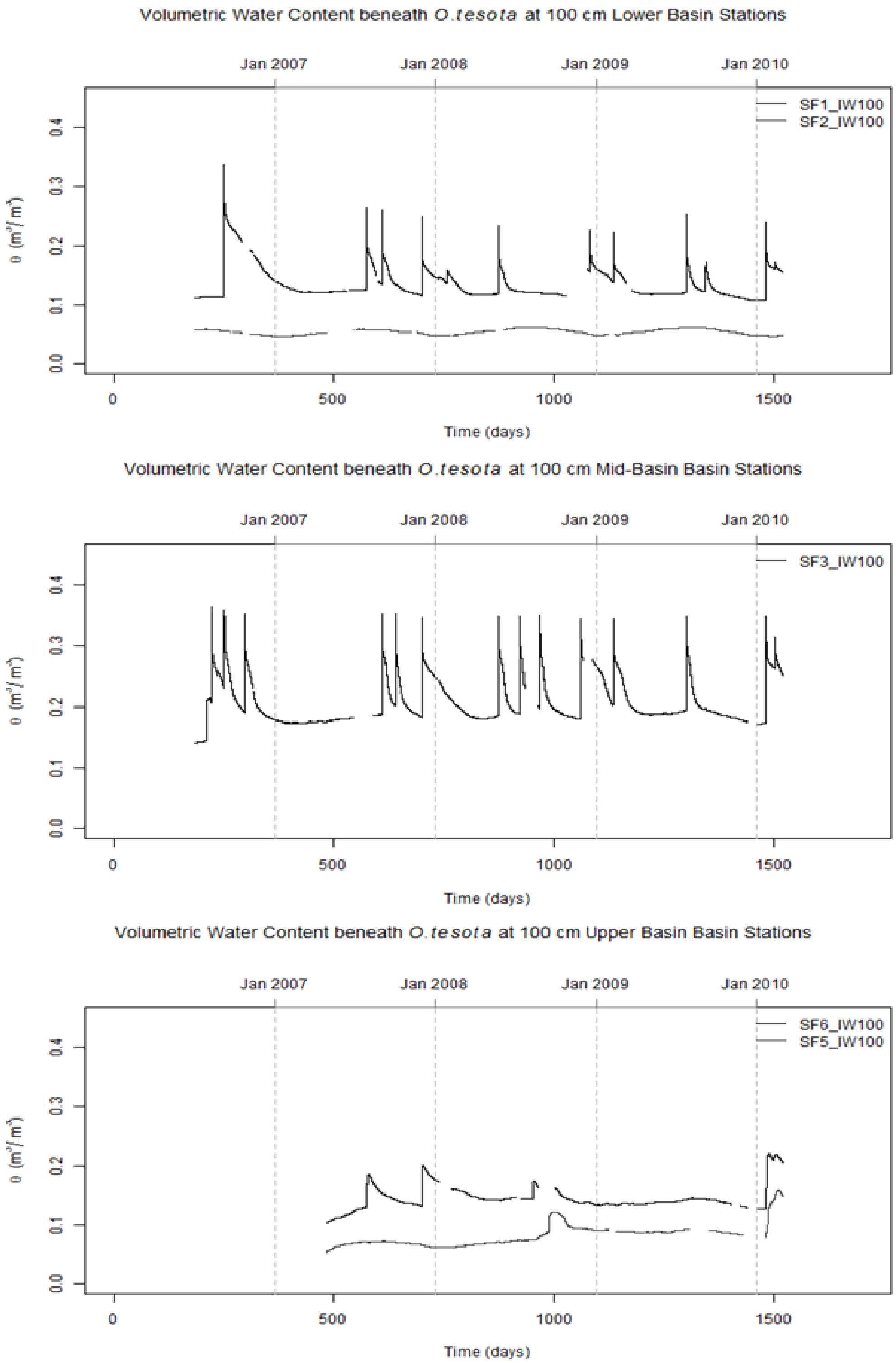


Figure 3.67. Fifteen minute volumetric soil moisture time series data comparing probes at 100 cm beneath *O. tesota* (Ironwood, IW), at three basin locations across two geomorphic surfaces. SF1,SF3, and SF6 are terrace sites, and SF2,SF4, and SF5 are wash sites.

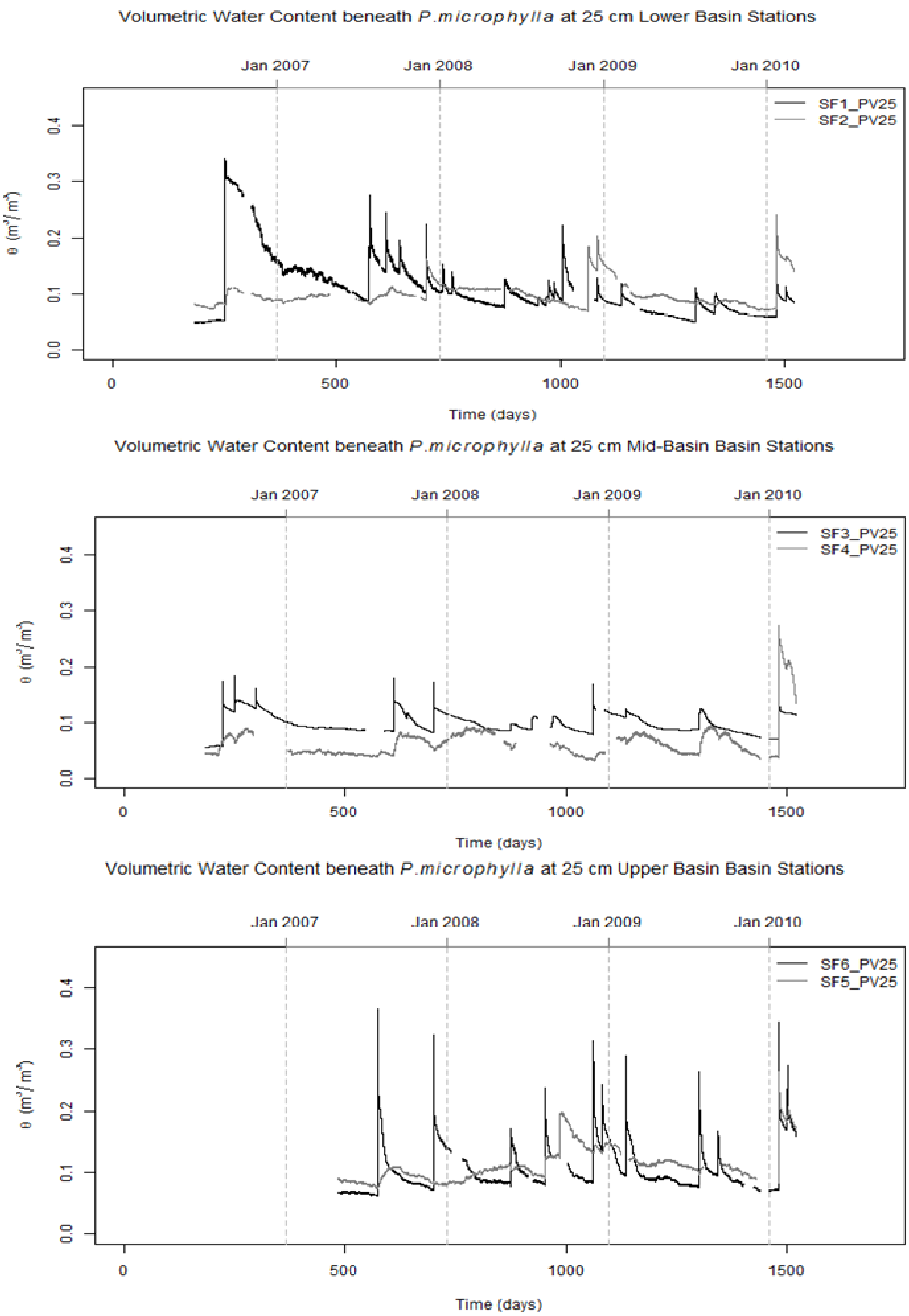


Figure 3.68. Fifteen minute volumetric soil moisture time series data comparing probes at 25 cm beneath *P. microphylla* (Foothill Palo Verde, PV), at three basin locations across two geomorphic surfaces. SF1,SF3, and SF6 are terrace sites, and SF2,SF4, and SF5 are wash sites.

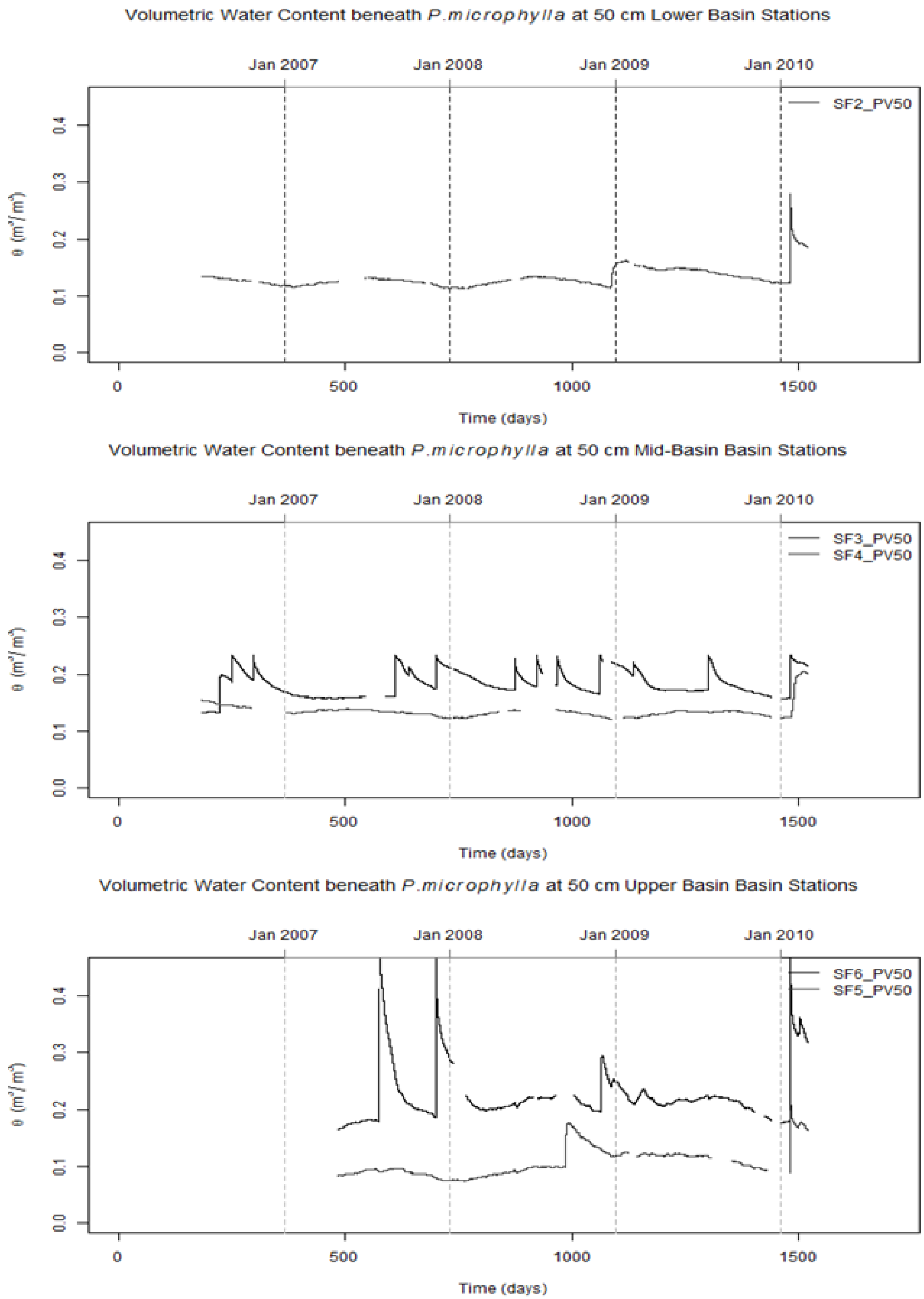


Figure 3.69. Fifteen minute volumetric soil moisture time series data comparing probes at 50 cm beneath *P. microphylla* (Foothill Palo Verde, PV), at three basin locations across two geomorphic surfaces. SF1,SF3, and SF6 are terrace sites, and SF2,SF4, and SF5 are wash sites.

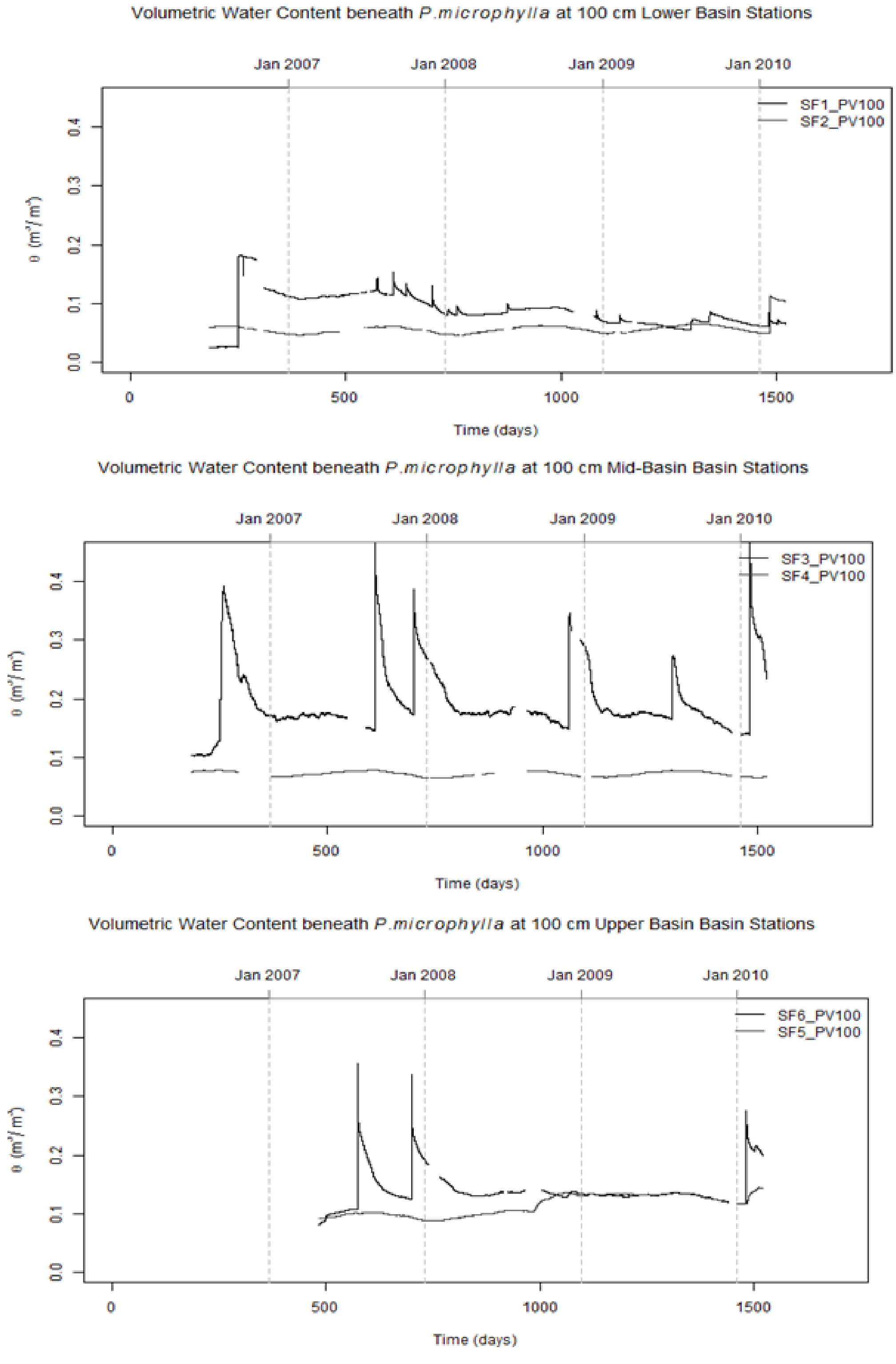


Figure 3.70. Fifteen minute volumetric soil moisture time series data comparing probes at 100 cm beneath *P. microphylla* (Foothill Palo Verde, PV), at three basin locations across two geomorphic surfaces. SF1,SF3, and SF6 are terrace sites, and SF2,SF4, and SF5 are wash sites.

While differences in rank sums were significant beneath bare ground by geomorphic surface, median soil moisture at 2.5 and 25 cm beneath bare ground was only greater on terraces by 1-2 percent relative to washes, which did not exceed the error variance associated with soil temperature (Figures 3.71-3.74). The number of events recorded on either surface was also similar at 2.5 cm with the exception of the lower sites, where missing data likely accounted for differences. And, at 25-100 cm beneath bare ground, more events were actually recorded on washes than terraces. Trivariate pooling of data by depth, geomorphic surface, and location suggests that median soil moisture was higher in the upper basin relative to the lower basin on washes at all depths, and on terraces, an increase from lower to upper basin was reflected at 2.5 cm and 50 cm (Figure 3.75; Table 3.14; Table D53). However, variance does not consistently increase from lower to upper basin on either surface except at 2.5 cm. Non-parametric statistical tests again showed significant differences in rank sums of weekly soil moisture ($\alpha = 0.05$) at 2.5 cm between all locations for both surfaces, with the exception of terrace upper and middle basin. Soil moisture on washes in the upper basin was most significantly different relative to the lower and middle basin wash sites at all depths (Table D53), suggesting moisture content of soils is higher in the upper basin wash. No consistent pattern in relative significance by location across depths was found for terraces at 25-100 cm, which is likely due to the high spatial heterogeneity in soil pedogenic properties on this surface, including induration from carbonates, differences in overall size fractions within the profiles, and the degree of compaction, which in turn affect the hydraulic characteristics. And, while runoff in washes is likely greater in the upper basin due to transmission losses in coarse alluvium, discontinuous induration or soil compaction along channels on terraces is probably related more to the relative fraction of salts and clays accumulated from aeolian deposition beneath desert pavement at different locations, which when

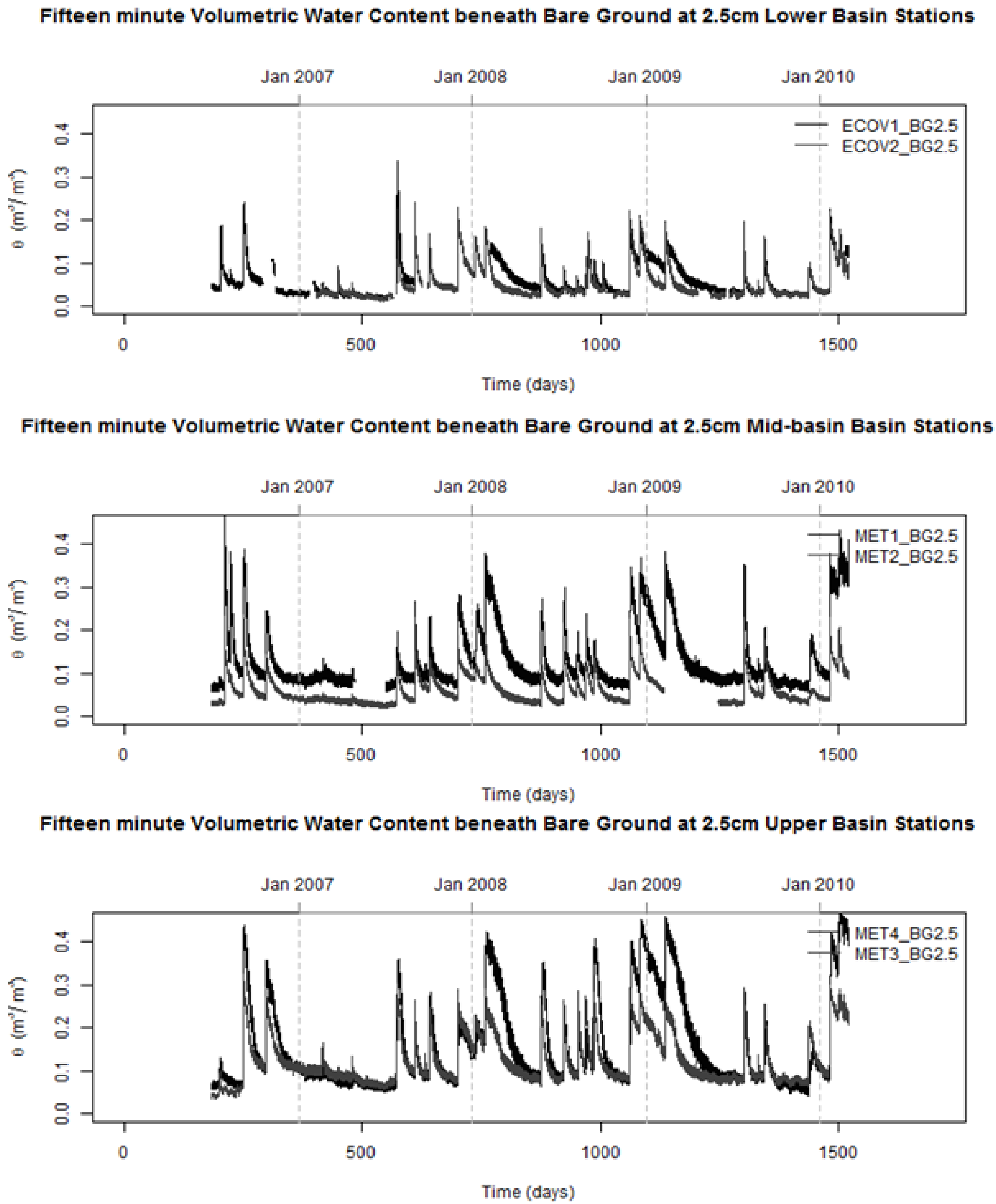


Figure 3.71. Fifteen minute volumetric soil moisture time series data comparing near surface probes at 2.5 cm beneath bare ground, at three basin locations across two geomorphic surfaces. ECOV1, MET1, and MET4 are terrace sites, and ECOV2, MET2, and MET3 are wash sites.

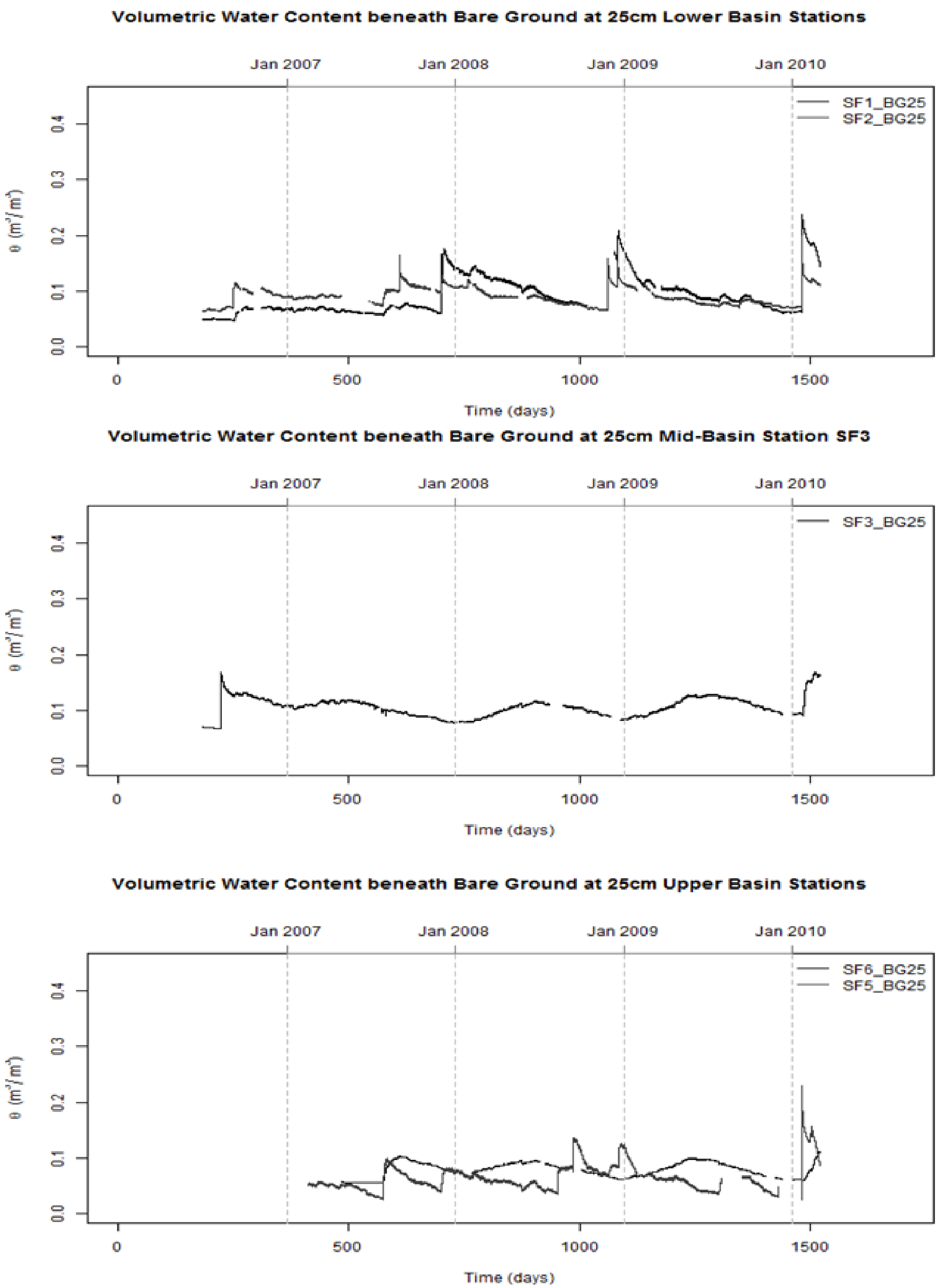


Figure 3.72. Fifteen minute volumetric soil moisture time series data comparing probes at 25 cm beneath bare ground, at three basin locations across two geomorphic surfaces. SF1,SF3, and SF6 are terrace sites, and SF2,SF4, and SF5 are wash sites.

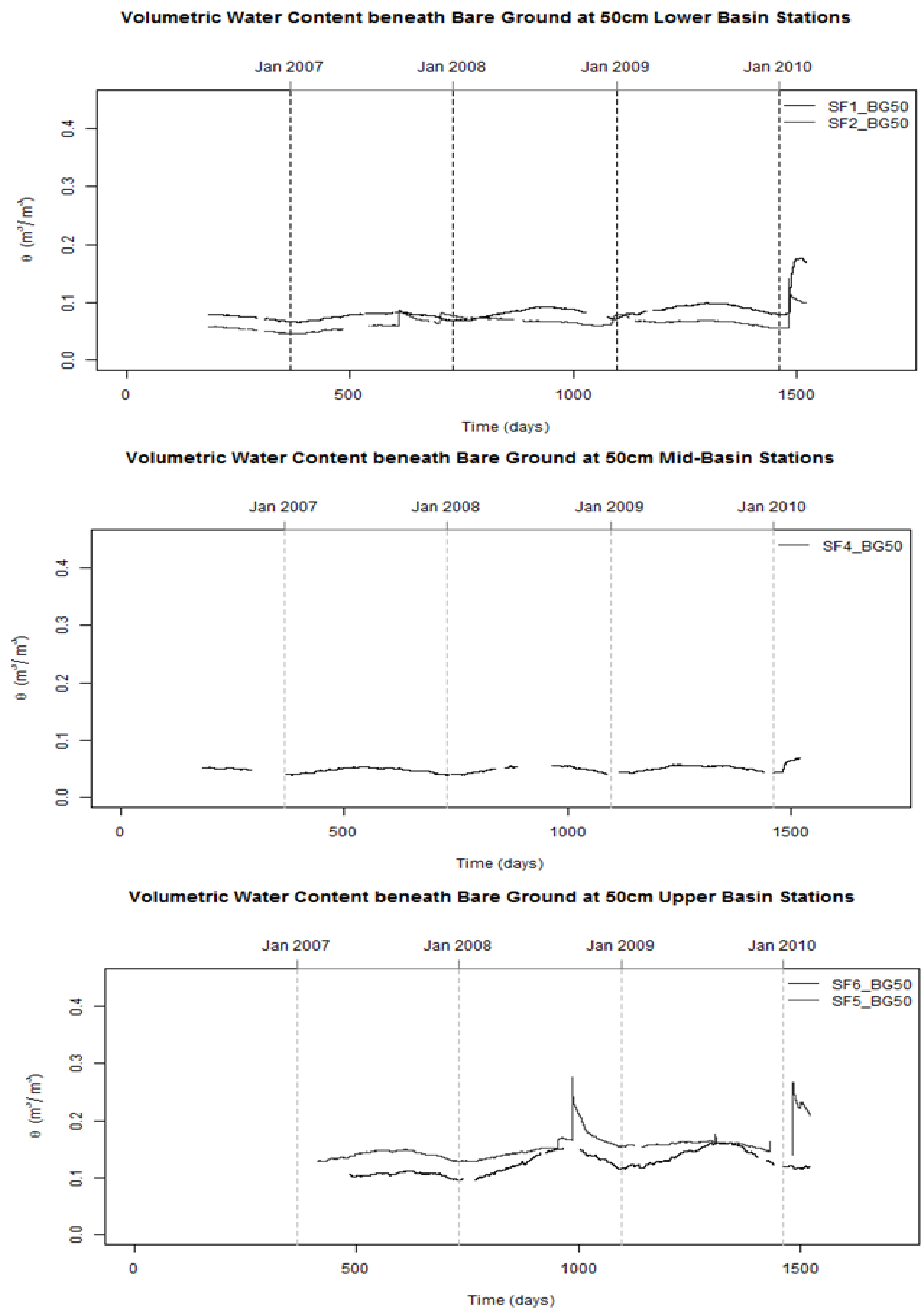


Figure 3.73. Fifteen minute volumetric soil moisture time series data comparing probes at 50 cm beneath bare ground, at three basin locations across two geomorphic surfaces. SF1,SF3, and SF6 are terrace sites, and SF2,SF4, and SF5 are wash sites.

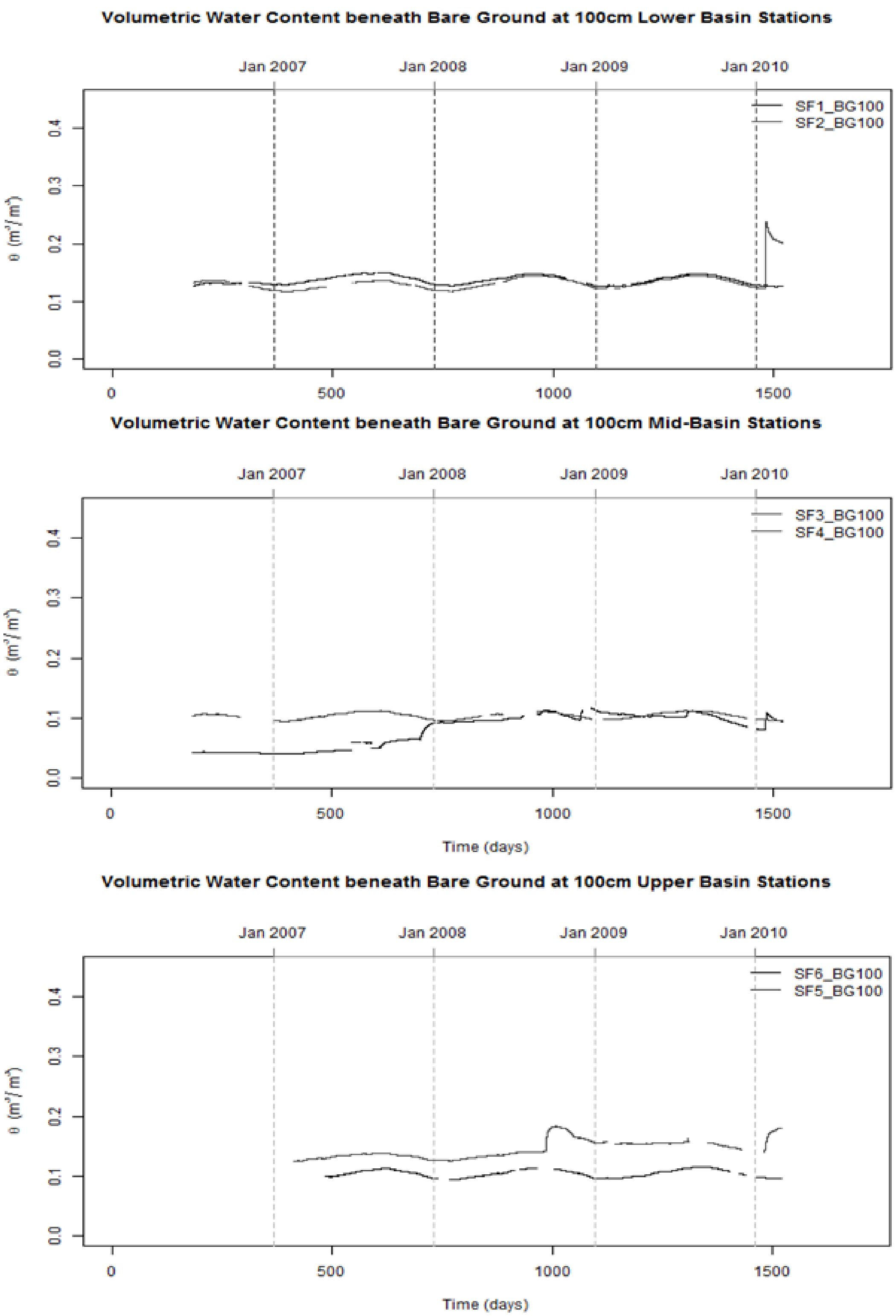


Figure 3.74. Fifteen minute volumetric soil moisture time series data comparing probes at 100 cm beneath bare ground, at three basin locations across two geomorphic surfaces. SF1,SF3, and SF6 are terrace sites, and SF2,SF4, and SF5 are wash sites.

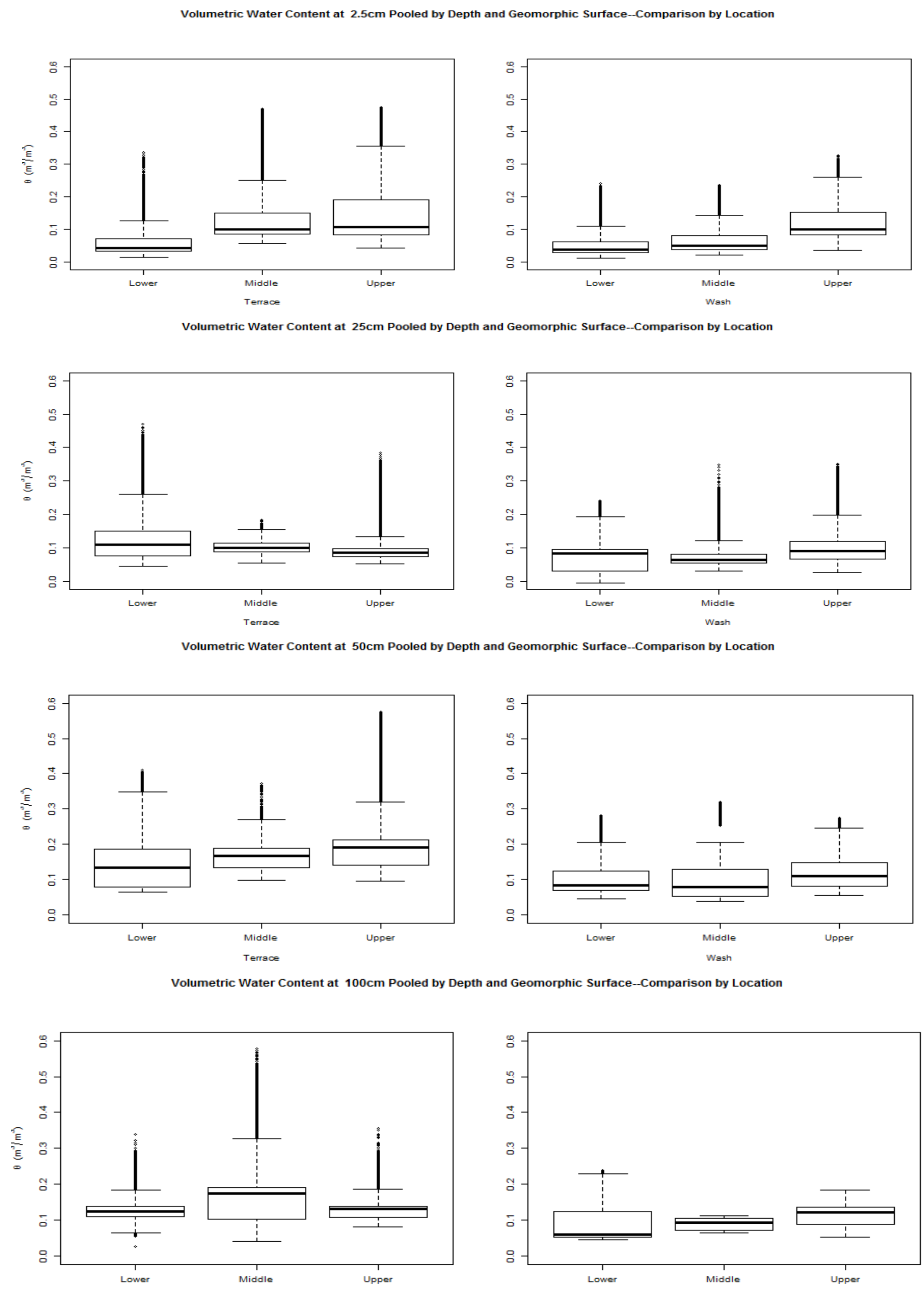


Figure 3.75. Fifteen minute volumetric soil moisture pooled by depth, geomorphic surface, and location in the Yuma Wash watershed.

Table 3.14. Fifteen minute volumetric soil moisture by depth, geomorphic surface, and location.

Depth	θ m^{-3}/m^{-3}					θ m^{-3}/m^{-3}				
	Lower Terrace					Lower Wash				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	0.04	0.01	0.34	0.03	0.07	0.04	0.01	0.24	0.03	0.06
25 cm	0.11	0.05	0.47	0.08	0.15	0.08	0.005	0.24	0.03	0.10
50 cm	0.13	0.07	0.41	0.08	0.19	0.08	0.04	0.28	0.07	0.12
100 cm	0.12	0.03	0.34	0.11	0.14	0.06	0.04	0.24	0.05	0.12
	Middle Terrace					Middle Wash				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	0.10	0.06	0.47	0.08	0.15	0.05	0.02	0.24	0.04	0.08
25 cm	0.10	0.06	0.18	0.09	0.11	0.06	0.03	0.35	0.05	0.08
50 cm	0.17	0.10	0.37	0.13	0.19	0.08	0.04	0.32	0.05	0.13
100 cm	0.17	0.04	0.58	0.10	0.19	0.09	0.06	0.11	0.07	0.10
	Upper Terrace					Upper Wash				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	0.11	0.04	0.48	0.08	0.19	0.10	0.04	0.33	0.08	0.15
25 cm	0.09	0.05	0.38	0.07	0.08	0.09	0.03	0.35	0.07	0.12
50 cm	0.19	0.10	0.57	0.14	0.21	0.11	0.05	0.28	0.08	0.15
100 cm	0.13	0.08	0.36	0.11	0.14	0.12	0.05	0.18	0.09	0.14

translocated to adjacent channels, might lead to less transmission loss wherever present. At the upper sites, a greater degree of soil compaction and possibly greater clays were noted throughout the profiles of both vegetated species during field installation of probes, but thicker calcic horizons were found at the mid-basin sites. Missing data at the upper sites at 25-100 cm in 2006-07 due to delayed installation of probes also added complexity to these analyses, which could not be accounted for.

Trivariate pooling by depth, basin location and cover type does not reflect any clear pattern of increasing soil moisture from lower to upper basin based on cover type at 25-100 cm (Figure 3.76; Table 3.15, Table D54). Statistical tests showed significant differences ($\alpha = 0.05$) between most locations for each cover type, with the exception of *P. microphylla* at 50-100 cm in the middle versus upper basin, *O. tesota* at 25 cm in the middle versus lower basin, and *O. tesota* at 50 cm in the upper versus lower basin. Differences by location were generally more significant for probes beneath bare ground than vegetated cover, but because of the significant

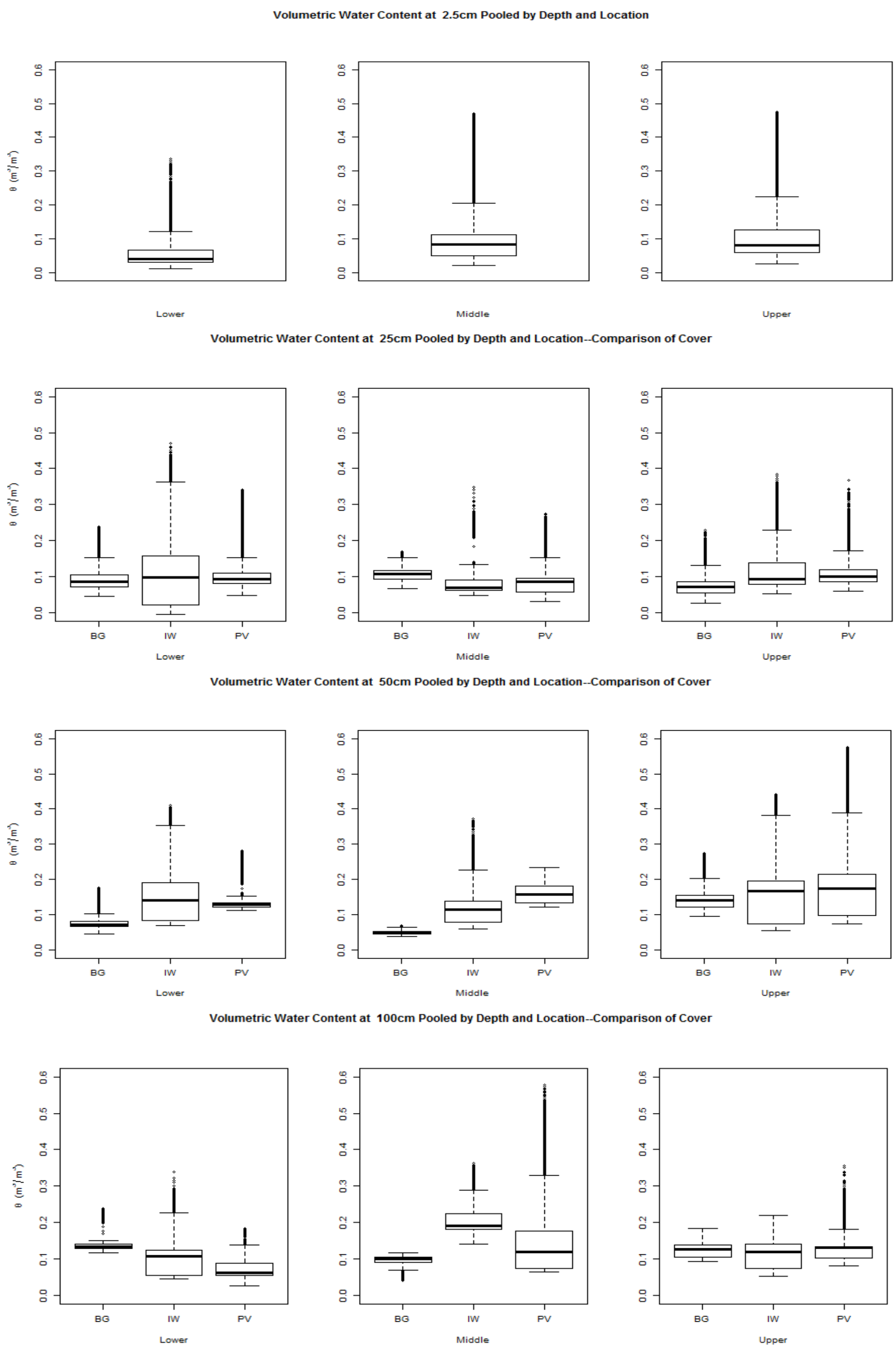


Figure 3.76. Fifteen minute volumetric soil moisture pooled by depth, location, and cover in the Yuma Wash watershed.

Table 3.15. Fifteen minute volumetric soil moisture by depth, location, and cover.

	Median θ m^3/m^3 (Lower)			Median θ m^3/m^3 (Middle)			Median θ m^3/m^3 (Upper)		
	BG	**IW**	**PV**	**BG**	**IW**	**PV**	**BG**	**IW**	**PV**
2.5cm	0.04	N/A	N/A	0.08	N/A	N/A	0.10	N/A	N/A
25cm	0.09	0.10	0.09	0.11	0.07	0.09	0.07	0.09	0.10
50cm	0.07	0.14	0.13	0.05	0.11	0.16	0.14	0.17	0.17
100cm	0.13	0.11	0.06	0.10	0.19	0.12	0.13	0.12	0.13
	Min θ m^3/m^3 (Lower)			**Min θ m^3/m^3 (Middle)**			**Min θ m^3/m^3 (Upper)**		
	BG	**IW**	**PV**	**BG**	**IW**	**PV**	**BG**	**IW**	**PV**
2.5cm	0.01	N/A	N/A	0.06	N/A	N/A	0.04	N/A	N/A
25cm	0.01	0.005	0.05	0.02	0.05	0.03	0.04	0.05	0.06
50cm	0.04	0.07	0.11	0.04	0.06	0.12	0.10	0.05	0.07
100cm	0.12	0.04	0.03	0.04	0.14	0.06	0.09	0.05	0.08
	Max θ m^3/m^3 (Lower)			**Max θ m^3/m^3 (Middle)**			**Max θ m^3/m^3 (Upper)**		
	BG	**IW**	**PV**	**BG**	**IW**	**PV**	**BG**	**IW**	**PV**
2.5cm	0.34	N/A	N/A	0.47	N/A	N/A	0.48	N/A	N/A
25cm	0.24	0.47	0.34	0.17	0.35	0.27	0.23	0.38	0.37
50cm	0.18	0.41	0.28	0.07	0.37	0.23	0.28	0.44	0.57
100cm	0.24	0.34	0.18	0.12	0.36	0.58	0.18	0.22	0.36
	Q1 θ m^3/m^3 (Lower)			**Q1 θ m^3/m^3 (Middle)**			**Q1 θ m^3/m^3 (Upper)**		
	BG	**IW**	**PV**	**BG**	**IW**	**PV**	**BG**	**IW**	**PV**
2.5cm	0.03	N/A	N/A	0.05	N/A	N/A	0.08	N/A	N/A
25cm	0.07	0.02	0.08	0.09	0.06	0.06	0.06	0.08	0.08
50cm	0.07	0.08	0.12	0.04	0.08	0.13	0.12	0.07	0.10
100cm	0.13	0.05	0.05	0.09	0.18	0.07	0.10	0.07	0.10
	Q3 θ m^3/m^3 (Lower)			**Q3 θ m^3/m^3 (Middle)**			**Q3 θ m^3/m^3 (Upper)**		
	BG	**IW**	**PV**	**BG**	**IW**	**PV**	**BG**	**IW**	**PV**
2.5cm	0.06	N/A	N/A	0.11	N/A	N/A	0.17	N/A	N/A
25cm	0.10	0.16	0.11	0.12	0.09	0.10	0.09	0.14	0.12
50cm	0.08	0.19	0.13	0.05	0.14	0.18	0.15	0.20	0.21
100cm	0.14	0.12	0.09	0.11	0.22	0.18	0.14	0.14	0.13

differences that exist between probes of the same cover type on different geomorphic surfaces, and between probes beneath different cover types on the same surface, particularly on terraces where vegetated cover types respond more frequently to precipitation than bare ground at 25-100 cm, it is important to consider individual probe behavior by location and cover for each geomorphic surface separately.

Comparing fifteen-minute time series data for the period of record for each cover type by location and geomorphic surface, data from terraces suggest soil moisture increases from lower to upper basin only at 2.5 cm beneath bare ground. Median differences between the terrace lower and upper basin at 2.5 cm were 7 percent with IQR differences of 5-12 percent, and these differences exceeded the median and IQR error variance associated with soil temperature influences at all terrace locations for this depth. Baseline soil moisture conditions were also higher in the upper relative to the lower terrace site. However, missing data at the lower terraces station (ECOV1) at 2.5 cm make it difficult to determine how much of the difference is due to actual moisture inputs received during the study period. On washes, median soil moisture also increases at 2.5 cm beneath bare ground from lower to upper basin by 6 percent, and the IQR by 5-9 percent, and these differences also exceed the median and IQR error variance associated with soil temperature at this depth. Baseline soil moisture was also higher in the upper basin on washes relative to the lower basin. However, missing data at the lower wash station (ECOV2) at 2.5 cm again make it difficult to determine how much of this difference is due to moisture inputs recorded during the study period.

No consistent increase or decrease in soil moisture at depths of 25-100 cm was found from lower to upper basin on terraces (Figures 3.77-3.84). At 25-100 cm, the number of events recorded on terraces was actually greater in the lower and mid-basin relative to the upper basin beneath vegetative cover, albeit at these depths, data were missing from the upper stations in 2006-07, which may have influenced differences. Data from some sites suggests possible induration from carbonates at various depths in the profiles, which would also have affected moisture conditions. At 25 cm, soil moisture was greater in the lower basin beneath *O. tesota* relative to the upper basin. At 50 cm, the increase in median soil moisture from lower to upper basin on terraces may be reflected in greater retention of soil moisture due to induration between 50-100 cm beneath vegetated species. However, baseline values beneath bare ground were also

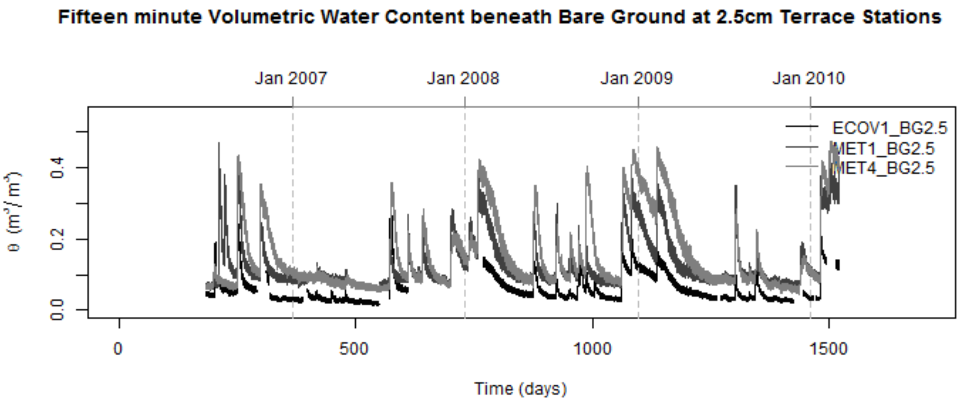


Figure 3.77. Fifteen minute volumetric soil moisture data at 2.5 cm beneath bare ground on terraces for the period of record, illustrating differences in baseline values from lower to upper basin. ECOV1=lower, MET1=middle, and MET4=upper.

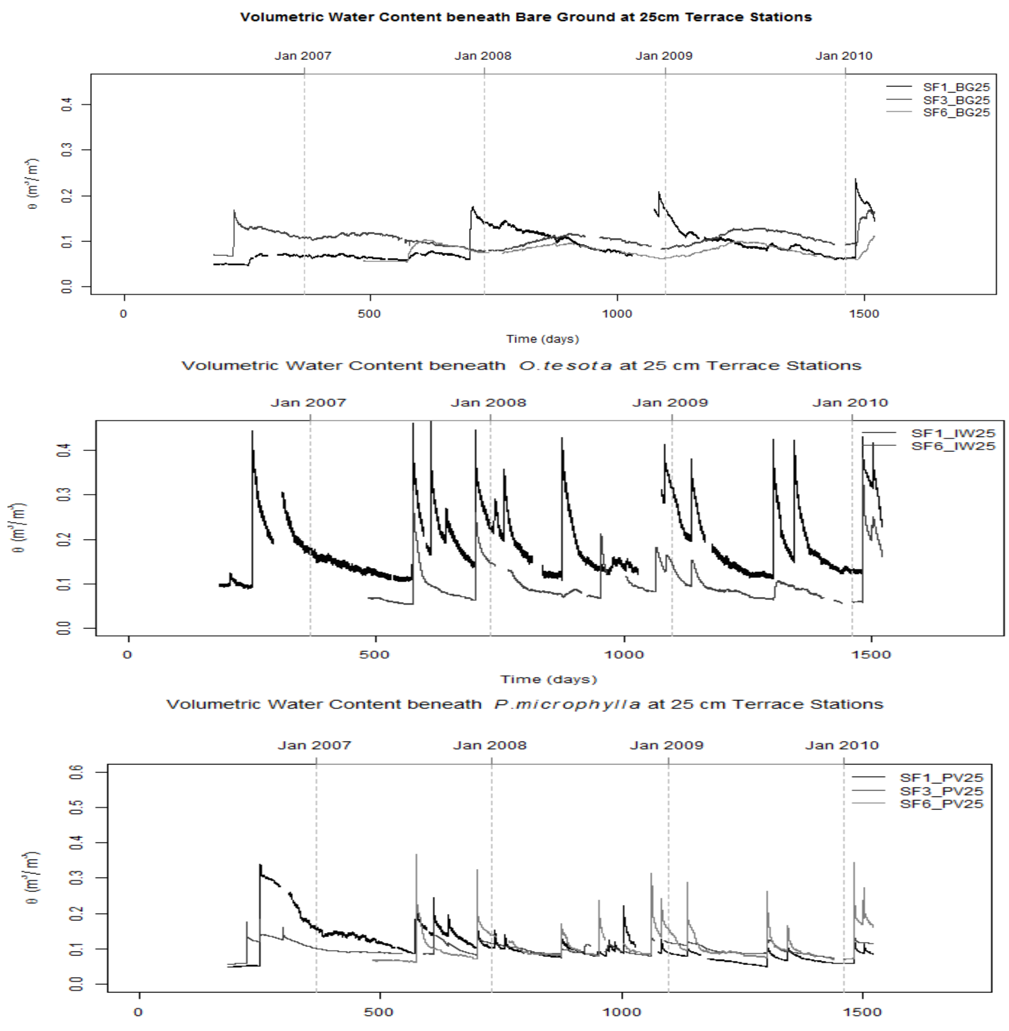


Figure 3.78. Fifteen minute volumetric soil moisture data at 25 cm on terraces for the period of record, illustrating differences in baseline values from lower to upper basin for each cover type. SF1=lower, SF3=middle, SF6=upper.

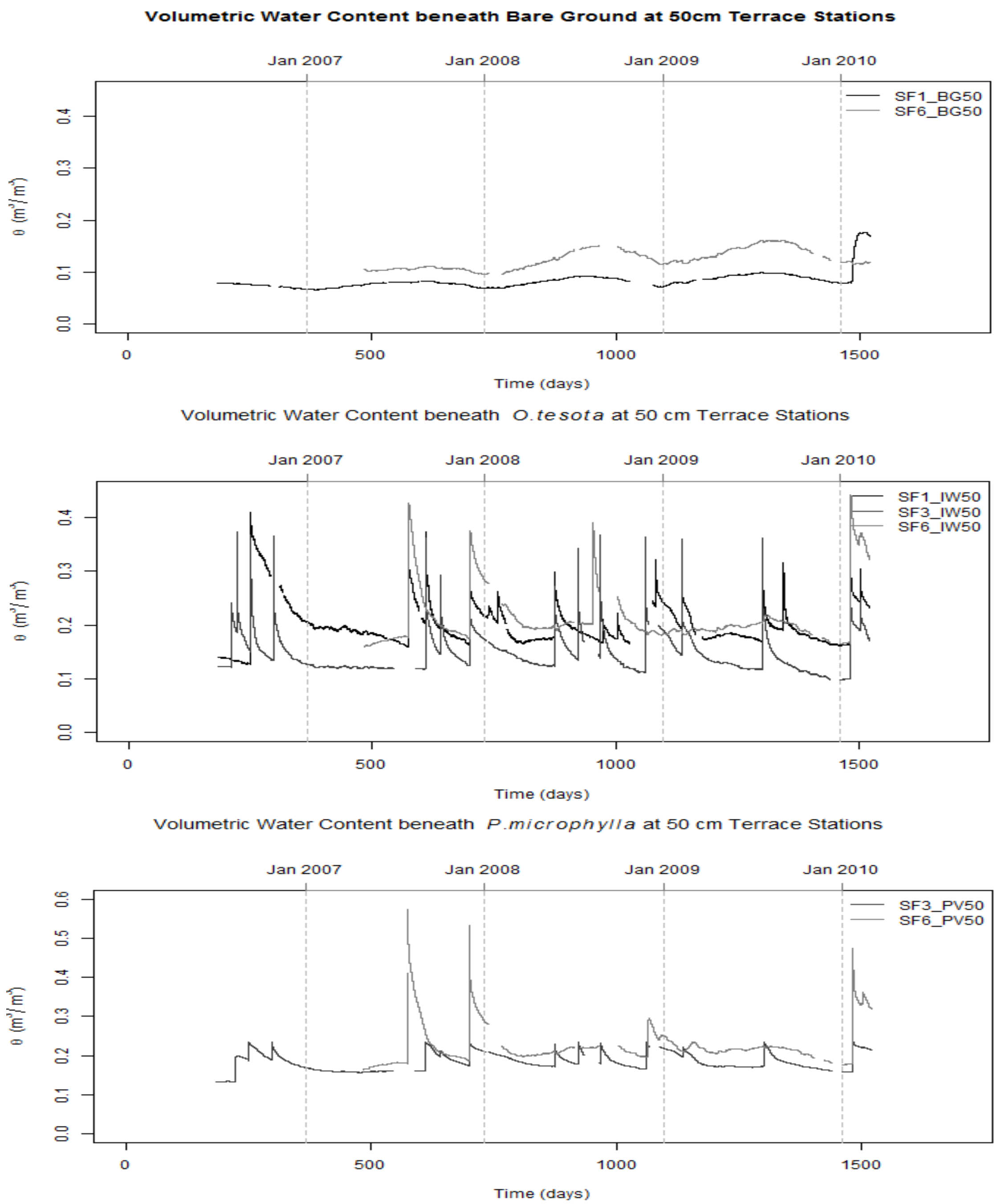


Figure 3.79. Fifteen minute volumetric soil moisture data at 50 cm on terraces for the period of record, illustrating differences in baseline values from lower to upper basin for each cover type. SF1=lower, SF3=middle, SF6=upper.

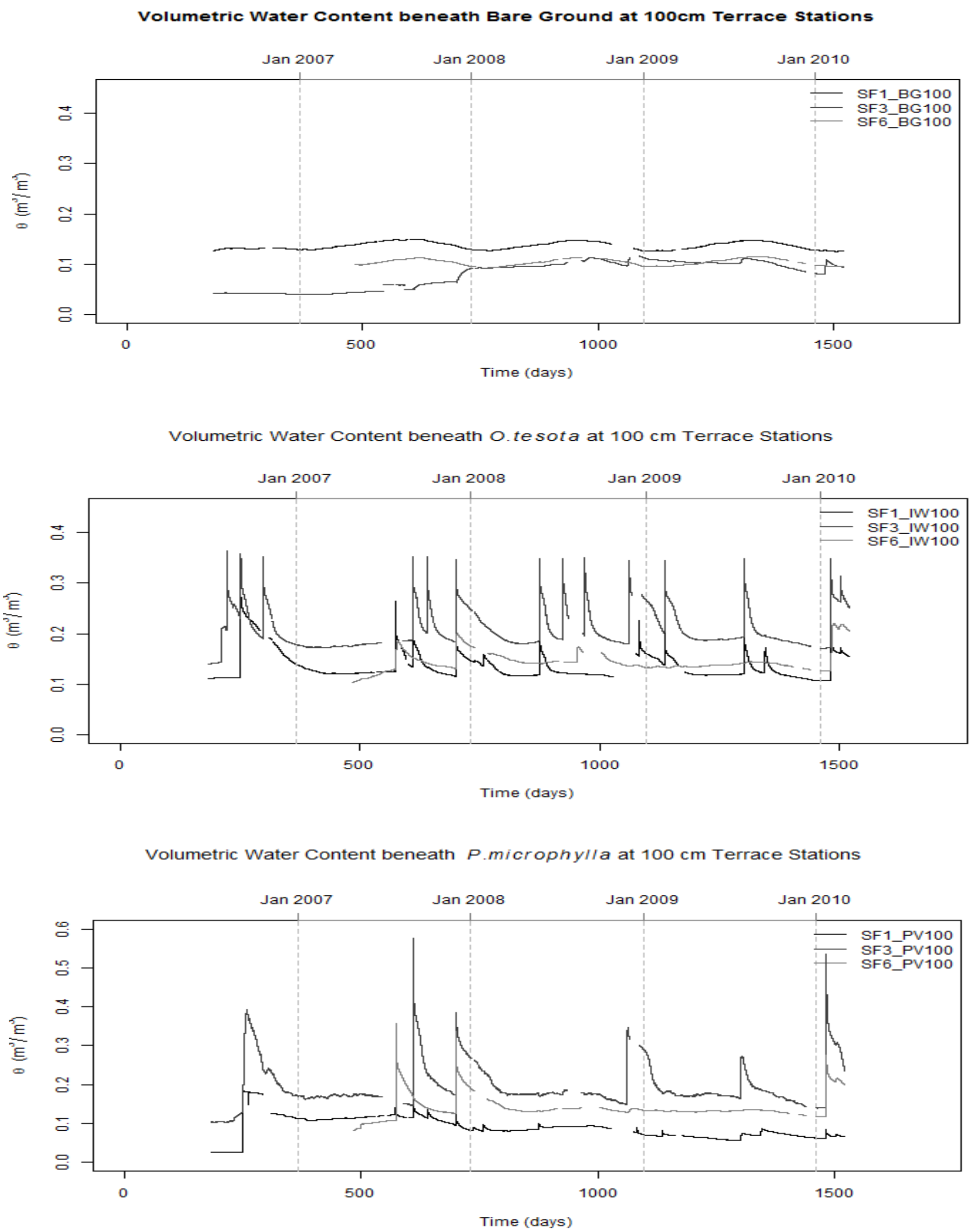


Figure 3.80. Fifteen minute volumetric soil moisture data at 50 cm on terraces for the period of record, illustrating differences in baseline values from lower to upper basin for each cover type. SF1=lower, SF3=middle, SF6=upper.

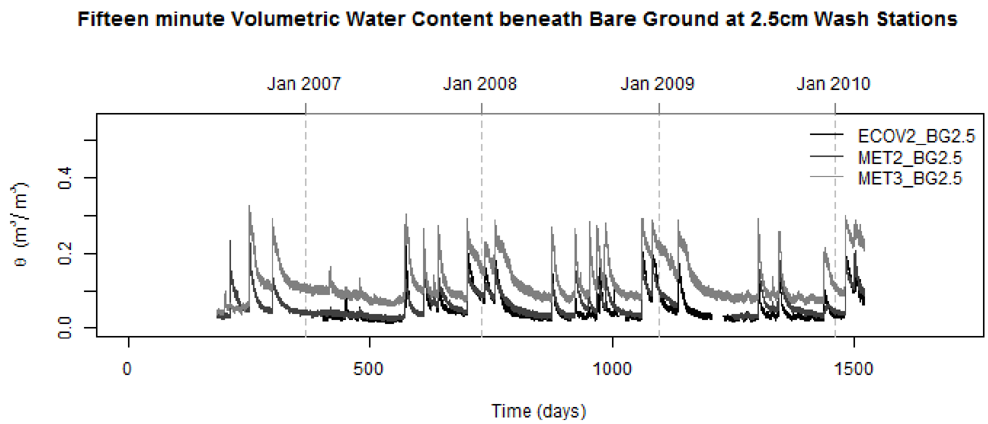


Figure 3.81. Fifteen minute volumetric soil moisture data at 2.5 cm beneath bare ground on washes for the period of record, illustrating differences in baseline values from lower to upper basin. ECOV2=lower, MET2=middle, and MET3=upper.

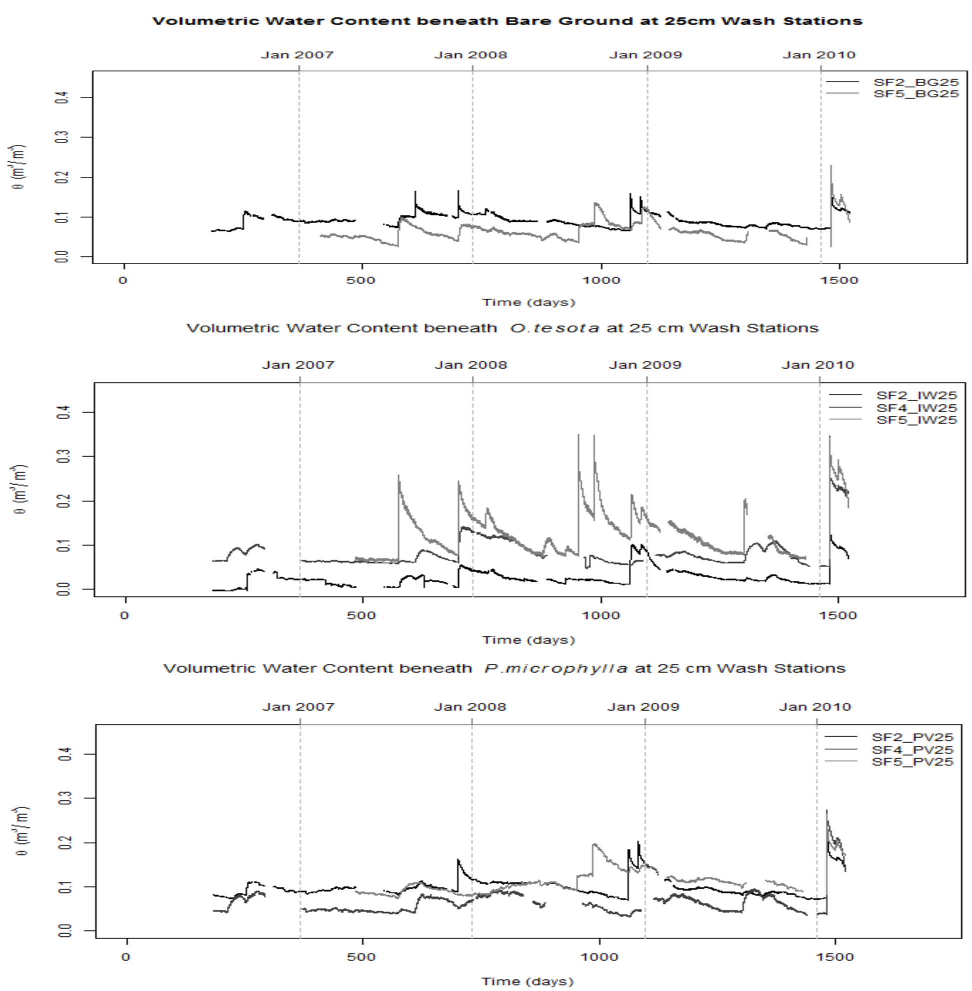


Figure 3.82. Fifteen minute volumetric soil moisture data at 25 cm on washes for the period of record, illustrating differences in baseline values from lower to upper basin.

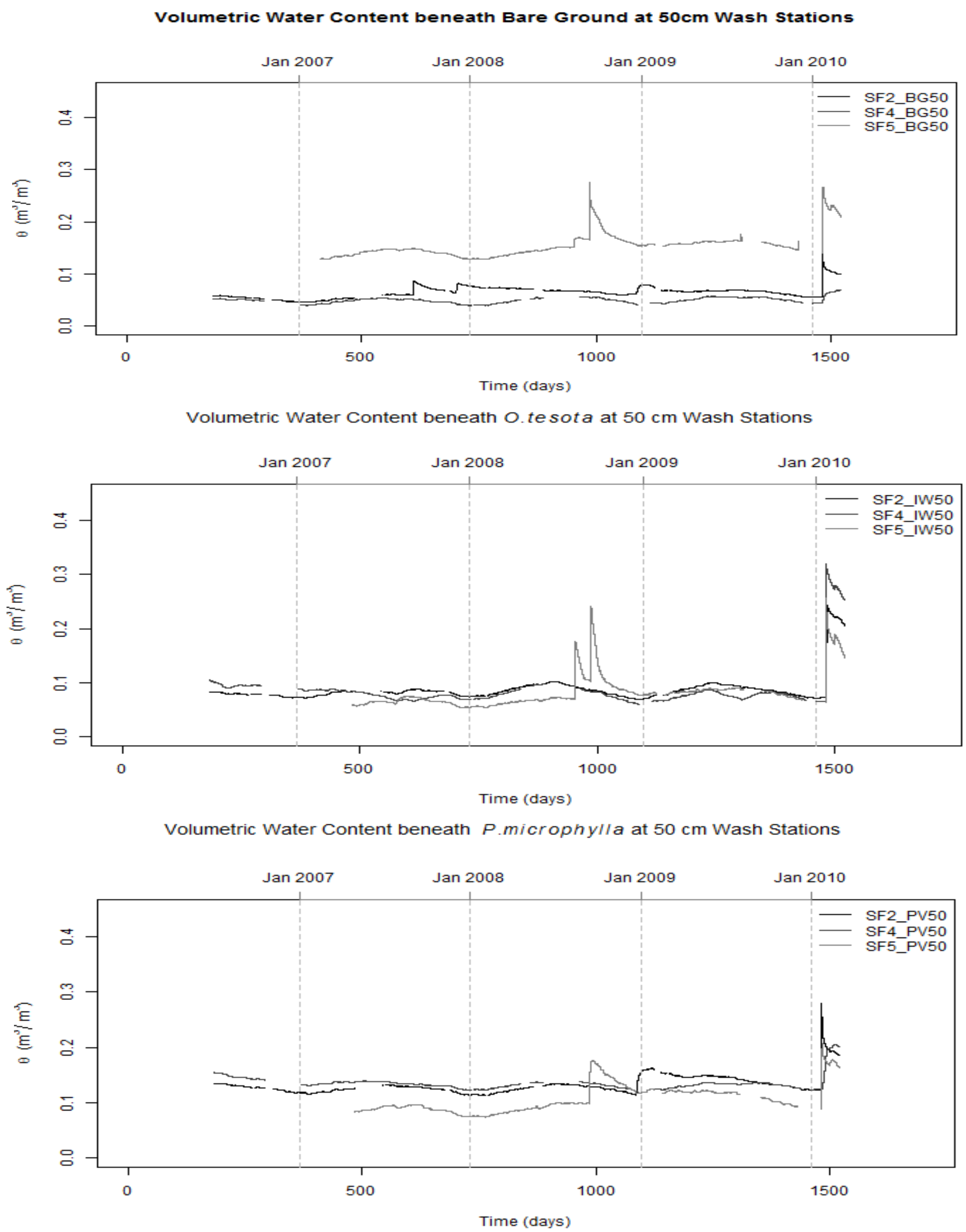


Figure 3.83. Fifteen minute volumetric soil moisture data at 50 cm on washes for the period of record, illustrating differences in baseline values from lower to upper basin.

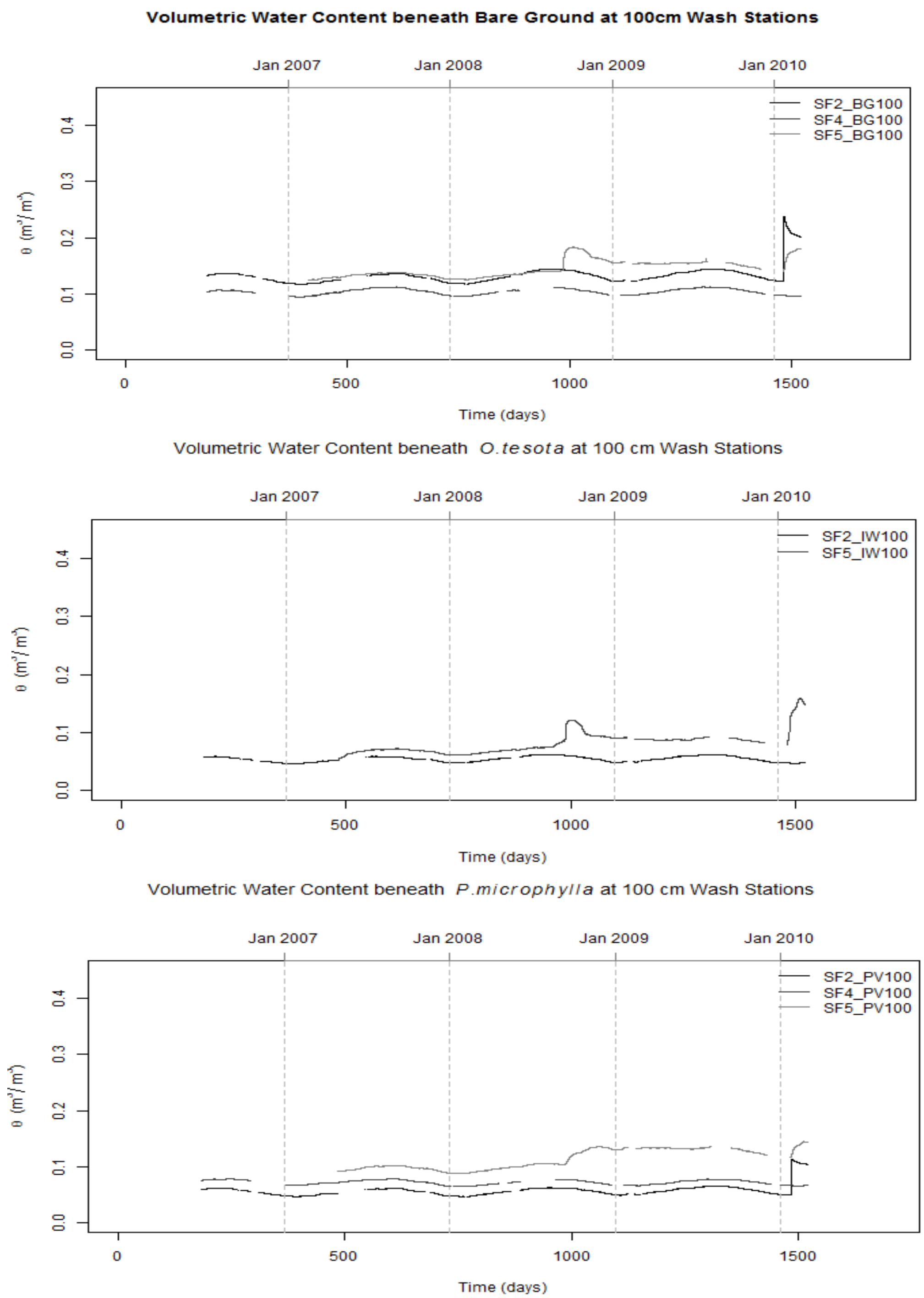


Figure 3.84. Fifteen minute volumetric soil moisture data at 100 cm on washes for the period of record, illustrating differences in baseline values from lower to upper basin.

higher at the upper basin terrace site, where no more than a single event was recorded during the study period. If the accumulation of salts and clays is higher at this site relative to the lower basin, translocation of these constituents may also have resulted in induration at greater depths, but also may have attenuated the probe signal at these depths, adversely affecting moisture readings. At 100 cm, fifteen-minute soil moisture was highest at the mid-basin terrace site, which may be reflective of a greater number of events recorded beneath *O. tesota* relative to the upper basin, but also may be due to higher salt content beneath *P. microphylla* at 100 cm, adversely affecting probe performance.

At 25-100 cm on washes, while the number of events increases from lower to upper basin beneath all cover types, and more so for vegetated cover, fifteen-minute soil moisture beneath *O. tesota* increases from lower to upper basin at 25 and 100 cm, but not at 50 cm, and only at 25 cm by an amount greater than the known error variance associated with soil temperature. And beneath *P. microphylla*, soil moisture increases from lower to upper basin only at 100 cm. Beneath bare ground, wash soil moisture increases at 50-100 cm, but not at 25 cm, and only at 50 cm by an amount greater than the known error variance. At these depths on washes, bare ground differences likely resulted more from baseline differences than in response to events received during the study period. Soil moisture in the upper wash was higher and more similar beneath both vegetated species than bare ground at 25 cm, whereas in the lower wash, soil moisture was lower and differences were greater beneath *O.tesota* relative to *P.microphylla* and bare ground. At 50 cm, soil moisture was higher beneath vegetated species in the lower and mid-basin relative to bare ground, but higher beneath bare ground relative to vegetated species at the upper wash site. It is possible that more frequent runoff in the upper basin from events not documented during the study period, combined with a shallower depth to an impermeable layer, explains some of the increase seen in the wash data, but limited events and lack of detailed hydraulic and pedogenic properties of the soils constrain these analyses, rendering any clear pattern in soil moisture by location difficult to discern.

Spatial analysis of soil moisture conditions specifically during wetting periods was conducted next to provide additional insight. Of the variables estimated from the model designed to identify soil moisture events, event peak magnitude, $\Delta\Theta$, defined as the maximum change in soil moisture content during a wetting event, and the mean event soil moisture, Θ, defined as the average of 15-minute volumetric soil moisture readings from the start to the end points of a wetting event, were chosen for comparison. In order to reduce the effects of soil temperature on peak magnitude at the near surface, temperature corrected soil moisture data at 2.5 cm were used to compare peak magnitudes.

Event mean soil moisture and event magnitude were first compared for differences by geomorphic surface and cover (Figures 3.85-3.86; Tables 3.16-3.17). Bivariate analysis of event means by geomorphic surface and depth, and by cover and depth, showed statistically significant differences in rank sums for both variables at all depths (Table D55). At 2.5 cm beneath bare ground, differences in event means were significant by geomorphic surface, again reflecting higher values on terraces relative to washes. Median soil moisture of the event means was 14 percent on terraces with an IQR of 11-25 percent, and 12 percent with an IQR of 8-16 percent on washes, differing by 2 percent, and 3-9 percent, respectively (Figure 3.86; Table 3.16). Differences at 2.5 cm were also greatest during winter, which may reflect higher retention of moisture on terraces relative to washes during winter months when evaporation plays a lesser role (Figure 3.70). Differences in medians were approximately the same as the known error variance (2 percent or less), but greater than the known error variance in the IQR (2 percent) due

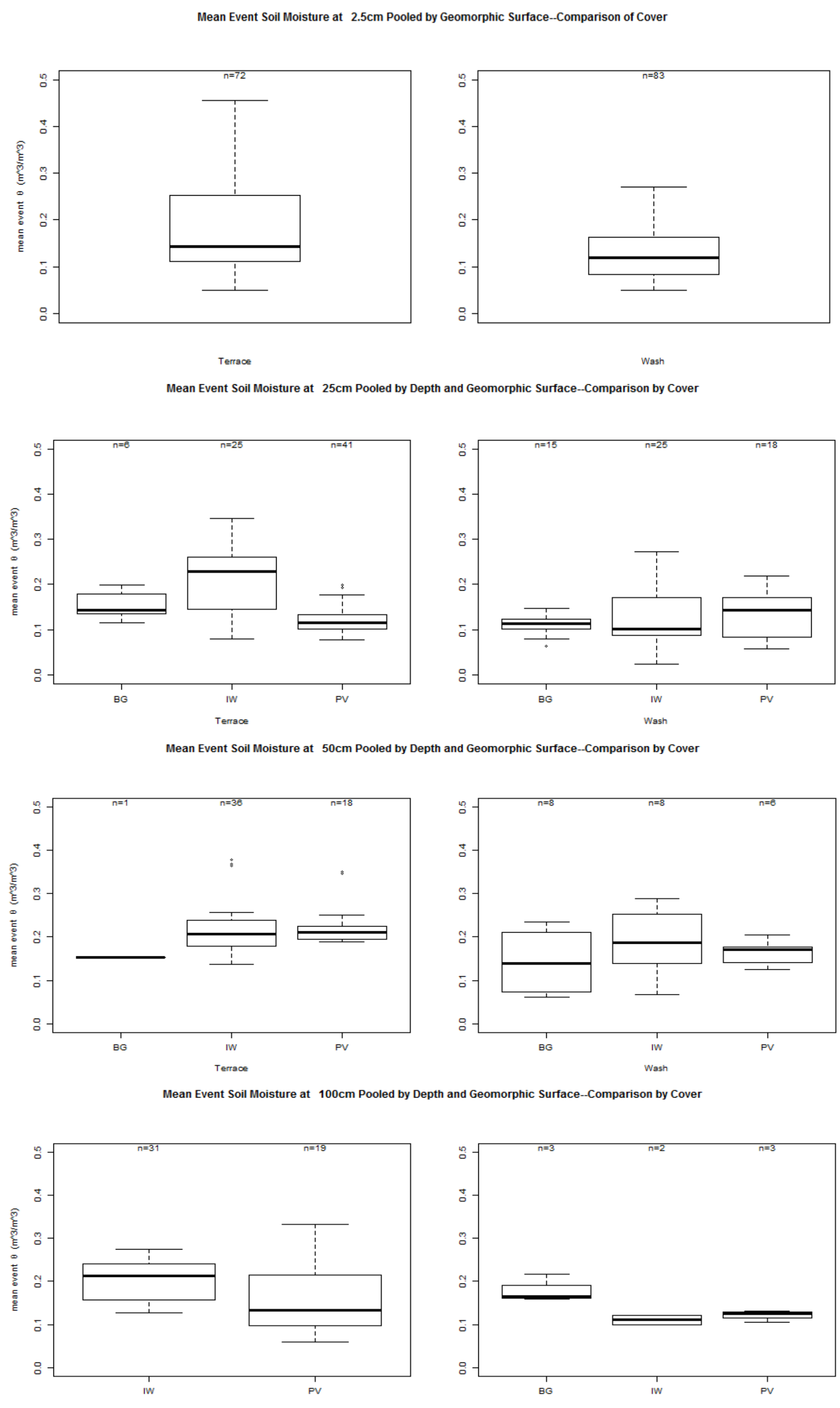


Figure 3.85. Event mean volumetric soil moisture pooled by depth, geomorphic surface and cover. No events recorded beneath bare ground at 100 cm .

Table 3.16. Event mean volumetric soil moisture by depth, geomorphic surface, and cover. Cover types are BG=bare ground, PV=Palo verde (*P.microphylla*), and IW=Ironwood (*O.tesota*).

Depth	Event mean θ m^3/m^3					Event mean θ m^3/m^3				
	BG Terrace					BG Wash				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	0.14	0.05	0.45	0.11	0.25	0.12	0.05	0.27	0.08	0.16
25 cm	0.14	0.12	0.20	0.14	0.17	0.11	0.06	0.15	0.10	0.12
50 cm	0.15	0.15	0.15	0.15	0.15	0.14	0.06	0.23	0.07	0.20
100 cm	--	--	--	--	--	0.16	0.16	0.22	0.16	0.19
	IW Terrace					IW Wash				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
25 cm	0.23	0.08	0.35	0.15	0.26	0.10	0.02	0.27	0.09	0.17
50 cm	0.21	0.14	0.38	0.18	0.24	0.19	0.07	0.29	0.14	0.24
100 cm	0.21	0.13	0.28	0.16	0.24	0.11	0.10	0.12	0.10	0.12
	PV Terrace					PV Wash				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
25 cm	0.12	0.08	0.20	0.10	0.13	0.14	0.06	0.22	0.09	0.17
50 cm	0.21	0.19	0.35	0.20	0.22	0.17	0.12	0.21	0.15	0.18
100 cm	0.13	0.06	0.33	0.10	0.22	0.12	0.10	0.13	0.11	0.13

to soil temperature influences. Trivariate pooling by geomorphic surface and cover reflected estimates of mean event soil moisture that are also greater beneath bare ground at 25 cm on terraces than washes by median differences of 3 percent with IQR differences of 4-5 percent. Differences may be attributed in part to the single bare ground probe at the lower terrace SF1 station, where more events were recorded at 25 cm and may have been due to localized disturbance of desert pavement relative to beneath bare ground at the other two sites, but also may be reflecting high salt contents which attenuated probe readings. Because no more than a single event was recorded on terraces at 25 cm beneath bare ground at SF3 or SF6 sites, it is unlikely that soil moisture is greater beneath bare ground at 25 cm on terraces relative to washes. And, at 50 and 100 cm beneath bare ground, too few events occurred on terraces to allow for statistical comparisons of event-specific metrics.

Beneath vegetated cover, mean event soil moisture was greater at all depths beneath *O. tesota* on terraces relative to washes, and differences were significant at 25 cm, and greater at 50

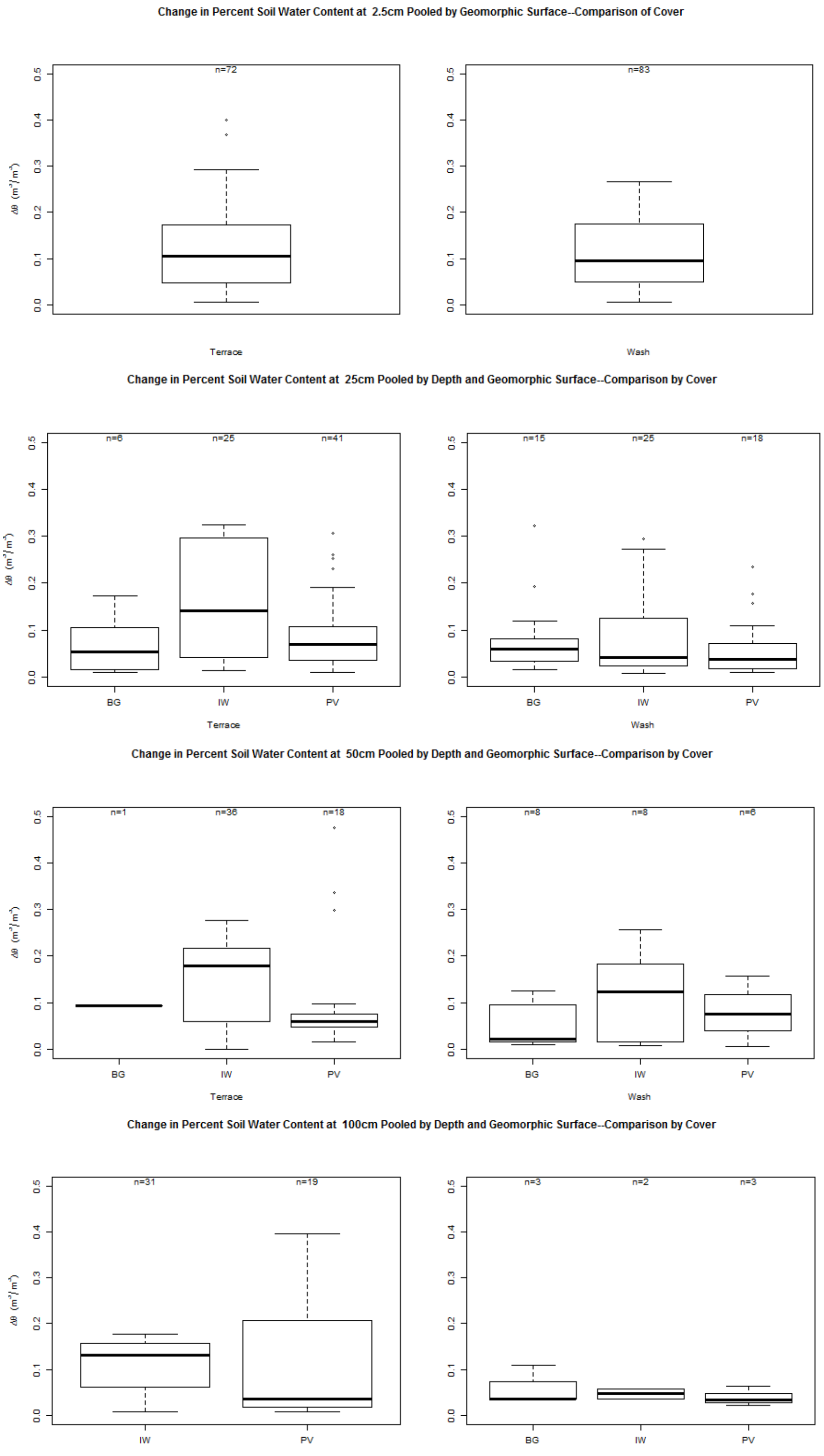


Figure 3.86. Event peak magnitude volumetric soil moisture pooled by depth, geomorphic surface and cover. No events reported beneath bare ground on terraces at 100 cm.

Table 3.17. Event peak magnitude volumetric soil moisture by depth, geomorphic surface, and cover. Cover types are BG=bare ground, PV=Palo verde (*P.microphylla*), and IW=Ironwood (*O.tesota*).

Depth	$\Delta\theta\ m^{-3}/m^{-3}$					$\Delta\theta\ m^{-3}/m^{-3}$				
	BG Terrace					BG Wash				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	0.11	0.01	0.40	0.05	0.17	0.09	0.01	0.27	0.05	0.18
25 cm	0.05	0.01	0.17	0.02	0.09	0.06	0.01	0.32	0.03	0.08
50 cm	0.09	0.09	0.09	0.09	0.09	0.02	0.01	0.13	0.02	0.09
100 cm	--	--	--	--	--	0.04	0.03	0.11	0.04	0.07
	IW Terrace					IW Wash				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
25 cm	0.14	0.01	0.33	0.04	0.30	0.04	0.01	0.30	0.02	0.13
50 cm	0.18	0.01	0.28	0.06	0.22	0.12	0.01	0.26	0.02	0.18
100 cm	0.13	0.01	0.18	0.06	0.16	0.05	0.04	0.06	0.04	0.05
	PV Terrace					PV Wash				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
25 cm	0.07	0.01	0.31	0.04	0.11	0.04	0.01	0.23	0.02	0.07
50 cm	0.06	0.02	0.48	0.05	0.08	0.07	0.01	0.16	0.05	0.11
100 cm	0.04	0.01	0.40	0.02	0.21	0.03	0.02	0.06	0.03	0.05

and 100 cm beneath *P. microphylla* on terraces relative to washes, with significant differences at 50 cm at all locations where comparable probes were operative (Figure 3.85; Tables 3.16, D56-D57). Median of the event means beneath *O. tesota* on terraces at 25 cm was 23 percent with an IQR of 15-26 percent, versus 10 percent on washes with an IQR of 9-17 percent. At 50 cm, differences in medians were only 2 percent with IQR differences of 4 percent or less, and at 100 cm, differences in medians were 10 percent with differences in IQR values of 6-12 percent. At 25 cm beneath *P. microphylla*, event means were not greater than *P. microphylla* on terraces relative to washes (Figures 3.65-3.70; 3.86; Table 3.11). At 50 cm, medians were 21 percent with IQR values of 20-22 percent on terraces, and 17 percent with IQR values of 15-18 percent on washes, a difference of 4 percent in medians and 5-4 percent in IQR values. At 100 cm beneath *P. microphylla*, differences in medians were only 1 percent, but the IQR differed by 1-9 percent (Figure 3.85; Table 3.16). These differences exceed known error variance for event means associated with soil temperature influences at 25-100 cm, which was less than 1 percent for medians, and are generally less than 2 percent for the IQR for both species on either surface, but for a few probes beneath *O. tesota* and *P. microphylla*. Based on the number of events recorded beneath these two species on terraces relative to washes, and mean event soil moisture, it is therefore likely that the differences found between these species on different geomorphic surfaces are due to higher and more frequent soil moisture inputs.

Trivariate tests for significance in event means could not be run between probes on different geomorphic surfaces at 100 cm, or between bare ground and vegetated cover types on the same geomorphic surface at 25-100 cm, due to either low n-values beneath bare ground at all depths (in the case of terraces), low n-values beneath all cover types at 100 cm on washes, or too many ties in ranked values. However, median values and/or variance of event means were greater beneath *O. tesota* relative to bare ground at 25 cm across both geomorphic surfaces, with differences that exceeded the error variance associated with soil temperature (Figure 3.85; Table 3.16). Median soil moisture for event means was the same at 25 cm beneath *P. microphylla* and bare ground at the lower terrace site, but only a single event occurred beneath bare ground relative to *P. microphylla* at the mid-basin site, and no events occurred beneath bare ground at the upper terrace site. Finally, since only a single event was recorded at 50 cm beneath bare ground at the lower terrace site, and no events were recorded at the other two sites or at 100 cm on any terrace site, event mean soil moisture comparisons between bare ground and *O. tesota* and *P. microphylla* are not relevant. Bivariate analysis of differences in rank sums of event means by depth and cover (pooling all data across both geomorphic surfaces) were most significant between *O. tesota* and bare ground at 25 and 50 cm, between bare ground and *P. microphylla* at 50 cm, but also beneath *O. tesota* and *P. microphylla* at 25 and 100 cm (Table D58). Differences between *O. tesota* and *P. microphylla* reflected generally greater event means for *O. tesota* relative to *P. microphylla* at 25 and 100 cm on terraces, but greater means for *P. microphylla* relative to *O.tesota* at 25 and 100 cm on washes, albeit no statistically significant differences were found in rank sums of event means between these species on washes (Table D57). Based on the number of events recorded beneath bare ground versus vegetated cover on terraces, and values of mean event soil moisture, it is likely that greatest and most consistent differences in event soil moisture means between bare ground and vegetated cover types at 25-100 cm can be attributed more so to terrace surfaces than to washes, where soil moisture was greater beneath vegetated species than bare ground, and especially between bare ground and *O. tesota* (Figure 3.85; Table 3.16).

As was the case with event means, trivariate tests for significance in peak magnitudes could not be run between probes of the same cover type on different geomorphic surfaces at 100 cm, or between bare ground and vegetated cover types on the same geomorphic surface at 25-100 cm, due to either low n-values beneath bare ground at all depths (in the case of terraces), low n-values beneath all cover types at 100 cm on washes, or too many ties in ranked values. Bivariate analysis of event peak magnitudes by geomorphic surface and depth showed statistically significant differences in rank sums by geomorphic surface and depth at 25 and 50 cm, and near significant at 100 cm at α =0.10; significant differences in peak magnitudes were not found at 2.5 cm using temperature-corrected data. By cover and depth, differences were significant only at 50 cm (Table D60), and these were found between *O. tesota* and bare ground, and between *O. tesota* and *P. microphylla* (Table D61), where *O. tesota* showed greater event magnitudes than bare ground or *P. microphylla*. At 2.5 beneath bare ground, event peak magnitudes did not differ by more than 2 percent by geomorphic surface, with the exception of a few data points. Median peak magnitudes at 2.5 cm were 11 percent with an IQR of 5-17 percent on terraces, and 9 percent with an IQR of 5-18 percent on washes (Figure 3.86; Table 3.17). At 25 cm beneath bare ground, peak magnitude differences were also very small by geomorphic surface, and at 50 and 100 cm beneath bare ground, too few events occurred on terraces to allow for statistical comparisons (Figures 3.71-3.74).

Beneath vegetated cover, event peak magnitudes were greater beneath *O. tesota* on terraces relative to washes at all depths, and significant at 25 cm, and greater between *P. microphylla* on terraces relative to washes at 25 and 100 cm but not at 50 cm, and not significantly at any depth (Figures 3.65-3.70; 3.86; Tables 3.17, D58-D59). At 25 cm beneath terrace *O. tesota,* median event peak magnitude was 14 percent with an IQR of 4-30 percent, whereas on washes, it was 4 percent with an IQR of 2-13 percent, a median difference of 10 percent and IQR difference of 2-17 percent. At 50 cm beneath terrace *O. tesota*, median peak magnitudes were 18 percent with an IQR of 6-22 percent, and 12 percent with an IQR of 2-18 percent on washes, a difference of 6 percent with an IQR difference of 4 percent. At 100 cm, medians were 13 percent with an IQR of 6-16 beneath terrace *O. tesota*, and 5 percent with an IQR of 4-5 percent beneath wash *O. tesota*, a difference of 8 percent with an IQR difference of 2-11 percent. For *P. microphylla*, differences in median peak magnitudes were not as substantial by geomorphic surface (1-3 percent) as between *O. tesota,* and medians and IQR values were generally not greater than the error variance.

Comparing cover types on the same surface, peak magnitudes were greatest beneath *O. tesota* relative to bare ground, and between *P. microphylla* and bare ground at 25-50 cm on terraces (Figure 3.86; Table 3.17). Median differences in magnitudes at 25 cm between *O. tesota* and bare ground on terraces were 9 percent with IQR differences of 2-21 percent, but only 2 percent between *P. microphylla* and bare ground. At 50 cm, median magnitudes were also greater for *O. tesota* relative to bare ground by 9 percent, and 5 percent for *P. microphylla* relative to bare ground, and these comparisons are based on only a single event which occurred at 50 cm beneath any bare ground terrace probe. On washes, differences in peak magnitudes beneath *O. tesota* and bare ground, and *P. microphylla* and bare ground were only greater at 50 cm, and not consistently so across all sites. Differences between *O. tesota* and *P. microphylla* reflected generally greater magnitudes for *O. tesota* at 25 and 50 cm on both surfaces, and on terraces differences were significant (Figure 3.86; Tables 3.17, D60). Median differences at 25 cm on terraces were 7 percent with a IQR differences of 0-19 percent; at 50 cm, 8 percent with IQR differences of 1-14 percent, and at 100 cm, 9 percent with IQR differences of 4-5 percent. No significant differences were found in rank sums of event magnitude between these species on washes (Table D60). Based on the limited number of events recorded beneath bare ground relative to beneath both vegetated species on terraces, and median values and the overall spread of the data for peak magnitudes beneath vegetated cover, it is likely that greatest differences in peak magnitudes occurred between *O. tesota* and bare ground and *O. tesota* and *P. microphylla* on terraces.

Event mean soil moisture and event magnitude were next examined for differences by geomorphic surface and location (Figure 3.87; Table 3.18). Bivariate analysis of event means by depth and by location revealed significant differences in rank sums between all locations at all depths (Table D61). Trivariate analysis by depth, location, and geomorphic surface showed significant differences in rank sums of event means between most locations at most depths on both surfaces (Table D62). On washes, event means appear greater in the upper basin relative to the lower basin sites at 2.5-50 cm, and differences were significant at 2.5 and 25 cm, but not at 50-100 cm (Figure 3.87; Tables 3.18, D62). Terrace event means also appear greater in the

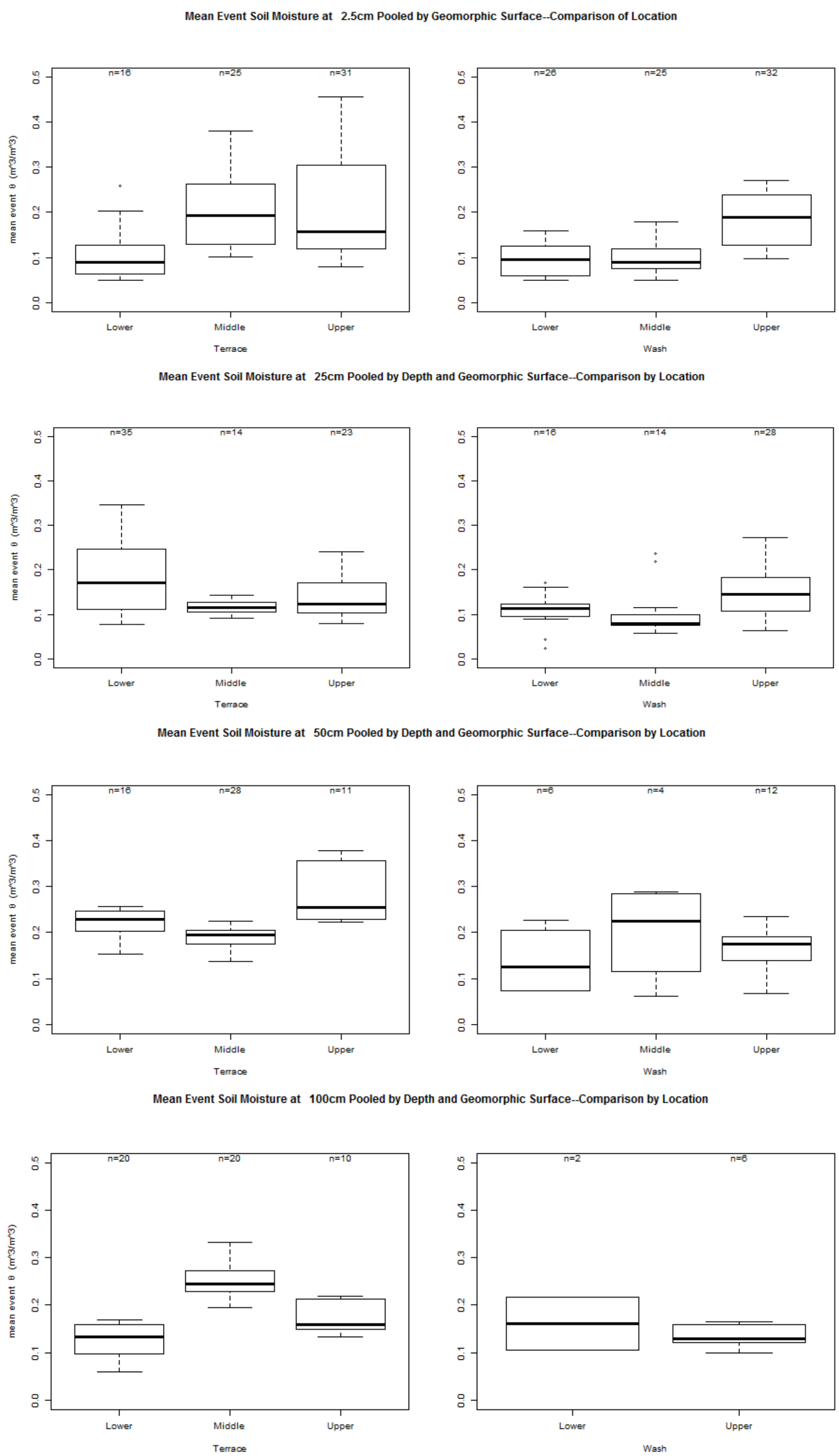


Figure 3.87. Event mean volumetric soil moisture pooled by depth, geomorphic surface, and location in the Yuma Wash watershed.

Table 3.18. Event mean volumetric soil moisture by depth, geomorphic surface, and location.

Depth	Event mean θ m^{-3}/m^{-3}					Event mean θ m^{-3}/m^{-3}				
	Lower Terrace					Lower Wash				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	0.09	0.05	0.26	0.06	0.13	0.10	0.05	0.16	0.06	0.13
25 cm	0.17	0.07	0.35	0.11	0.25	0.11	0.02	0.17	0.09	0.12
50 cm	0.23	0.15	0.26	0.20	0.25	0.12	0.07	0.23	0.08	0.19
100 cm	0.13	0.06	0.17	0.10	0.16	0.16	0.10	0.22	0.13	0.19
	Middle Terrace					Middle Wash				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	0.19	0.10	0.38	0.13	0.26	0.09	0.05	0.18	0.07	0.12
25 cm	0.12	0.09	0.14	0.11	0.13	0.08	0.05	0.24	0.08	0.10
50 cm	0.19	0.14	0.22	0.18	0.21	0.22	0.06	0.29	0.14	0.28
100 cm	0.24	0.19	0.33	0.23	0.27	--	--	--	--	--
	Upper Terrace					Upper Wash				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	0.16	0.08	0.46	0.12	0.30	0.19	0.10	0.27	0.13	0.24
25 cm	0.12	0.08	0.24	0.10	0.17	0.14	0.06	0.27	0.11	0.18
50 cm	0.25	0.22	0.38	0.23	0.36	0.17	0.07	0.23	0.14	0.19
100 cm	0.16	0.13	0.22	0.15	0.21	0.13	0.10	0.16	0.12	0.15

upper basin relative to the lower basin sites and were significant for all depths except 25 cm (Table D62). However, as was the case with analysis of 15-minute data for the period of record, variability by cover across different geomorphic surfaces required evaluating differences by location by considering individual probe behavior.

Comparing event means for each cover type by location on each of the geomorphic surfaces, with the exception of beneath bare ground at 2.5 cm, the data do not suggest any consistent pattern of increasing or decreasing soil moisture at 25-100 cm on either geomorphic surface from lower to upper basin. At 2.5 cm beneath bare ground on terraces, medians of the event means differed by 7 percent with IQR differences of 6-17 percent between the lower and upper basin, and by 10 percent with IQR differences of 7-13 percent between the lower and middle basin (Figure 3.87; Table 3.18). On washes, median event mean soil moisture increases at 2.5 cm from lower to upper basin by a difference of 9 percent with an IQR increase of 7-11 percent, and from middle to upper basin by a difference of 10 percent with IQR differences of 6-

12 percent. At 25 cm on washes, the increase in event means from lower to upper basin can be attributed solely to *O. tesota;* event means did not increase from lower to upper basin beneath *P. microphylla* or bare ground (Figure 3.82). Medians beneath *O. tesota* at 25 cm increased by a difference of 10 percent from lower to upper basin on washes. Yet at 50 cm, wash event means increased from lower to upper basin for bare ground and *P. microphylla*, but not for *O. tesota* (Figure 3.83), and medians did not differ by more than 2 percent, with the exception of bare ground. In this case, differences may be more due to baseline values rather than soil moisture events recorded during the period of study. And while pooled differences at 100 cm may be in part influenced by a slightly greater number of events recorded at the upper wash basin relative to the lower, differences are likely more influenced by the greater baseline values seen at the upper site relative to the lower site, especially beneath *P. microphylla.* On terraces, greater event means in the upper site relative to the lower at 50-100 cm as seen in pooled data by geomorphic surface and location may be due in part to an overall greater number of events recorded at the *lower* terrace site, including smaller events that were not captured at the upper site. A greater number of smaller events recorded at the lower site resulted in a median value for event means that was less than that for the upper site, where only larger events were recorded at these depths. This proved to be an inherent limitation of comparing event-specific variables with differing n-values, which is further discussed in Chapter 4. A decrease in the number of events recorded at the upper basin terrace site relative to the lower basin at 50-100 cm likely reflects differences in soil characteristics between sites, which may impede infiltration at the upper site for smaller events.

Event magnitudes were examined next for differences by geomorphic surface and location. Bivariate analysis by depth and by location revealed significant differences in rank sums only at 25 and 100 cm, and only between the lower and mid-basin, and the mid- and upper basin stations, albeit with opposite trends. Terrace peak magnitudes were greater in the lower versus mid-basin site at 25 cm, but higher at the mid-basin versus lower site at 100 cm (Figures 3.78, 3.80; Tables D63-D64). Terrace magnitudes were also higher in the upper basin relative to the mid-basin at 25 cm, whereas at 100 cm, magnitudes were higher in the mid-basin relative to the upper basin. Statistically significant differences were not found in rank sums for peak magnitudes between the lower and upper basin with the exception of 100 cm on washes, and this was based on a very few number of events. As with event means, these data required further scrutiny of individual probe data.

While median values and variance of event magnitudes at 2.5 cm beneath bare ground are greater at the upper basin sites relative to the lower sites on both geomorphic surfaces, statistical differences in rank sums by geomorphic surface and location were not found (Figures 3.77, 3.81, 3.88; Tables 3.19, D60, D65). Median differences at 2.5 cm between the lower and upper basin were 3 percent with IQR differences of 1-2 percent on terraces; on washes, median differences were 4 percent, with IQR differences of 0-4 percent. Since data at 2.5 cm were temperature corrected for peak magnitude analysis, error variance due to soil temperature influences does not require considering.

At 25 cm on terraces, greatest median differences in peak magnitudes were 6 percent with IQR differences of 4-12 from mid- to upper basin, and are likely due to higher magnitudes beneath *P. microphylla* at the upper site, but are also likely influenced by missing data for the mid-basin terrace probe beneath *O. tesota* (SF3IW25). At 100 cm on terraces, a greater response beneath *O. tesota* at the mid-basin site relative to the upper site likely influenced magnitude differences between these two sites at this depth. High peak magnitudes, likely reflective of high

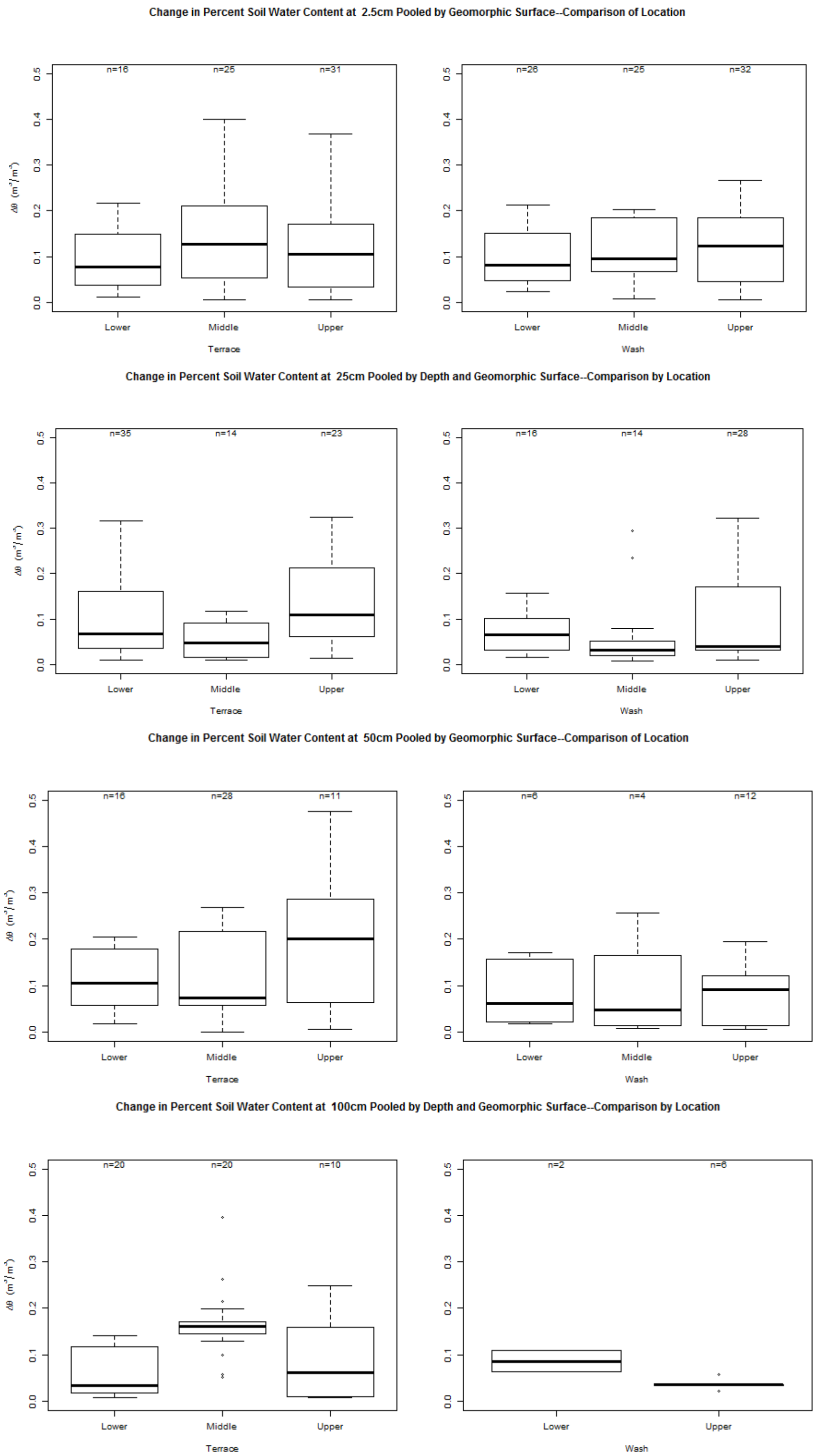


Figure 3.88. Event peak magnitude volumetric soil moisture (Δθ m^{-3}/m^{-3}) pooled by depth, geomorphic surface and location.

Table 3.19. Event peak magnitude volumetric soil moisture ($\Delta\theta$ m^{-3}/m^{-3}) by depth, geomorphic surface, and location.

Depth	$\Delta\theta$ m^{-3}/m^{-3}					$\Delta\theta$ m^{-3}/m^{-3}				
	Lower Terrace					Lower Wash				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	0.08	0.01	0.22	0.04	0.15	0.08	0.02	0.21	0.05	0.15
25 cm	0.07	0.01	0.32	0.04	0.16	0.07	0.01	0.16	0.03	0.10
50 cm	0.11	0.02	0.21	0.06	0.18	0.06	0.02	0.17	0.03	0.14
100 cm	0.03	0.01	0.14	0.02	0.12	0.09	0.06	0.11	0.07	0.10
	Middle Terrace					Middle Wash				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	0.13	0.01	0.40	0.05	0.21	0.10	0.01	0.20	0.07	0.18
25 cm	0.05	0.01	0.12	0.02	0.09	0.03	0.01	0.30	0.02	0.05
50 cm	0.07	0.01	0.27	0.06	0.22	0.05	0.01	0.26	0.02	0.12
100 cm	0.16	0.05	0.40	0.15	0.17	--	--	--	--	--
	Upper Terrace					Upper Wash				
	Median	Min	Max	Q1	Q3	Median	Min	Max	Q1	Q3
2.5 cm	0.11	0.01	0.37	0.03	0.17	0.12	0.01	0.27	0.05	0.19
25 cm	0.11	0.01	0.33	0.06	0.21	0.04	0.01	0.32	0.03	0.17
50 cm	0.20	0.01	0.48	0.06	0.29	0.09	0.01	0.20	0.02	0.12
100 cm	0.06	0.01	0.25	0.01	0.14	0.03	0.02	0.06	0.03	0.04

electrical conductivity in soils at mid-basin *P. microphylla* probe SF3PV100, along with a lesser number of recorded events at the upper terrace site at 100 cm, also likely influenced this outcome. At 25 cm on washes, higher magnitudes found at the lower site relative to the mid-basin are due only to differences in peak magnitudes recorded beneath *P. microphylla*. At 100 cm on washes, no events were recorded at the mid-basin site, so comparisons could not be made.

Event means and event peak magnitudes were also compared by cover and location by pooling data for both geomorphic surfaces (Figures 3.89-3.90; Tables 3.20-3.21), but because of the differences found by cover type and geomorphic surface for terraces, these comparisons are also difficult to interpret and required referring to individual probe behavior. Statistical tests could not be run by location and cover between lower and mid-basin, or between upper and mid-basin sites due to low n-values for one of the datasets. Significant differences in rank sums of event means were found between the lower and upper basin sites, beneath bare ground at 2.5 and 50 cm, between *O. tesota* at 25 cm, and between *P. microphylla* at 25 and 100 cm, but no

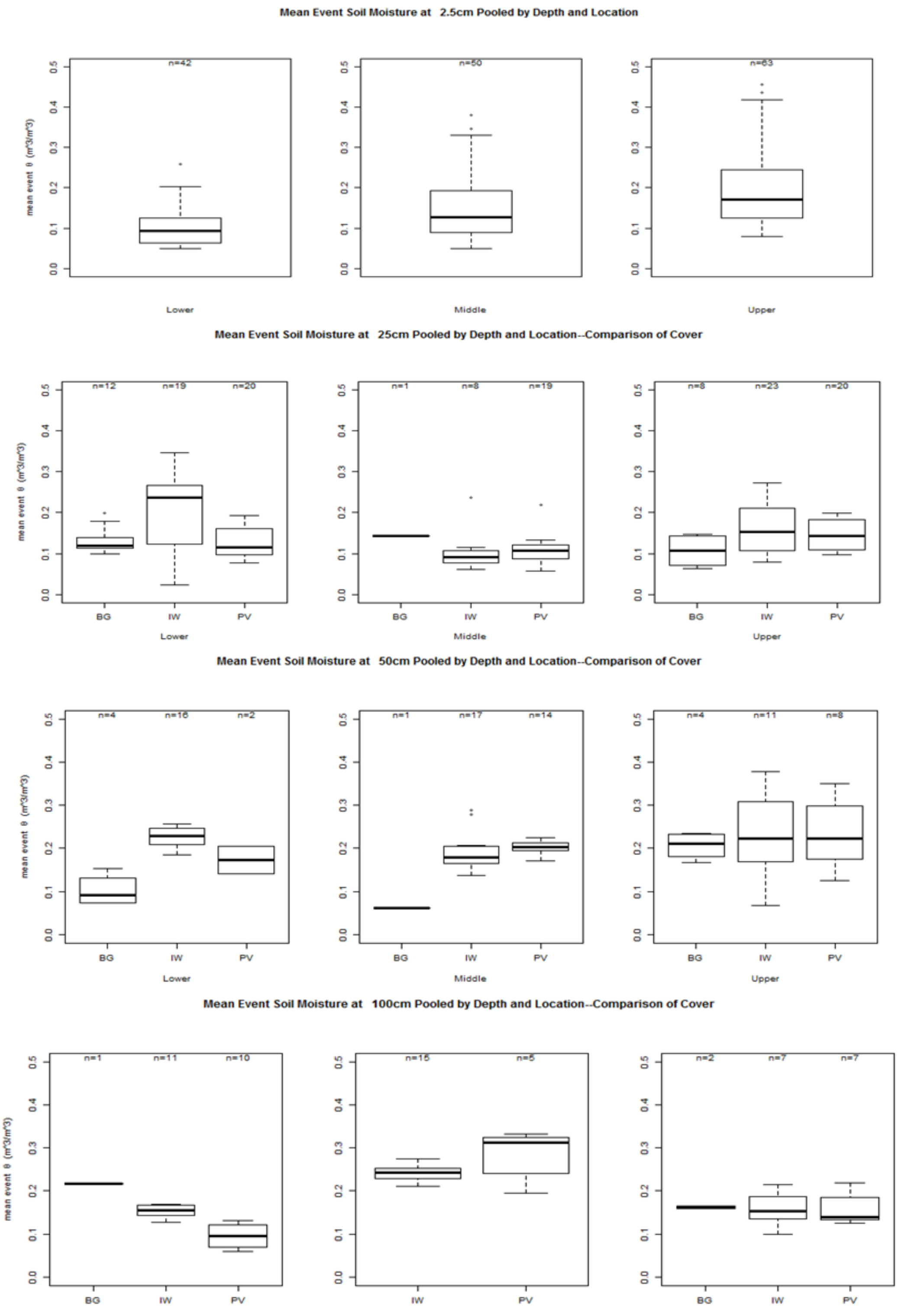


Figure 3.89. Event mean volumetric soil moisture pooled by depth, location, and cover in the Yuma Wash watershed.

Table 3.20. Event mean volumetric soil moisture by depth, cover, and location.

	Median Δθ m^3/m^3 (Lower)			Median Δθ m^3/m^3 (Middle)			Median Δθ m^3/m^3 (Upper)		
Depth	BG	IW	PV	BG	IW	PV	BG	IW	PV
2.5cm	0.09	N/A	N/A	0.13	N/A	N/A	0.17	N/A	N/A
25cm	0.12	0.24	0.12	0.14	0.09	0.11	0.11	0.15	0.14
50cm	0.09	0.23	0.17	0.06	0.18	0.20	0.21	0.22	0.22
100cm	0.22	0.15	0.10	--	0.24	0.31	0.16	0.15	0.14
	Min Δθ m^3/m^3 (Lower)			Min Δθ m^3/m^3 (Middle)			Min Δθ m^3/m^3 (Upper)		
Depth	BG	IW	PV	BG	IW	PV	BG	IW	PV
2.5cm	0.05	N/A	N/A	0.05	N/A	N/A	0.08	N/A	N/A
25cm	0.10	0.02	0.08	0.14	0.06	0.06	0.06	0.08	0.10
50cm	0.07	0.18	0.14	0.06	0.14	0.17	0.17	0.07	0.12
100cm	0.22	0.13	0.06	--	0.21	0.19	016	0.10	0.13
	Maximum Δθ m^3/m^3 (Lower)			Maximum Δθ m^3/m^3 (Middle)			Maximum Δθ m^3/m^3 (Upper)		
Depth	BG	IW	PV	BG	IW	PV	BG	IW	PV
2.5cm	0.26	N/A	N/A	0.38	N/A	N/A	0.46	N/A	N/A
25cm	0.20	0.35	0.19	0.14	0.24	0.22	0.15	0.27	0.20
50cm	0.15	0.26	0.21	0.06	0.29	0.22	0.23	0.38	0.35
100cm	0.22	0.17	0.13	--	0.27	0.33	0.16	0.21	0.22
	Q1 Δθ m^3/m^3 (Lower)			Q1 Δθ m^3/m^3 (Middle)			Q1 Δθ m^3/m^3 (Upper)		
Depth	BG	IW	PV	BG	IW	PV	BG	IW	PV
2.5cm	0.06	N/A	N/A	0.09	N/A	N/A	0.12	N/A	N/A
25cm	0.11	0.12	0.10	014	0.08	0.09	0.08	0.11	0.11
50cm	0.07	0.21	0.16	0.06	0.17	0.19	0.19	0.17	0.18
100cm	0.22	0.14	0.07	--	0.23	0.24	0.16	0.13	0.13
	Q3 Δθ m^3/m^3 (Lower)			Q3 Δθ m^3/m^3 (Middle)			Q3 Δθ m^3/m^3 (Upper)		
Depth	BG	IW	PV	BG	IW	PV	BG	IW	PV
2.5cm	0.13	N/A	N/A	0.19	N/A	N/A	0.25	N/A	N/A
25cm	0.14	0.27	0.16	0.14	0.10	0.12	0.14	0.21	0.18
50cm	0.12	0.25	0.19	0.06	0.20	0.21	0.23	0.31	0.27
100cm	0.22	0.17	0.12	--	0.25	0.33	0.16	0.19	0.19

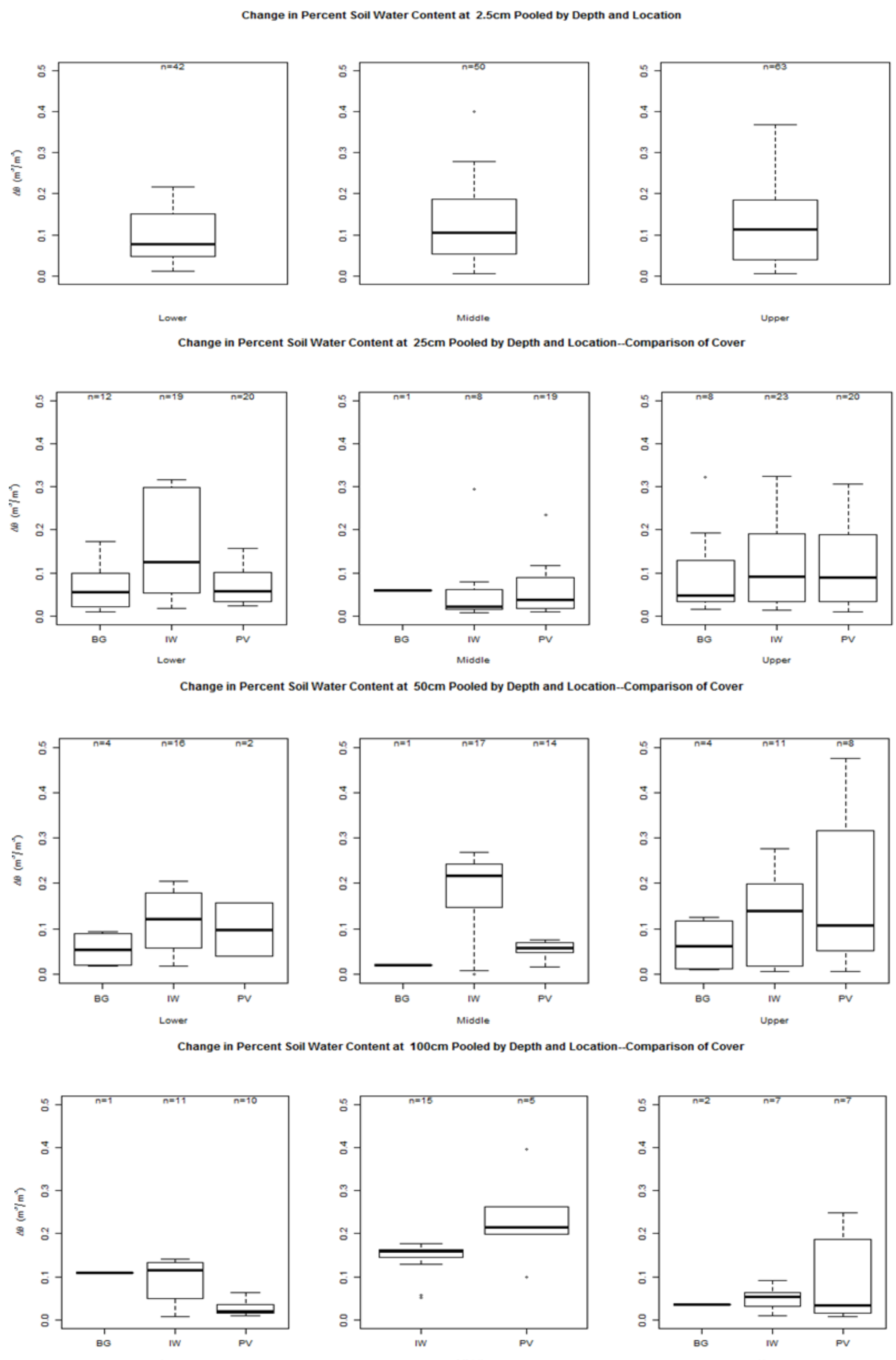


Figure 3.90 Event peak magnitude volumetric soil moisture ($\Delta\theta$ m^3/m^3) pooled by depth, location, and cover in the Yuma Wash watershed.

Table 3.21. Event peak magnitude volumetric soil moisture ($\Delta\theta\ m^3/m^3$) by depth, location, and cover.

	Median $\Delta\theta\ m^3/m^3$ (Lower)			Median $\Delta\theta\ m^3/m^3$ (Middle)			Median $\Delta\theta\ m^3/m^3$ (Upper)		
Depth	BG	IW	PV	BG	IW	PV	BG	IW	PV
2.5cm	0.08	N/A	N/A	0.10	N/A	N/A	0.11	N/A	N/A
25cm	0.06	0.13	0.06	0.06	0.02	0.04	0.05	0.09	0.09
50cm	0.05	0.12	0.10	0.02	0.22	0.06	0.06	0.14	0.11
100cm	0.11	0.11	0.02	--	0.16	0.21	0.04	0.05	0.03
	Min $\Delta\theta\ m^3/m^3$ (Lower)			Min $\Delta\theta\ m^3/m^3$ (Middle)			Min $\Delta\theta\ m^3/m^3$ (Upper)		
Depth	BG	IW	PV	BG	IW	PV	BG	IW	PV
2.5cm	0.01	N/A	N/A	0.01	N/A	N/A	0.01	N/A	N/A
25cm	0.01	0.02	0.02	0.06	0.01	0.01	0.02	0.01	0.01
50cm	0.02	0.02	0.04	0.02	0.01	0.02	0.01	0.01	0.01
100cm	0.11	0.01	0.01	--	0.05	0.10	0.03	0.01	0.01
	Maximum $\Delta\theta\ m^3/m^3$ (Lower)			Maximum $\Delta\theta\ m^3/m^3$ (Middle)			Maximum $\Delta\theta\ m^3/m^3$ (Upper)		
Depth	BG	IW	PV	BG	IW	PV	BG	IW	PV
2.5cm	0.22	N/A	N/A	0.40	N/A	N/A	0.37	N/A	N/A
25cm	0.17	0.17	0.32	0.06	0.30	0.23	0.32	0.32	0.31
50cm	0.08	0.21	0.16	0.02	0.27	0.08	0.13	0.28	0.47
100cm	0.11	0.14	0.06	--	0.18	0.39	0.04	0.09	0.25
	Q1 $\Delta\theta\ m^3/m^3$ (Lower)			Q1 $\Delta\theta\ m^3/m^3$ (Middle)			Q1 $\Delta\theta\ m^3/m^3$ (Upper)		
Depth	BG	IW	PV	BG	IW	PV	BG	IW	PV
2.5cm	0.05	N/A	N/A	0.06	N/A	N/A	0.04	N/A	N/A
25cm	0.02	0.05	0.03	0.06	0.02	0.02	0.03	0.03	0.03
50cm	0.02	0.06	0.07	0.02	0.15	0.05	0.01	0.02	0.06
100cm	0.11	0.05	0.02	--	0.14	0.20	0.03	0.03	0.02
	Q3 $\Delta\theta\ m^3/m^3$ (Lower)			Q3 $\Delta\theta\ m^3/m^3$ (Middle)			Q3 $\Delta\theta\ m^3/m^3$ (Upper)		
Depth	BG	IW	PV	BG	IW	PV	BG	IW	PV
2.5cm	0.15	N/A	N/A	0.19	N/A	N/A	0.19	N/A	N/A
25cm	0.10	0.30	0.10	0.06	0.05	0.09	0.10	0.19	0.19
50cm	0.09	0.18	0.13	0.02	0.24	0.07	0.11	0.20	0.31
100cm	0.11	0.13	0.03	--	0.16	0.26	0.04	0.06	0.19

differences were found in event peak magnitudes by cover between these sites when data were pooled across both geomorphic surfaces (Tables D65-D66).

Data were next investigated for differences in the temporal domain. Median fifteen-minute volumetric soil moisture by season, year, and season-year is illustrated in Figures 3.91-3.93 and Tables 3.22-3.24. Descriptive statistics are provided in Tables D42-D45, and significance test results in Tables D67-D68. While seasonal differences in median volumetric soil moisture are small in the top 25 cm and do not vary in time at 50-100 cm, the spread of the

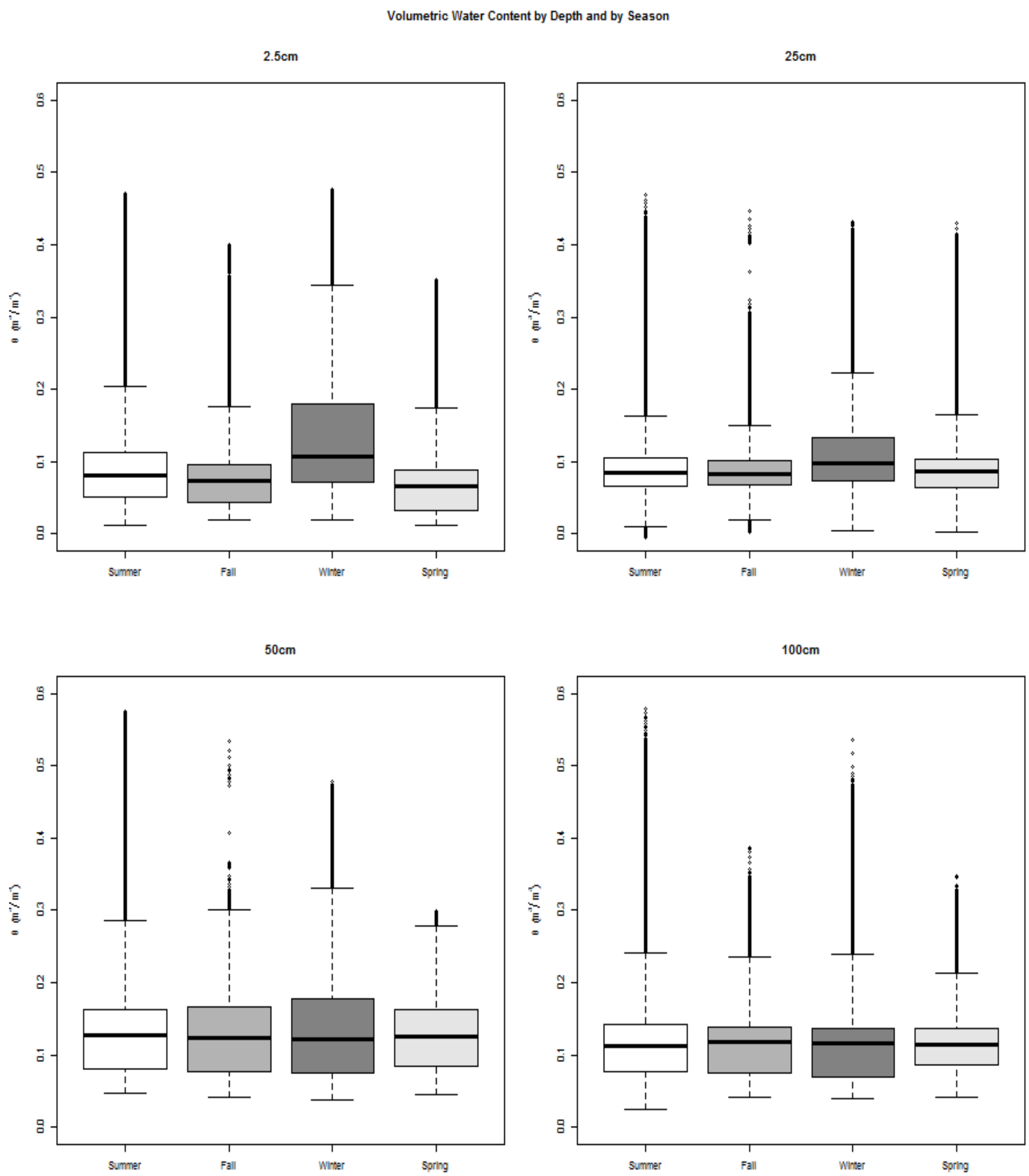


Figure 3.91. Fifteen minute volumetric soil moisture by depth and by season in the Yuma Wash watershed.

Table 3.22. Fifteen minute volumetric soil moisture by season in the Yuma Wash watershed.

Median θ m^3/m^3				
	Summer	Fall	Winter	Spring
2.5 cm	0.08	0.07	0.11	0.07
25 cm	0.09	0.08	0.10	0.09
50 cm	0.13	0.12	0.12	0.13
100 cm	0.11	0.12	0.12	0.11
Min θ m^3/m^3				
	Summer	Fall	Winter	Spring
2.5 cm	0.01	0.02	0.02	0.01
25 cm	0.01	0.01	0.01	0.01
50 cm	0.05	0.04	0.04	0.05
100 cm	0.03	0.04	0.04	0.04
Max θ m^3/m^3				
	Summer	Fall	Winter	Spring
2.5 cm	0.47	0.40	0.48	0.35
25 cm	0.47	0.45	0.43	0.43
50 cm	0.57	0.53	0.48	0.30
100 cm	0.58	0.37	0.54	0.35
Q1 θ m^3/m^3				
	Summer	Fall	Winter	Spring
2.5 cm	0.05	0.04	0.07	0.03
25 cm	0.07	0.07	0.07	0.06
50 cm	0.08	0.08	0.07	0.09
100 cm	0.08	0.08	0.07	0.09
Q3 θ m^3/m^3				
	Summer	Fall	Winter	Spring
2.5 cm	0.11	0.10	0.18	0.09
25 cm	0.10	0.10	0.13	0.10
50 cm	0.16	0.17	0.18	0.16
100 cm	0.14	0.14	0.14	0.14

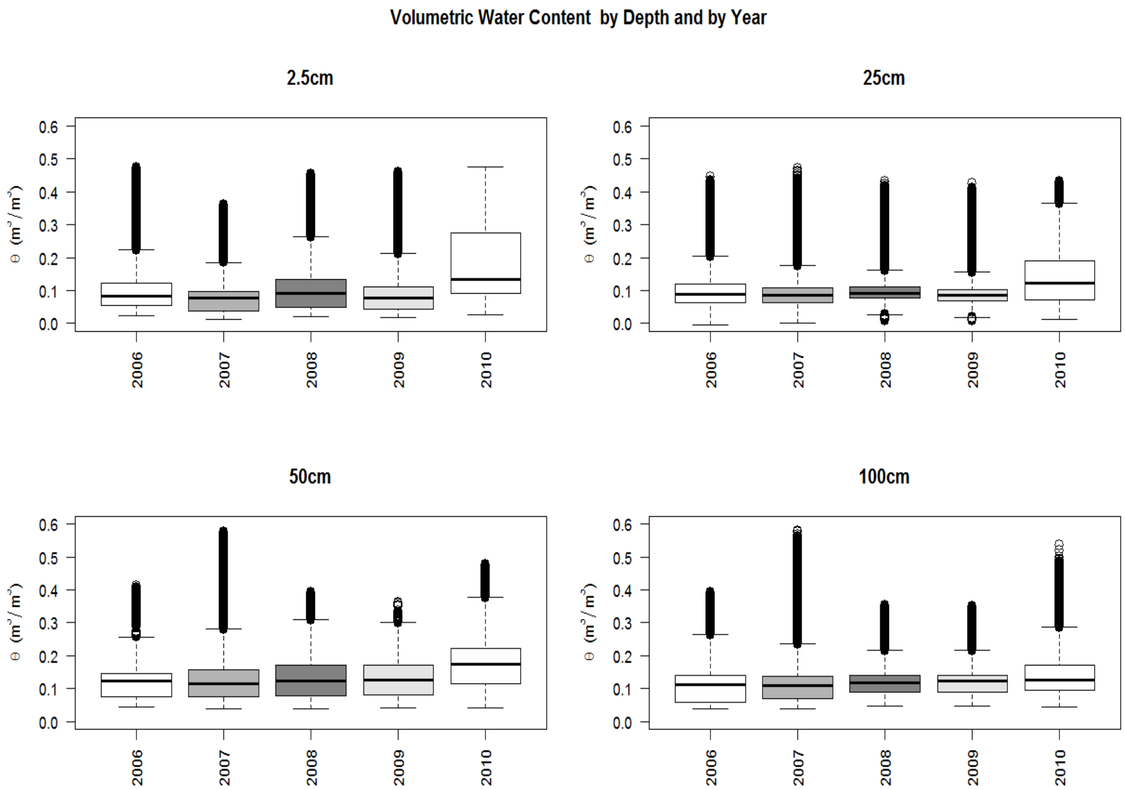


Figure 3.92. Fifteen minute volumetric soil moisture by depth and by year in the Yuma Wash watershed.

Table 3.23. Fifteen minute volumetric soil moisture medians by year in the Yuma Wash watershed.

Median θ m^3/m^3					
	2006	2007	2008	2009	2010
2.5 cm	0.08	0.08	0.09	0.08	0.13
25 cm	0.09	0.09	0.09	0.09	0.12
50 cm	0.12	0.12	0.12	0.13	0.17
100 cm	0.11	0.11	0.11	0.12	0.13

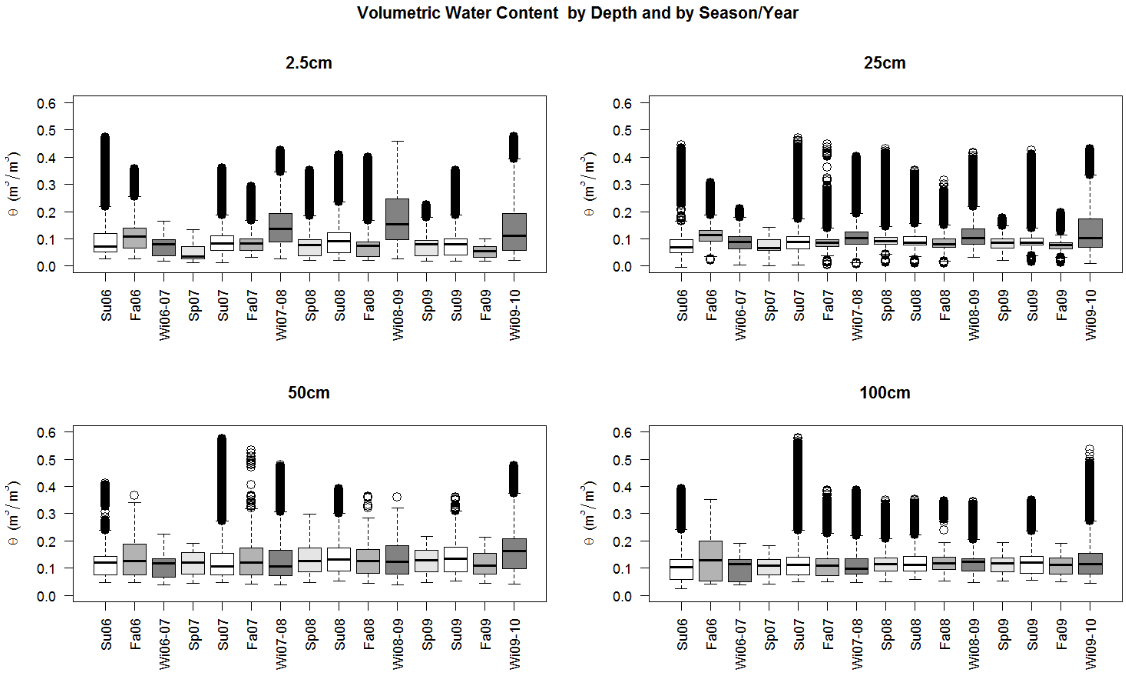


Figure 3.93. Fifteen minute volumetric soil moisture by depth and by season/year in the Yuma Wash watershed.

Table 3.24. Fifteen minute volumetric soil moisture medians by season and year in the Yuma Wash watershed.

Median θ m^3/m^3				
	2.5 cm	**25 cm**	**50 cm**	**100 cm**
Summer 2006	0.07	0.07	0.12	0.11
Fall 2006	0.11	0.12	0.13	0.13
Winter 2006-07	0.08	0.09	0.12	0.12
Spring 2007	0.04	0.07	0.12	0.11
Summer 2007	0.08	0.09	0.11	0.11
Fall 2007	0.08	0.09	0.12	0.11
Winter 2007-08	0.14	0.10	0.11	0.10
Spring 2008	0.08	0.09	0.13	0.12
Summer 2008	0.09	0.09	0.13	0.11
Fall 2008	0.07	0.08	0.13	0.12
Winter 2008-09	0.15	0.10	0.12	0.12
Spring 2009	0.08	0.09	0.13	0.12
Summer 2009	0.08	0.09	0.13	0.12
Fall 2009	0.05	0.08	0.11	0.11
Winter 2009-10	0.11	0.10	0.16	0.12

data suggests that winter soil moisture is generally higher in the top 25 cm, and likely reflects the generally greater amount of precipitation received in winter relative to fall and spring, a lower evapotranspiration rate that likely occurs relative to spring and summer, residual soil moisture from late fall events when they occur, and a greater spatial distribution of precipitation relative to other seasons (Figure 3.91; Table 3.22). Significant differences ($\alpha = 0.05$) were found in rank sums of fifteen minute soil moisture between all seasons at 2.5 cm, but winter was the most significantly different than the other three seasons (Tables 3.16, D67), and the only season that differed from other seasons by a magnitude greater than the known error variance. Medians varied by 3-4 percent, and upper IQR differences were 7-9 percent between winter and the other three seasons; less than 2 percent median and IQR error variance was estimated due to soil temperature at 2.5 cm. At 25 cm, only winter soil moisture was significantly different than the other three seasons, but median and IQR differences were less than 2 percent between any season, which did not exceed the error variance. No statistical differences were found between seasons at 50-100 cm.

On an annual basis, fifteen minute soil moisture medians between the three years with four seasons of records (2007-2009) do not vary by more than one percent at any depth (Figure 3.92; Table 3.23). While medians were nearly identical, statistical differences were found in rank sums at 2.5-25 cm between 2007 versus 2008, and 2008 versus 2009 (Table D68). At 50-100 cm, differences were significant between 2007 and 2008, and 2007 and 2009, but the greatest differences were found in the top 25 cm. Values within 1.5 of the upper IQR were greater at 2.5 and 50 cm in 2008, and may reflect the generally wetter year relative to 2007 or 2009. Peak event magnitudes during soil moisture events were higher at 25-50 cm in 2007 than 2008 or 2009, and likely reflect the greater number of summer events that occurred relative to winter in that year, and relative to summers in the other years (Figure 3.93; Table 3.24). Soil moisture in 2010 reflects winter values only, and 2006 reflects only summer and fall soil moisture, so 2007-09 data are not comparable against these two years. Regardless of significance tests, however, differences by year did not exceed error variance at any depth.

Differences by geomorphic surface were consistently higher on terraces than washes for all years and all seasons, with the exception of 25 cm during winter 2010 (Figures 3.94-3.95), during which time the largest event of the study period was recorded. Differences were most statistically significant during winter and summer (Table D49), likely reflecting more frequent and deeper infiltration of soil moisture events beneath vegetative cover on terraces relative to washes during both seasons, and greater moisture retention in winter. By location, soil moisture was greater in the upper relative to the lower basin at 2.5 cm and 50 cm depths for each year and season (Figures 3.96-3.97), at 25 cm in summer and spring, and in winter 2010, and is higher at 100 cm in 2008-2010 and for all seasons except spring. Because soil moisture at the near surface reflects an increase from lower to upper basin for each season and year, this suggests that differences at this depth cannot be accounted for on the basis of missing data alone. By cover, median volumetric soil moisture beneath *P. microphylla* and *O. tesota* was also consistently higher than beneath bare ground for a few years and all seasons except spring at 25 cm, for all years and seasons at 50 cm, and for all years except 2008 and all seasons except summer for *O. tesota* at 100 cm (Figures 3.98-3.99). Median soil moisture at 100 cm beneath *P. microphylla* was consistently less than beneath *O. tesota* and bare ground for all years with the exception of winter 2010. However, as previously discussed, these data are complexed by pooling of vegetation types over different geomorphic surfaces. The generally higher median annual soil moisture beneath vegetated versus unvegetated cover, and higher median between *O. tesota*

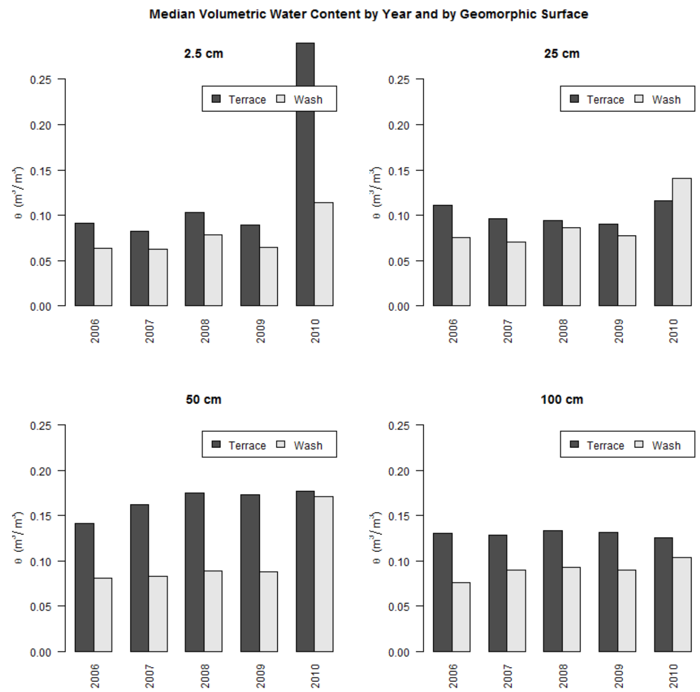


Figure 3.94. Fifteen minute median annual volumetric water content by depth and geomorphic surface in the Yuma Wash watershed.

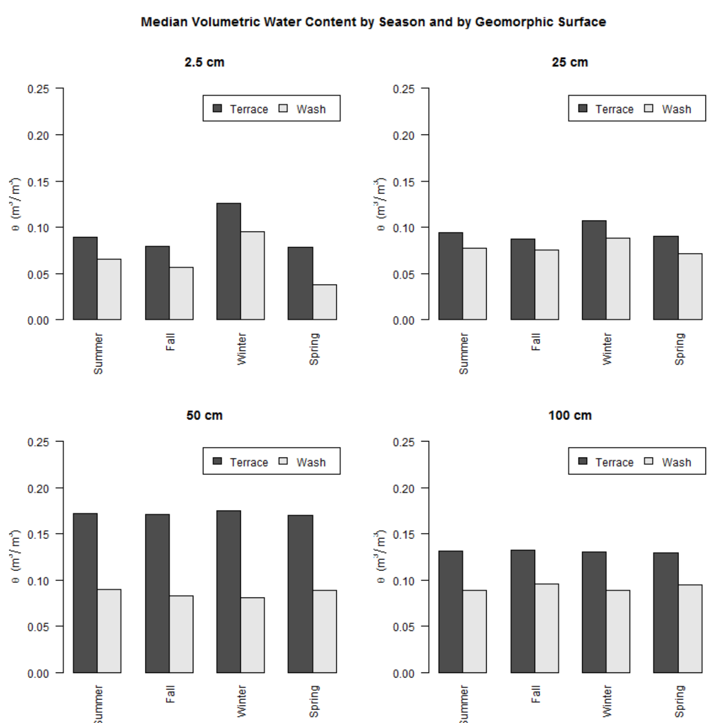


Figure 3.95. Fifteen minute median seasonal volumetric water content by depth and geomorphic surface in the Yuma Wash watershed.

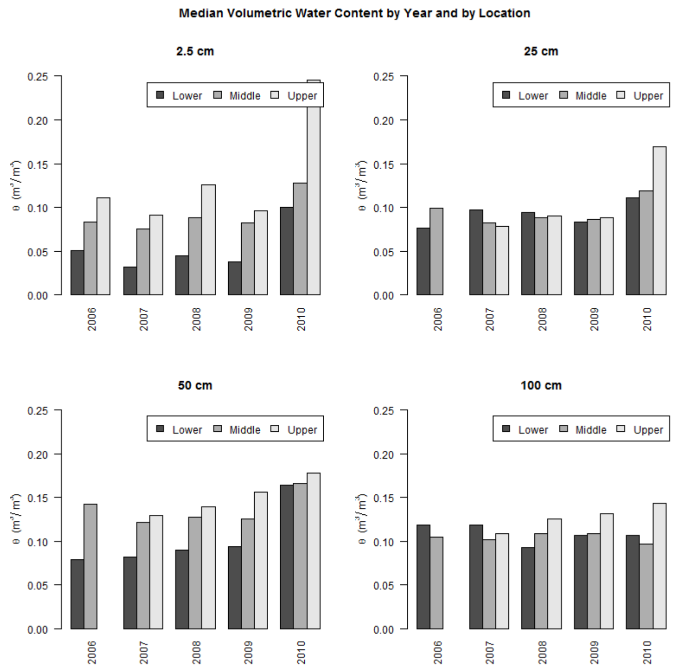


Figure 3.96. Fifteen minute median annual volumetric water content by depth and location in the Yuma Wash watershed.

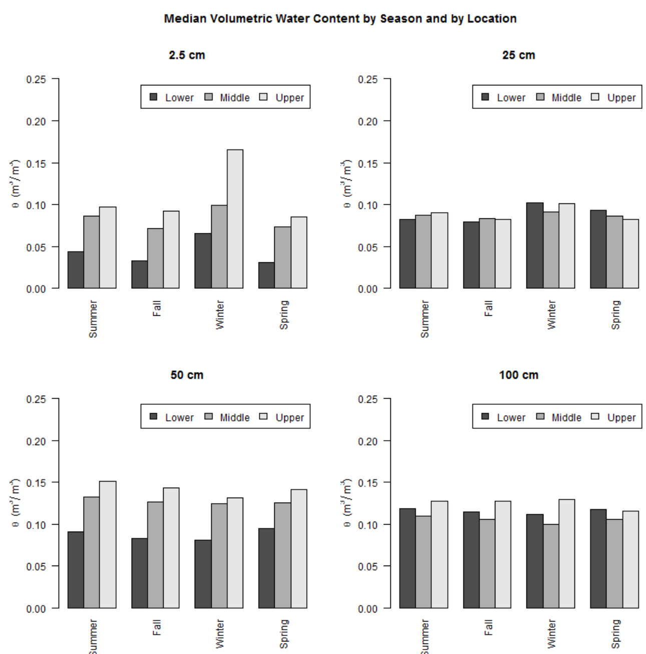


Figure 3.97. Fifteen minute median seasonal volumetric water content by depth and location in the Yuma Wash watershed.

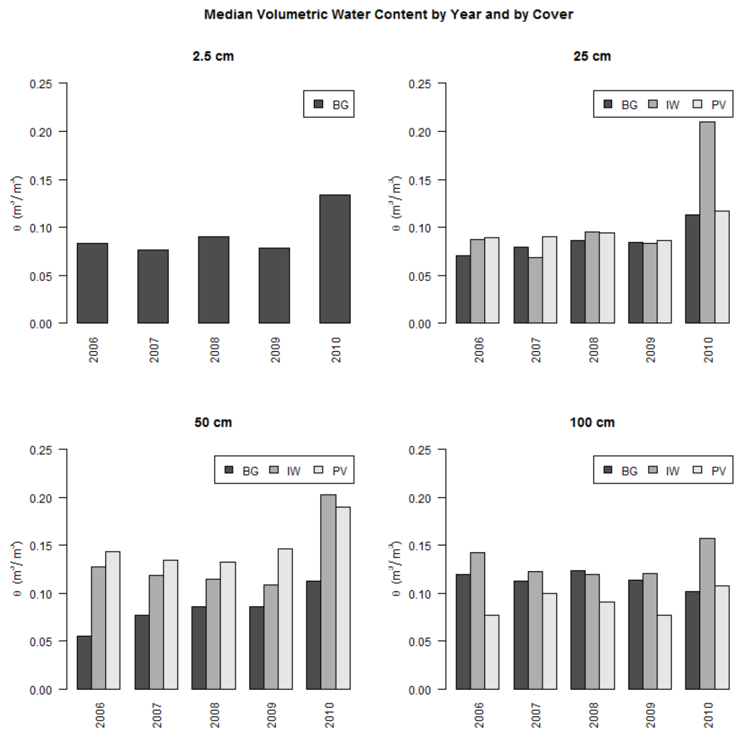


Figure 3.98. Fifteen minute median annual volumetric water content by depth and cover in the Yuma Wash watershed.

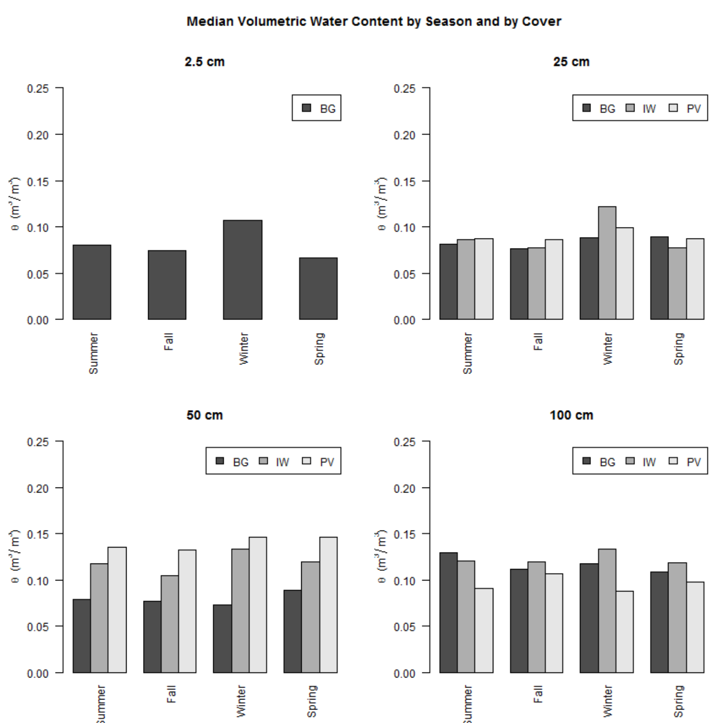


Figure 3.99. Fifteen minute median seasonal volumetric water content by depth and cover in the Yuma Wash watershed.

relative to *P. microphylla* at 100 cm, are likely reflective more of terrace surfaces than washes, at least for the period of study. Based on the number of events recorded, differences were greatest during summer and winter when most events were recorded beneath vegetative cover on terraces.

Comparing event means and event magnitudes for differences in the temporal domain, neither was significant by year at any depth, with the exception of peak magnitude at 25 cm between 2007 and 2008, which probably reflects higher relative precipitation occurring in summer and fall of 2007, although median differences were less than 2 percent (Tables D69-D70). Seasonally, winter event means were significantly greater relative to the other three seasons at 2.5 cm (Table 3.25), and fall event magnitudes were significantly greater than the other three seasons at 2.5 cm (Tables D71-D72).

Higher mean event moisture in winter likely reflects antecedent conditions of the soils from previous wetting events in fall, a generally greater number of events recorded during winter relative to fall and spring, and differences in evaporative losses, which are typically less during winter than other seasons. Higher event peak magnitudes likely reflect greater per event precipitation received during fall when precipitation occurs. Median differences in event means in winter versus other seasons were 4-5 percent, with IQR differences of 1-12 percent, with greatest differences between winter and summer. Median differences in magnitudes between fall and other seasons were 7-10 percent, with IQR differences of 6-9 percent. At 25 cm, differences in rank sums of event mean soil moisture were significant for all seasons except spring and summer, albeit the number of spring events was very limited relative to all seasons. Differences were greatest between winter and spring, and winter and summer. Median differences at 25 cm were 3 percent, and IQR differences ranged from 5-10 percent. At 50 cm, differences were

Table 3.25. Event mean volumetric soil moisture by season.

Median θ m³/m³				
	Summer	Fall	Winter	Spring
2.5 cm	0.12	0.13	0.17	0.13
25 cm	0.09	0.12	0.12	0.09
50 cm	0.17	0.17	0.18	0.18
100 cm	0.13	0.14	0.15	0.11
Min θ m³/m³				
	Summer	Fall	Winter	Spring
2.5 cm	0.05	0.05	0.05	0.07
25 cm	0.02	0.06	0.04	0.08
50 cm	0.07	0.07	0.06	0.16
100 cm	0.06	0.11	0.07	0.09
Max θ m³/m³				
	Summer	Fall	Winter	Spring
2.5 cm	0.30	0.32	0.46	0.26
25 cm	0.26	0.27	0.35	0.23
50 cm	0.25	0.23	0.38	0.20
100 cm	0.31	0.33	0.33	0.22
Q1 θ m³/m³				
	Summer	Fall	Winter	Spring
2.5 cm	0.08	0.11	0.12	0.09
25 cm	0.10	0.11	0.15	0.09
50 cm	0.19	0.20	0.23	0.19
100 cm	0.16	0.22	0.17	0.13
Q3 θ m³/m³				
	Summer	Fall	Winter	Spring
2.5 cm	0.15	0.17	0.27	0.21
25 cm	0.13	0.16	0.20	0.10
50 cm	0.21	0.22	0.26	0.19
100 cm	0.23	0.24	0.22	0.17

significant between winter and summer and winter and fall, but medians did not differ by more than 1 percent, and IQRs by more than 5 percent. No differences in event means were significant at 100 cm by season (Table D71), and no statistically significant differences were found for event peak magnitudes at 25-100 cm by season (Table D72), but fall magnitudes were generally higher at 25-100 cm than the other three seasons (Table 3.26). At 25 cm, medians differed by 6-7 percent in fall versus winter and spring, and IQR differences ranged from 2-4

Table 3.26. Event peak magnitude volumetric soil moisture by season.

Median θ m^3/m^3				
	Summer	Fall	Winter	Spring
2.5 cm	0.10	0.18	0.08	0.11
25 cm	0.03	0.09	0.03	0.02
50 cm	0.11	0.12	0.08	0.13
100 cm	0.10	0.16	0.06	0.11
Min θ m^3/m^3				
	Summer	Fall	Winter	Spring
2.5 cm	0.01	0.07	0.01	0.03
25 cm	0.01	0.01	0.01	0.01
50 cm	0.01	0.02	0.01	0.06
100 cm	0.02	0.01	0.01	0.01
Max θ m^3/m^3				
	Summer	Fall	Winter	Spring
2.5 cm	0.40	0.29	0.29	0.25
25 cm	0.31	0.31	0.32	0.31
50 cm	0.48	0.34	0.30	0.15
100 cm	0.26	0.21	0.40	0.16
Q1 θ m^3/m^3				
	Summer	Fall	Winter	Spring
2.5 cm	0.04	0.13	0.05	0.07
25 cm	0.06	0.06	0.06	0.04
50 cm	0.05	0.06	0.02	0.09
100 cm	0.03	0.09	0.02	0.06
Q3 θ m^3/m^3				
	Summer	Fall	Winter	Spring
2.5 cm	0.17	0.20	0.13	0.16
25 cm	0.12	0.12	0.14	0.08
50 cm	0.19	0.23	0.16	0.14
100 cm	0.16	0.18	0.11	0.14

percent. At 50 cm, medians differed by 4 percent and IQRs by 4-7 percent in fall versus winter, and at 100 cm, medians differed by 10 percent and IQRs by 7 percent in fall versus winter (Table 3.26). Limited data in spring and fall constrain interpretation of statistical tests results, however.

In summary, findings suggest that volumetric soil moisture recorded during the period of record in the Yuma Wash watershed varied spatially by depth, geomorphic surface, location and cover type, and temporally more by season than by year. Spatially, significant differences in rank sums of soil moisture at 2.5 cm were found by location and by geomorphic surface, and were greater by location, showing a general increase in soil moisture on both surfaces from lower to upper basin, and generally higher soil moisture on terraces relative to washes. Significant differences in rank sums of soil moisture were also found at 25-100 cm by location, geomorphic surface and by cover type. Greatest differences at 25-100 cm were found by geomorphic surface beneath vegetated cover types, suggesting greater soil moisture beneath *O. tesota* (at 25-100 cm) and *P. microphylla* (at 50-100 cm) on terraces relative to the same species on washes. Greatest differences by cover type were found beneath vegetated cover and bare ground on terraces, suggesting soil moisture was generally greater beneath *O. tesota* at 25-100 cm and *P. microphylla* at 50-100 cm on terraces relative to bare ground. Both of these findings are likely due in large part to the presence of desert pavement and an underlying vesicular A horizon (Av) on the bare ground surface of terraces, which retards infiltration, leading to greater runon to adjacent vegetated cover on this geomorphic surface. Significant differences were also found between *O. tesota* and *P. microphylla* on terraces at all depths, but differences were much less significant than between either species and bare ground. *O. tesota* had a generally higher soil moisture than *P. microphylla* at 25 cm at two of the three terrace sites, and greater soil moisture response at the lower terrace at all depths. On washes, differences in rank sums of soil moisture were significant by cover, but no consistent pattern was found between bare ground and either species, or between *O. tesota* and *P. microphylla.* However, analysis on this site was severely constrained due to very few runoff events.

By depth, soil moisture in the top one meter was higher at 50-100 cm relative to the top 25 cm, but this was more so beneath vegetated cover on terraces than on washes, likely resulting from increased frequency of moisture as runon from adjacent bare ground pavement surfaces on terraces. Lack of seasonal evaporative influence on both surfaces at depths of 50-100 cm relative to the top 25 cm may in part influence differences in soil moisture by depth, along with differences in water-holding capacity due to soil properties not quantified in this study. On terraces, higher moisture at 50 cm may also result at some sites from carbonate induration or soil compaction between 50-100 cm, or translocation of clays to 50 cm, but at some sites may also reflect errors in permittivity estimates due to probe sensitivity to these constituents.

By season, winter soil moisture was higher relative to other seasons in the top 25 cm, likely due to reduced evaporative influence during winter, residual soil moisture from late fall precipitation events, higher total precipitation received in winter during the study period relative to spring and fall, and a greater distribution of precipitation across the basin during winter relative to other seasons. Seasonal differences were generally less apparent at depths of 50 and 100 cm. Event peak magnitudes were greatest in fall relative to other seasons, which likely reflects greater per event precipitation that generally occurs in this season relative to others, and these differences were reflected at depths to 100 cm. Annual differences in median and IQR soil moisture for all metrics were less than 2 percent, although differences within 1.5 of the interquartile range do reflect wetter versus drier years.

These findings reflect considerable spatial and temporal complexity in soil moisture within the Yuma Wash watershed, and highlight some of the challenges associated with multivariate data collected over a broad spatial scale. Differences in soil pedogenic and hydraulic properties that were not quantified in this study, spatially and temporally variable precipitation, probe sensitivity to temperature, which in turn influences electrical conductivity in high carbonate soils, and sensitivity to aerosolic clays that may have been translocated into the depth profiles of some soil profiles, causing compaction and cementation, and missing data all add error variance to soil moisture estimates. Finally, datasets that were unequal in size and non-normal in distribution also introduced limitations to statistical analyses. These complexities are each addressed in greater detail in Chapter 4.

Limitations notwithstanding, analyses generally suggest the following with respect to the study hypotheses:

Hypothesis 1:

H_o: *Soil moisture does not vary significantly by geomorphic surface.*

H_a: *Soil moisture varies significantly by geomorphic surface.*

Soil moisture does vary significantly by geomorphic surface. Results suggest that differences in rank sums of weekly soil moisture means were significant by geomorphic surface at all depths (α =0.05). Relative differences depended upon soil characteristics beneath different cover types and at different depths. Rank sums of fifteen minute soil moisture summarized as weekly means were most significantly different beneath both *O. tesota* at 25-100 cm, and *P. microphylla* at 50-100 cm on terraces relative to the same species on washes. Median soil moisture at 25 cm beneath *O. tesota* on terraces was 13 percent versus 6 percent on washes, 18 percent at 50 cm on terraces versus 8 percent on washes, and 15 percent at 100 cm on terraces versus 6 percent on washes. Median soil moisture beneath *P. microphylla* was the same on both surfaces at 25 cm (9 percent), 20 percent at 50 cm on terraces versus 13 on washes, and 13 percent at 100 cm on terraces versus 7 percent on washes. Event means and peak magnitudes between these species on different geomorphic surfaces were also higher beneath both species on terraces relative to washes at all depths, but only significantly so for *O. tesota* at 25 cm, and *P. microphylla* at 50 cm. Too few events were recorded beneath these species on washes to compare statistical differences at 100 cm using event- specific metrics. However, comparing event-based metrics biased comparisons by comparing soil moisture values for only a few larger events which were recorded in the washes against a greater number of smaller magnitude events on terraces. The number of events recorded beneath both species on terraces was greater by 1.5-4 times more than the number recorded on washes at all depths, with the exception of beneath *O. tesota* at 25 cm at the upper basin terrace and wash sites, where the number of events recorded did not differ by more than 1 event.

Differences in baseline soil moisture values at 25-100 cm were also higher on terraces than washes by 2-6 percent, which varied with depth and cover type. Higher silt and clay fraction reported elsewhere for these intermediate aged terrace surfaces (McDonald et al, 2004) relative to younger alluvial deposits in the washes may suggest higher water-holding capacities of these soils. However, the soil moisture probe used in this study is also sensitive to high salt and clay contents and soil compaction, which were not quantified in this study. At soil solution electrical conductivities greater than 2 dS/m, the probe requires a soil-specific calibration, which was developed for each probe, but how well laboratory calibration compensated for this influence on soil moisture readings is not known. Soil solution electrical conductivities have been previously measured at 5-7 dS/m (Caldwell, per comm) on these terrace surfaces elsewhere on the Yuma Proving Grounds. Conductivities this high, if encountered at any of the instrumented sites, would likely have resulted in inaccurate soil moisture estimates.

Differences in rank sums of soil moisture beneath bare ground were also significant ($\alpha = 0.05$) by geomorphic surface, but less so than beneath vegetated cover, and with an opposite trend at 25-100 cm. On washes, more events were recorded beneath bare ground than on terraces at all depths, particularly at 50-100 cm, although relative differences were small (1-2 events). Differences in fifteen-minute soil moisture were statistically significant at 25 cm, but did not reflect greater moisture on washes; rather, results suggested a higher soil moisture content beneath bare ground on terraces, but not by an amount greater than the error factor. Soil moisture medians were only greater beneath bare ground on washes relative to terraces at 100 cm, and only by 2 percent. Based on the few events recorded beneath bare ground on terraces, only 1 event at 50 cm and none at 100 cm, these differences likely illustrate the relative effect of high salts and clays beneath pavements on terraces on soil moisture readings, rather than differences due to moisture inputs. At 2.5 cm, the number of events recorded beneath bare ground on each surface differed by only a single event, with the exception of the lower basin sites where missing data likely account for these differences. Fifteen-minute soil moisture differences between wash and terrace probes at the near surface did not vary by more than the error variance (2-3 percent medians), and peak magnitudes did not differ by more than 2 percent. However, event means within the IQR were greater on terraces by 3-9 percent, and greatest differences were in winter (see Figure 85), which suggests a longer residence time of soil moisture beneath bare ground on terraces at the near surface relative to washes in winter when evaporation is lowest. Since precipitation did not vary significantly by geomorphic surface, differences found can likely be attributed to varying soil characteristics on these surfaces, and on terraces, primarily to the presence of desert pavement and a vesicular A (Av) horizon. A higher silt and clay fraction in soils generally leads to greater water-holding capacities relative to soils with a higher sand fraction, which is more typical of wash soils. However, vesicular A horizons in this region also are one of the main sources of carbonates and clays in this system, and both can attenuate the signal of the soil moisture probe used in this study. Soil-specific calibration may have corrected for some of these differences, but temperature influences and possibly high salt solutions moving through the profiles during wetting events (which would not have been accounted for in calibration) may have introduced additional error. A partial acceptance of the alternative hypothesis is therefore supported by higher soil moisture response beneath *O. tesota* at 25-100 cm, and *P. microphylla* at 50-100 cm on terraces versus the same species on washes. Differences at the near surface may exist, but did not exceed the known error variance, with the exception of event means.

<u>Hypothesis 2</u>:

H_o: Soil moisture does not vary significantly by cover.

H_a: Soil moisture does vary significantly by cover.

Soil moisture does vary significantly by cover. Partial acceptance of the alternative hypothesis is supported by significant differences in rank sums of weekly soil moisture means by cover at all depths on both geomorphic surfaces. Differences were consistently higher between *O. tesota* and bare ground at 25-100 cm on terraces, and between *P. microphylla* and bare ground at 50-100 cm on terraces at all sites, and differences were greatest in winter. Median soil moisture at 25 cm beneath *O. tesota* on terraces was 13 percent versus 9 percent beneath bare ground, 18 percent at 50 cm beneath *O. tesota* versus 9 percent beneath bare ground, and 15 percent at 100 cm beneath *O. tesota* versus 11 percent beneath bare ground, and differences in IQRs were even greater. Median soil moisture beneath terrace *P. microphylla* was the same at 25 cm as beneath bare ground (9 percent), 20 percent at 50 cm beneath *P. microphylla* versus 9 beneath bare ground, and 13 percent at 100 cm beneath *P. microphylla* versus 11 percent beneath bare ground. Baseline soil moisture did not differ on terraces by cover type at 25 cm, where evaporative influence would be greater than deeper in the profiles; differences at 50-100 cm varied from 1-6 percent depending on depth and cover type, but were greater beneath vegetated cover than bare ground. The number of events recorded beneath terrace *O. tesota* and

P. microphylla was greater relative to beneath bare ground at all depths at all locations. With the exception of the lower terrace site, where infiltration of moisture beneath bare ground at 25 cm occurred for 5 events, only a single event was recorded beneath bare ground at any terrace station at 25-50 cm, and no events were detected at 100 cm. Significance tests could therefore not be run on event-specific data (i.e., event means and peak magnitudes) between vegetated species and bare ground due to lack of sufficient event data beneath bare ground on terraces. However, median differences in peak magnitudes at 25 cm between *O. tesota* and bare ground on terraces were 9 percent with IQR differences of 2-21 percent, but only 2 percent between *P. microphylla* and bare ground. At 50 cm, median magnitudes were also greater for *O. tesota* relative to bare ground by 9 percent, and 5 percent for *P. microphylla* relative to bare ground, and these comparisons are based on only a single event which occurred at 50 cm beneath any bare ground terrace probe. Probe performance may have been affected by soil pedogenic properties that were not quantified in this study, notably high salts and clays, and compaction at some sites, but differences in the number of events recorded, statistical differences in rank sums of weekly means, and peak magnitude differences suggest more frequent moisture inputs and higher soil moisture beneath both species relative to bare ground on this geomorphic surface.

On washes, statistical differences were found in rank sums of weekly soil moisture means by cover, but differences were inconsistent and highly variable by cover type, depth, and location, revealing no discernible pattern of greater or lesser soil moisture between vegetated cover and bare ground, or between *O. tesota* and *P. microphylla* on this surface. At 25 and 50 cm, differences at some locations were actually greater between soils beneath the two vegetative species than between either species and bare ground. And at depths of 100 cm on washes, median soil moisture was generally lower beneath both vegetated species than beneath bare ground, but this was likely due to differences in baseline soil moisture rather than events recorded during the study period. The number of events recorded on washes also did not differ consistently by cover, and not by more than 1-2 events at any site, with the exception of the upper site at 25 cm between *O. tesota* relative to *P. microphylla* and bare ground. Response to precipitation was very limited for washes at the sites instrumented during the study, which constrained analyses of differences by cover type beneath this surface. Most events recorded on terraces were likely a result of runon processes, whereas on washes, runoff was likely documented for only a few events. Differences in pedogenic properties of the soils beneath each of these cover types that were not quantified in this study also limit the interpretation of findings.

Hypothesis 3:

H_o: *Soil moisture does not vary significantly by location.*

H_a: *Soil moisture varies significantly by location.*

Soil moisture does vary significantly by location. Partial acceptance of the alternative hypothesis is supported by significant differences found in rank sums of fifteen minute soil moisture summarized as weekly means at 2.5-100 cm between all sites on both surfaces, with the exception of mid- and upper basin at 2.5 cm on terraces. Differences in event means were significant at all depths by location, in all seasons, but more so in summer and winter. Event magnitudes differed significantly at some locations and depths, and not at others. Soil moisture generally was found to increase from lower to upper basin on both surfaces, and greater total and per event precipitation and greater maximum intensities recorded, particularly in summer 2008, along with greater precipitation in winter 2010 in the upper relative to the lower basin, may have contributed in part to these differences. However, missing precipitation and soil moisture data at

2.5 cm for several months in 2006 and 2007 introduce additional error that cannot be accounted for.

On washes at 2.5 cm, fifteen-minute soil moisture median and IQR differences were 6 percent and 5-9 percent, respectively, from lower to upper basin, which exceeded the known error variance from soil temperature influence. On terraces at 2.5 cm, fifteen- minute soil moisture medians differed between the lower and upper basin by 7 percent, with IQR differences of 5-12 percent. Event peak magnitudes, which were temperature corrected at this depth, were higher in the upper basin relative to the lower at 2.5 cm with median differences on terraces of 3 percent, and 4 percent on washes, but differences in rank sums were not significant between the lower and upper basin.

On washes at 25-100 cm, very limited soil moisture event data in the wash at these depths constrained analysis by location. Results suggested that significant differences were found in rank sums of weekly soil moisture means by location at these depths, but inconsistently by depth and cover type. At 25 cm, an increase in soil moisture from the lower to upper wash in response to events recorded during the period of study was documented only beneath *O. tesota*. Medians differed by 9 percent, and IQR differences were 5-12 percent. At 50 cm, increases in fifteen minute soil moisture from lower to upper basin reflected baseline differences beneath bare ground more than an increased response from lower to upper basin to events captured during the study period beneath any of the cover types. At 100 cm on washes, median soil moisture increased from lower to upper basin beneath *P. microphylla* and *O. tesota*, but only for *P. microphylla* by an amount greater than the known error variance due to temperature influences. Differences were also based on no more than 2 events recorded at this depth during the period of record. Event means and peak magnitudes at 100 cm were actually higher beneath

O. tesota in the mid- and lower basin relative to the upper wash site, and differed by less than 2 percent by location beneath *P. microphylla*. A more extensive root network from 25-100 cm was noted beneath both *O. tesota* and *P. microphylla* at the upper wash site relative to the lower and mid-basin sites, which may suggest greater available moisture in the top meter of soil at this site, but only beneath *O. tesota* at 25 cm were there enough documented runoff events during the study to suggest greater moisture in the upper site. Missing data at the upper stations at 25-100 cm also may have influenced these findings. While data at 25-100 cm were not missing at the lower sites during 2006-07 as they were at 2.5 cm, they were missing at 25-100 cm depths at the upper sites during approximately the same period due to a delay in installation. Despite this, an increasing number of soil moisture events was recorded at these depths from lower to upper basin on washes beneath all cover types during the study, and more so beneath vegetated cover. It is likely that during summer 2006, two large events that were recorded at the upper basin wash site at 2.5 cm may have been recorded deeper in the profile had stations been operative. One of these events was recorded at 25-100 cm in the lower wash, and both were recorded at the mid-basin wash. And, during the single largest event of the study in winter 2010, where precipitation was recorded at 68 mm at all stations, mean event soil moisture increased from 15 percent in the lower basin, to 25 percent in the upper basin.

On terraces at 25-100 cm, fifteen-minute soil moisture, event means, and peak magnitudes were highest beneath *O. tesota* in the lower basin relative to *O. tesota* in the upper basin. Differences by location were inconsistent between these metrics beneath *P. microphylla* on terraces; peak magnitudes increased from lower to upper basin, while event means decreased, and fifteen-minute soil moisture medians were roughly equal. This variation is likely due to localized pedogenic and biologic variations, including induration from carbonates, translocation of clays, and differences in rooting depths of these species which are locally constrained by these soil properties. At 25 cm beneath bare ground on terraces, the lower terrace site recorded 5 events at 25 cm relative to 1 at the mid-basin, and none at the upper basin site. Only the largest precipitation event in winter 2010 resulted in soil moisture response at 50 cm, which was recorded at the lower and mid-basin sites, but not at the upper site. No events were recorded at 100 cm beneath bare ground at any site. Beneath vegetated cover on terraces, the number of events recorded was higher in the lower and mid-basin relative to the upper basin at all depths. If soil moisture increases from lower to upper basin were real at 2.5 cm and not an artifact of probe error, it is possible that this had an indirect influence on the relative number of events recorded beneath the Av horizon at 25 cm at these sites, and also on the number recorded beneath the adjacent vegetated cover. Greater soil moisture at near surface in the upper basin might reflect less runon to adjacent vegetated cover, while lower soil moisture at the near surface in the lower basin might reflect more infiltration beneath the Av horizon, but also more runoff to adjacent vegetated cover.

Hypothesis 4:

H_o: Soil moisture does not vary significantly by season or year.

H_a: Soil moisture varies significantly by season or year.

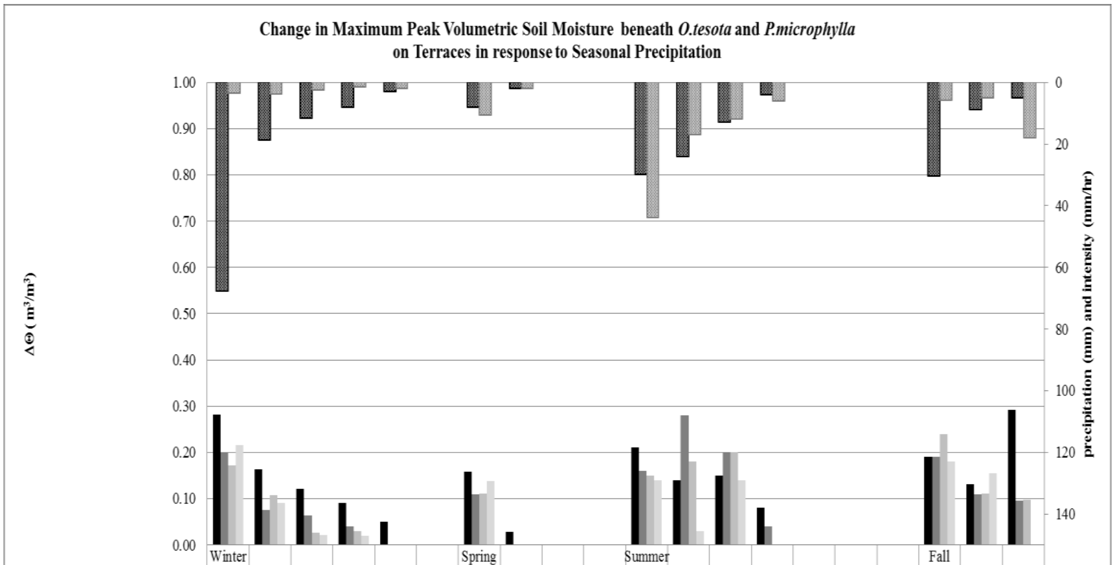
Soil moisture varies significantly by season, but not by year. A partial acceptance of the alternative hypothesis is supported by significant differences in rank sums of seasonal soil moisture in the top 25 cm. Differences were significant between all seasons at 2.5 cm, and winter was the most different from other seasons. Fifteen-minute medians were higher in winter by 3-4 percent, and IQRs were higher by 7-9 percent relative to other seasons, which exceeded known error variance due to soil temperature. Event means during wetting periods were also significantly different at 2.5 cm, with higher medians in winter by 3-4 percent, and higher IQRs by 1-12 percent relative to other seasons. Event peak magnitudes were highest in fall, and significant at 2.5 cm relative to other seasons, with higher medians by 7-10 percent, and higher IQRs by 3-9 percent relative to other seasons.

At 25 cm, seasonal differences in fifteen-minute soil moisture were only significant for winter versus the other three seasons, and only by medians and IQRs of 2 percent, which did not exceed the known error factor. Differences in rank sums of event means were significant at 25 cm for most seasons, and winter was the most significant relative to the other three seasons. Medians were higher by 3 percent, with IQRs higher by 4-10 percent relative to other seasons. Differences in rank sums of peak magnitude soil moisture were not significant in fall relative to other seasons at 25 cm, but soil moisture medians differed by 6-7 percent relative to winter and spring, with IQR differences of 2-4 percent, which exceeded error variance. At 50-100 cm, fifteen-minute and event mean soil moisture medians did not differ between seasons by more than 1 percent when data were pooled across all cover types on both geomorphic surfaces. Fifteen-minute soil moisture did not differ between years at any depth by more than 2 percent, and no significant differences were found in rank sums by year in event means or event peak magnitudes.

Higher winter moisture likely reflects the generally greater amount of total precipitation received during winter months relative to fall and spring, residual soil moisture from occasionally late fall events, a lower evapotranspiration rate that occurs in winter relative to other seasons, and a greater spatial distribution of precipitation across the landscape relative to all other seasons. Higher peak magnitudes in fall likely reflect response to a smaller number of events with greater per event precipitation of moderate intensity or moderate per event precipitation of higher intensity that generally occur during fall relative to other seasons.

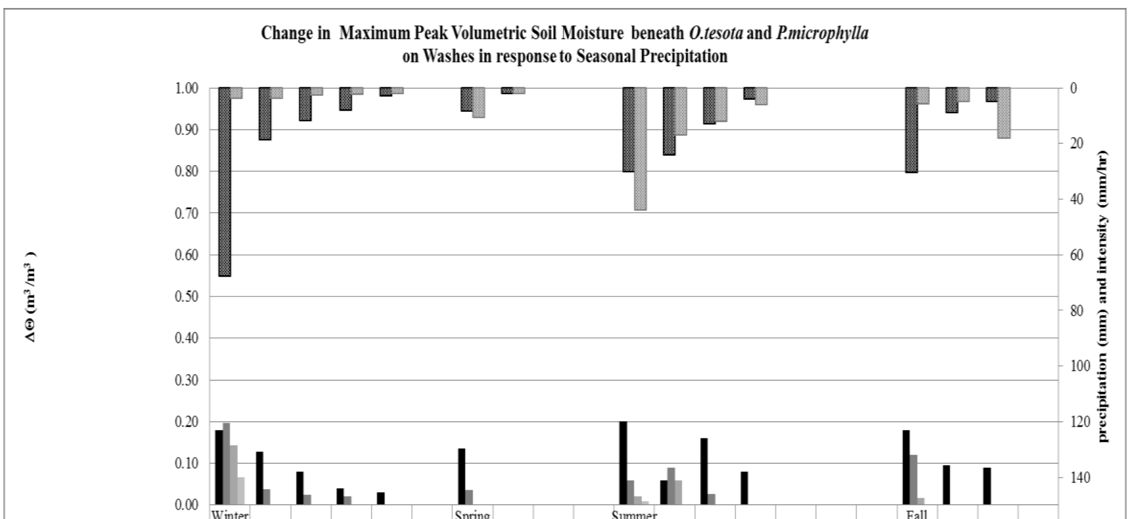
While seasonal influences were greater in the top 25 cm for data pooled for all cover types and both geomorphic surfaces, spatial differences by geomorphic surface were actually greatest at depths of 50-100 cm beneath vegetative cover types. Figures 3.100-3.101 illustrate the peak response of soils at 25-100 cm beneath *O. tesota* and *P. microphylla* on each geomorphic surface to a subset of precipitation events recorded at various stations in each season. Given the wide range of variability found in the data for the study period, these values are meant as a generalized comparison of seasonal soil moisture response to precipitation for each of the two species on each geomorphic surface, and do not reflect the full spatial and temporal variation in response found during the study period. Bare ground estimates were not included due to the non-response of most terrace bare ground probes to precipitation.

Precipitation recorded during the study period did not exceed the amount or rate required for moisture to infiltrate on washes to 50 cm for more than 5 events at any probe, and at 100 cm for more than 2 events at any probe. Data suggest that detection of soil moisture changes at 100 cm beneath *O. tesota* and *P. microphylla* on washes required winter precipitation of either large magnitude and low intensity (68 mm at 4 mm/hr), or summer precipitation of moderate to high magnitude and high intensity (30 mm at 44 mm/hr). Changes at 50 cm required summer storms of moderate magnitude and intensity (24 mm at 17 mm/hr), or higher magnitude lower intensity storms in fall (30 mm at 6 mm/hr). At 25 cm, changes in soil moisture were detected in response to moderate storms of low to moderate intensities in all seasons, from 12 mm at 3 mm/hr events in winter, to 8 mm at 12 mm/hr in spring, to 13 mm at 12 mm/hr in summer. Comparatively, changes in peak magnitude soil moisture beneath *O. tesota* and *P. microphylla*



	Winter						Spring				Summer							Fall		
Terrace 2.5cm	0.28	0.16	0.12	0.09	0.05		0.16	0.03			0.21	0.14	0.15	0.08				0.19	0.13	0.29
Terrace 25cm	0.20	0.08	0.06	0.04			0.11				0.16	0.28	0.20	0.04				0.19	0.11	0.10
Terrace 50cm	0.17	0.11	0.03	0.03			0.11				0.15	0.18	0.20					0.24	0.11	0.10
Terrace 100cm	0.22	0.09	0.02	0.02			0.14				0.14	0.03	0.14					0.18	0.15	
Precipitation (mm)	68	19	12	8	3		8	2			30	24	13	4				30	9	5
Precipitation Intensity (mm/hr)	4	4	3	2	2		11	2			44	17	12	6				6	5	18

Figure 3.100. Precipitation totals and intensities, and maximum change in volumetric soil moisture for select rainfall events recorded beneath *O. tesota* and *P. microphylla* on relict terraces.



	Winter						Spring				Summer							Fall			
Wash 2.5 cm	0.18	0.13	0.08	0.04	0.03		0.14				0.20	0.06	0.16	0.08				0.18	0.10	0.09	
Wash 25cm	0.20	0.04	0.02	0.02			0.04				0.06	0.09	0.03					0.12			
Wash 50cm	0.14										0.02	0.06						0.02			
Wash 100cm	0.07										0.01										
Precipitation (mm)	68	19	12	8	3		8	2			30	24	13	4				30	9	5	
Precipitation Intensity (mm/hr)	4	4	3	2	2		11	2			44	17	12	6				6	5	18	

Figure 3.101. Precipitation totals and intensities, and maximum change in volumetric soil moisture for select rainfall events recorded beneath *O. tesota* and *P. microphylla* on relict terraces.

on terraces were detected at 100 cm for comparatively smaller magnitude and intensity storms. Winter events delivering 12 mm at 3 mm/hr, summer events 13mm at 12 mm/hr, and fall events 9 mm at 5 mm/hr all resulted in changes in soil moisture at 100 cm. Fall events low in magnitude but high in intensity (5 mm at 18 mm/hr) also resulted in soil moisture increases to 50 cm on terraces, when the same event on washes recorded soil moisture response only at the near surface. Three of the largest events recorded during the period of study illustrate these differences.

A convective storm on August 8, 2008 delivered 21 mm at a mean intensity of 19 mm/hr to the upper basin, resulting in a maximum increase of 5 percent volumetric soil moisture at 50 cm beneath the wash surface, and no change in soil moisture was recorded at 100 cm. By comparison, maximum changes in soil moisture beneath vegetated cover on terraces ranged from 16 percent at 50 cm to 21 percent at 100 cm. A second convective storm on September 11, 2008 delivered 32 mm at a mean intensity of 30 mm/hr at the upper basin stations, which resulted in an average maximum increase of 11 percent volumetric soil moisture at 50 cm beneath the wash surface, and 3 percent at 100 cm, versus 16 and 17 percent at 50-100 cm on terraces, respectively. The largest frontal event recorded at all stations delivered an average of 68 mm at a mean intensity of 4 mm/hr on January 21, 2010 at all stations, resulting in an average maximum increase of 14 percent volumetric soil moisture at 50 cm on washes, and 7 percent at 100 cm. By comparison, maximum changes in soil moisture beneath vegetated cover on terraces ranged from 17 at 50 cm, to 22 percent at 100 cm. Terrace probes beneath vegetated cover also recorded up to 15 events at any one probe at 50-100 cm, and most soil moisture events appear to be runon generated from bare ground pavement on this surface. An unexpected finding was that small to moderate winter precipitation events (~8-19 mm, 2-3 mm/hr) resulted in increases in soil moisture beneath vegetated cover on terraces at 25-100 cm. It may be that increased antecedent moisture conditions in the Av horizon following substantial fall or winter events reduce infiltration rates into this layer, generating runoff during subsequent winter events of lower intensities to adjacent vegetated areas. While the relationship between antecedent soil moisture and runoff was not quantified in this study, events recorded during fall and winter of 2007 and 2008, and winter 2010 suggest this occurs. It was expected that only large winter precipitation events, or summer and fall events at high intensity rates or magnitudes, would initiate moisture fluxes at these depths on terraces. Fall moisture events at the near surface beneath bare ground seem to provide antecedent moisture conditions necessary to initiate runoff during subsequently smaller events in winter, contributing to the maintenance of a higher winter soil moisture. Higher differences in winter soil moisture may be due in part to longer residence time of soil moisture due to reduced evapotranspiration and higher water-holding capacities relative to wash surface soils, especially in winter months when evaporation is likely lowest.

Data from this study suggest soil moisture in the top one meter beneath the dripline radius of *O. tesota* and *P. microphylla* was generally greater and fluctuated more frequently on relict alluvial terraces than beneath the same species on alluvial washes in the Yuma Wash watershed, especially at 50-100 cm, in response to seasonal precipitation inputs. Findings also suggest the presence of desert pavement and the underlying vesicular (Av) horizon at the near surface on relict alluvial terraces plays a significant role in these differences, as seasonal moisture is redistributed at the surface away from bare ground beneath this layer of soil and stones, and concentrated as runon to adjacent vegetated areas on terraces where this layer has been removed through erosional processes. And, while the apparent increase in soil moisture on both geomorphic surfaces from lower to upper basin at 2.5 cm suggested by the data is complexed by missing data at this depth at the lower basin sites during 2006 and 2007, higher near surface soil moisture in the upper basin in all seasons and years for the period of record, greater precipitation in years with no missing data, and an increasing number of soil moisture events recorded on washes at 25-100 cm from lower to upper basin suggest other plausible reasons for these differences. Qualitative differences in pedogenic properties of the soils may also provide some insight in support of these findings, but also highlight the importance of obtaining greater detail in future work on how these heterogeneities affect soil moisture patterns in arid landscapes. Findings from the study, limitations of the research, and the implications for future work are discussed next.

CHAPTER 4

DISCUSSION

4.1 Summary of Research

The research presented herein addressed several basic research questions on how precipitation and soil moisture varied in various space and time domains in the Yuma Wash watershed, an arid dryland in Lower Colorado River Valley of the Sonoran Desert, in the southwestern US. Six tipping bucket rain gages coupled with sixty soil moisture probes placed in the top meter of soil at depths of 2.5, 25, 50, and 100 cm recorded precipitation and volumetric soil moisture beneath bare ground, *O. tesota*, and *P. microphylla* in three general locations (lower, middle, and upper basin), on two geomorphic surfaces (Holocene alluvial washes and middle to late Pleistocene alluvial terraces). Data were collected from July 2006-February 2010.

Findings from the study suggest Yuma Wash has a generally bimodal, summer and winter-dominated precipitation regime, with occasional fall and rare spring rainfall characteristic of southwestern US arid drylands. Interannual variability in precipitation was high for the period of record, with lower than regional mean annual precipitation recorded in 2007 and 2009, and greater than regional average precipitation in 2008. Greater recorded precipitation relative to the closest meteorological station 30 km to the south on the Yuma Proving Grounds (YPG/DCP1) may suggest an orographic influence due to surrounding mountainous topography in Yuma Wash relative to much of the surrounding valley floor that YPG encompasses. Summer precipitation varied most in space and was generally highest in intensity, and winter precipitation varied most in time and was generally lowest in intensity relative to other seasons. Per event precipitation was generally highest in fall, but over sixty percent of the total winter precipitation recorded for the period of record was delivered in a single storm event in 2010. Total summer and fall precipitation for the period of record, per event summer precipitation, and summer maximum intensities were greater in the upper basin relative to the lower, albeit interannual variation in spatial distribution was high for both seasons for the study period, and missing data in 2006 and 2007 added some error variance. Occasional high intensities were recorded during winter rainfall, and coupled with antecedent soil moisture from fall storms, may have contributed to greater soil moisture conditions in winter on relict terrace surfaces.

Precipitation findings introduced considerable complexity to spatially analyzing soil moisture response, as few events delivered the same amount of precipitation at the same rate at multiple stations. Analysis of soil moisture data for general response patterns by geomorphic surface, location, and cover type revealed distinct differences in soil response to precipitation between relict terrace surfaces and younger alluvial washes. Soils in the top one meter beneath the dripline radius of *O. tesota* and *P. microphylla* were wetted much more frequently and to greater depths on relict terraces than soils beneath the same species on interfluves in washes, and relative to beneath bare ground on terraces where desert pavement and a vesicular A (Av) horizon was present. At the near surface (2.5 cm), while nearly identical soil moisture events were recorded on both surfaces at a given location, soil moisture response at 25 cm was 1.5-4 times more frequent beneath vegetated cover on terraces relative to washes, and up to 15 times more frequent at 50-100 cm. And, moisture events were 3-15 times greater beneath these species than beneath bare ground pavements with Av horizons on terraces. Median soil moisture beneath *O. tesota* ranged from 13-18 percent from 25-100 cm, versus 6-8 percent on washes, and from 9-20 percent beneath *P. microphylla* on terraces, versus 7-13 percent on washes. Beneath bare ground, soil moisture medians ranged from 9-11 percent on terraces versus 7-13 percent on washes depending on depth, with highest moisture levels generally recorded at 50 cm.

There was also some evidence to suggest near surface (2.5 cm) soil moisture was greater on both geomorphic surfaces in the upper relative to the lower basin. Median soil moisture at 2.5 cm on terraces ranged from 4 percent in the lower basin to 11 percent in the upper basin, and on washes, from 4 percent to 10 percent from lower to upper basin. Greater thickness in the vesicular A horizon was noted at this site relative to the mid- and upper basin, but detailed analysis of the pedogenic differences in texture, structure, and chemical constituents was not conducted. Missing data and relative differences in probe sensitivity to local pedogenic properties may also have influenced these results. The relative degree of soluble salts and clays of aeolian origin may have had an influence on moisture differences at the near surface by location, but temperature correcting these data would have resulted in only a two percent correction to median values, and peak magnitudes (which were temperature corrected at 2.5 cm) remained higher in the mid- and upper basin relative to the lower basin. It is not known from these data how much the soil specific calibration compensated for these differences.

The number of soil moisture events recorded also increased from lower to upper basin at 25-100 cm, but only on wash surfaces, and the amount or rate of rainfall required to infiltrate beyond 25 cm on washes was restricted to less than 5 events in the upper basin, and 1-2 events in the lower and mid-basin. On terraces, soil moisture varied between and within sites, but did not show an increasing trend from lower to upper basin at 25-100 cm. Beneath vegetated cover at 25-100 cm on terraces, soil moisture events ranged from 5-15 depending on location, and response was generally greater in the lower and mid-basin relative to the upper basin, particularly at 50-100 cm. A higher fraction of silts and fines translocated throughout the soil profiles, considerable compaction of soils, and shallow rooting depths to 25 cm were noted at the upper terrace sites during installation, which may provide one explanation for the lesser response to precipitation at these depths.

Differences in soil moisture from the lower to the upper basin may be due to several influences, however. Higher total and per event precipitation may have resulted in greater near surface soil moisture, but higher water holding capacity of the near surface soil horizon at the upper site due to increased thickness of the vesicular A horizon may also have reduced runoff to adjacent vegetated cover. Similarly, a less developed Av horizon at the lower terrace site might suggest a lower water-holding capacity, resulting in greater runoff to adjacent vegetated cover, but also a deeper infiltration of soil moisture beneath the Av horizon. Greater accumulation of clays and salts in the vesicular A horizon from aeolian dust (from 2-6 cm) has been previously shown to increase water retention at the surface (Young et al, 2004), and reduce infiltration to soil profiles below. This might also provide an alternate explanation as to why greater drainage was recorded beneath the terrace bare ground probe at 25 cm in the lower wash, rather than resulting from damaged pavement during installation.

Seasonal influence on soil moisture was greatest in the top 25 cm, and soil moisture was highest during winter. An unexpected finding was that several winter events of moderate magnitude and intensity resulted in runon to vegetated cover on terraces, and at the lower terrace site, the same events resulting in soil moisture increases beneath vegetated cover also resulted in infiltration to 25 cm beneath pavement bare ground. The events all occurred during periods of higher antecedent moisture conditions resulting from moderate to high fall or winter precipitation events. This was an unexpected finding, and may provide some support for a lower water-holding capacity of the Av horizon at the lower terrace site, but also points to relative importance of the general surface conditions of the soil on terraces versus washes. Summer, fall and winter precipitation played a role in soil moisture changes on both surfaces during the period of study, but relative changes on terraces were significantly greater beneath *O. tesota* and *P. microphylla* relative to washes, and highlights the hydrologic role of pavement surfaces in the Yuma Wash watershed in the redistribution of water. The limitations of the findings are discussed next.

4.2 Limitations of Findings and Recommendations for Future Research

Quantifying precipitation and soil moisture in Yuma Wash over a broad spatial and narrow time scale resulted in considerable variability in estimates of these hydrologic components. While general differences in seasonal precipitation and the response of soils across two geomorphic surface were documented in this study, local heterogeneities in soils due to pedogenic processes, combined with extreme soil temperature fluctuations, likely had significant influence on soil moisture estimates, both within and across geomorphic surfaces of varying age. Site specific calibration and a temperature correction applied to probe readings were attempted to address some of the error variance associated with these properties, but laboratory conditions under which these calibrations were conducted likely did not mimic conditions as water moved through some soil profiles *in situ*. It is likely that excavation of soil samples for the calibration procedure may have inadvertently resulted in preferential sampling of less consolidated soil material, which may have reduced the salt and clay content of samples. This may have affected probe calibrations. Removal of larger size fractions of gravel and cobbles was required to pack columns for calibration based on the recommended procedure, which likely also affected estimates of bulk density. Also, the temperature correction recommended by the manufacturer for the particular probe used was not developed for soils that undergo temperature extremes such as those recorded in Yuma Wash. Since real permittivity due to soil moisture is inversely related to temperature (e.g., as temperature increases, permittivity decreases), and electrical conductivity is directly related to temperature (e.g., EC increases as temperature increases), it was expected that the temperature correction would increase summer soil moisture and reduce winter estimates. However, temperature correcting the data resulted in a reduction in summer moisture estimates, and in some cases negative values, and albeit relatively smaller, increases with occasional decreases in winter estimates of soil moisture.

Time domain reflectometry (TDR) is a popular method used to quantify soil moisture *in situ*, but the conditions of the soils in Yuma Wash—particularly on terraces, may have introduced variability in soil moisture estimates the researcher was unable to quantify in the study. High salt contents, soil compaction and cementation, and the presence of clay minerals can all act to attenuate the signal of TDR probes, particularly in extreme climates, where seasonal temperature variation is high. Differences in soil moisture at depth may have been particularly confounded on terraces at 50-100 cm by the presence of high salts, which tend to covary with depth of leaching. So while soil moisture may be highest at 50 cm, highest concentrations of salts are also likely at this depth on this surface. Discussions with other researchers during and since this work was conducted have confirmed these influences can be problematic in arid landscapes. TDR technology that operates within a higher frequency range apparently can reduce some of these influences on imaginary permittivity, and future work is needed comparing these types of instrumentation for their performance in arid landscapes.

Data collection in a remote region with extreme climatic variation resulted in data gaps, further compromising comparisons in space and time. Storm damage to instrumentation, delays or disruption in installation due to weather and military operations, and temporary malfunction of sensors in between data retrieval periods were all problems encountered during the research period. Additionally, erratic soil moisture readings due to poor probe contact with soils (perhaps due to excessive gravel), imaginary permittivity caused by excessive salts, clays, compaction and induration, shrinking and swelling of soil temperature sensor wires during extreme temperature fluctuations, and/or rodent damage to buried cable, are all hypothesized influences which compromised the study findings.

Statistical methods that were selected for these data imposed additional constraints on interpretations of the findings. While non-parametric analyses that do not rely on an assumption of normality in data distribution was a more statistically valid approach to working with non-normally distributed data, some power was lost in comparing rank sum values rather than the actual nominal data. Data sets restricted in size also limited some analyses, particularly precipitation and soil moisture event data for fall and spring, at 50-100 cm depths on washes, and beneath bare ground cover on terraces. Comparing event-based metrics to elucidate spatial differences was also problematic and required consideration of actual number of events recorded at each site, as sites that recorded only large events inevitably reflected greater median values than sites that may have received greater total moisture, but from both large and small events. An alternate approach to analyzing soil moisture event data might have been to compare the response across geomorphic surfaces only to shared precipitation events of equal magnitude and intensity for each basin location separately. This would have allowed for the separation of variation due to differences in precipitation characteristics. In the case of fifteen-minute soil moisture data, large sample sizes were also restrictive in that very small differences were detected as statistically significant, and may or may not have ecological relevance.

Finally, the title of the originally proposed and funded work that was to be conducted by the researcher was entitled *Quantifying the Complex Hydrologic Response of a Desert Ephemeral Wash.* The idea for this work stemmed from three years of prior field research in

Yuma Wash and elsewhere under the tutelage of the researcher's advisor. As a rather naive and ambitious graduate student, the researcher wished that a bigger story could be told about desert hydrology, and sought independent funding for a continued four-year effort. The scope of the proposed follow on work was to quantify several hydrologic components in Yuma Wash, and to estimate evapotranspiration across two geomorphic surfaces at three basin locations using various methods, including eddy covariance, tree sapflux, pan evaporimeters, and energy budget analyses. Quantifying soil moisture was to be a component of that work. However, with independent funding also came the sole responsibility for project execution, budget, personnel, and data management, and all interim and final reporting requirements. In hindsight, it was far more than a single graduate student ought to have attempted, and as a consequence, the research required considerable scaling back. In doing so, it was discovered that the story that might have been told would not have been an accurate one, had the complexities found in data presented herein not been elucidated.

It is the hope of this researcher that readers will not only glean a bit of insight on arid lands hydrology from the findings presented, but perhaps more importantly, will employ the knowledge gained from what was not accomplished during the research process toward improved future research on arid lands hydrology. The following recommendations are offered to future new researchers in arid lands hydrology. First, recognizing the scale at which additional processes are likely operating that are influencing what is being measured is a critical first step to study design, thus allowing a researcher to better constrain potentially confounding variables. Second, when conducting field research, careful consideration of the environmental conditions under which instrumentation may be compromised in performance is paramount to obtaining good data. In climatically extreme conditions where data are scant and many instruments have not been tested, small investments in trial studies are as valuable as *a priori* second opinions. Third, while it seems an obvious truth that limiting the scope of work to a level that is manageable for the researcher helps in bringing a piece of research to fruition, for some of us, experience is often our best teacher. In retrospect, I believe it is the wiser that look for guidance from those who have come before us. Much of the data originally collected during this study now lie dormant, waiting for their part of the story to be told. Coming from a very different place of reasoning than when the initial idea for the research was formulated, I find it indeed ironic that the original title of the proposed work still seems quite fitting.

4.3 Relevance of findings

Despite the many limitations of this study, it is hoped that the results have made a small contribution to our limited understanding of how precipitation and soil moisture vary in this arid landscape, and specifically highlight the important hydrologic role relict alluvial terraces mantled with desert pavement and an underlying vesicular horizon play in redistributing limited precipitation to vegetated species that grow on them in the Yuma Wash watershed. This is the first research in Yuma Wash that has quantified precipitation and soil moisture response at multiple sites on varying geomorphic terrain in Yuma Wash, and some insight was gained on how soils beneath *O. tesota* and *P. microphylla* on relict alluvial terraces respond to precipitation relative to soils beneath bare ground and relative to each other, and relative to soils beneath the same species on younger alluvial washes. How this water might be utilized by each of these species is beyond the scope of this dissertation, but there are interesting follow on questions that might be asked in a more eco-hydrology framework.

For example, understanding the relative moisture requirements of each species and their response to measured soil moisture by measuring pre-dawn water potential following events, and quantifying seasonal sapflux might shed some light on whether differences in soil moisture beneath the dripline radius have any correlation with water use strategies employed by these species. Measurement of plant water potential provides a direct measurement of available soil moisture integrated over a plant's rooting system, and limited, unpublished data by McDonald et al. (2004) show both species elsewhere in the Sonoran desert responded to a single precipitation event of 35 mm with estimated soil moistures near both species of 8 to 23 percent. It is plausible that soil moisture beneath the dripline radius of these species on wash surfaces in the Yuma Wash watershed does not correlate well with plant water use. Both of these species have tap and secondary root networks, and on washes, may extend their lateral root networks well beyond their interfluvial surfaces into larger flow pathways in the braided channel network to gain access to lower volume runoff that does not cover the interfluvial surface. Relative to the same species on terraces, whose rooting zones are restricted to areas where pavement and Av horizons have been removed, soil moisture conditions quite distal to the actual plant may be better correlated with plant available water.

It has been hypothesized by other researchers (McDonald et al., 2004) that *O. tesota* and *P. microphylla* in desert washes can access deeper vadose zone soil moisture (>2 m) recharged from large, infrequent runoff events (every 3-10 years), whereas the same species on relict terraces may depend more on annual inputs from smaller storms to support their respiratory processes. This research provided some evidence in support of this claim, but linkages to plant available water were not made. These two species also employ different carbon fixation strategies, *O. tesota* relying exclusively on leaf area for photosynthesis and *P. microphylla* employing leaf and stem photosynthesis. Apparently stem photosynthesis provides a greater degree of water use efficiency, and has been linked to more persistent sources of water, whereas leaf canopies have been tied to more shallow water dynamics (Comstock and Ehleringer, 1988). This may explain in part why observed root densities were greater beneath *O. tesota* relative to *P. microphylla* at nearly all sites in this study, and may also explain some of the recorded differences in soil moisture. Quantifying biological characteristics such as the depths, densities, and lateral and vertical extension of root networks in each of these species on each surface, and changes in water potential following events, as well as understanding the role of canopy and leaf litter interception, might shed further light on the relationship between soil moisture and these vegetative species. While broad in spatial extent and narrow in time and scope, the data presented herein provide a much needed baseline on the soil moisture component beneath these species toward this end.

Since the cessation of this research, permission to access Yuma Wash has become increasingly restrictive to the scientific community, as testing of military equipment and operations are now being conducted on a regular basis, and permanent installations have occurred in upper reaches of the watershed. The extent to which this increased traffic and land use activity will alter hydrologic conditions in the watershed is not known. As political, economic and religious ideological conflicts continue to escalate in arid lands into the 21st century, increasing pressure is being put on all US Southwest desert environments, which are the primary test and training grounds for the United States military. The role of desert pavement and the underlying vesicular A horizon in redistributing scarce water to vegetated areas on relict terraces has been demonstrated in this study. Vulnerability of this surface layer to disturbance from vehicular traffic may have important hydrologic implications in Yuma Wash. Military operations should be conducted to avoid disturbance of these desert pavement surfaces wherever possible.

As increasing aridity is projected under various climate change scenarios, it is perhaps more critical than ever to obtain hydrologic data that can improve water balances for arid lands, and assist resource managers who may witness large ecological changes over short time spans. Extrapolating point measurements of these hydrologic components across scales, or using point measurements to make inferences about differences over larger scales may result in large discrepancies in estimates of atmospheric-land surface exchanges. Additional resources are needed to continue monitoring the hydrologic conditions in Yuma Wash, and how these change, along with vegetation, with changes in land condition. Yuma Wash is bordered by the Imperial National Wildlife Refuge to the south, and changes in hydrologic condition in the wash may also impact water quantity and quality downstream. Changes in runoff/runon instigated by disturbance to pavements, for example, may alter subsurface recharge from the vadose zone to the groundwater table, and further downstream where Yuma Wash terminates to the Colorado River. Managers at the Imperial National Wildlife Refuge protect habitat along 30 miles of the Colorado River in this region. It is not known how much subsurface flow from Yuma Wash reaches the Colorado River, nor what chemical constituents from unexploded ordinance and other munitions may be carried out of Yuma Wash in subsurface flows. This study provided a first dataset on precipitation and soil moisture in the top one meter across two of the predominant geomorphic surfaces in Yuma Wash. Future hydrologic research should include quantifying biological linkages between soil moisture and plant water use, including evaporative losses, and monitoring of subsurface flows and groundwater recharge from terraces to washes and to the outlet of Yuma Wash. There is much to be understood going forward.

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APPENDIX A

PROGRAMMING CODE FOR INSTRUMENTATION DATA COLLECTION AND DATA POST-PROCESSING

Programming Code for Instrumentation Data Collection: datalogger programming language used for all instrumentation was either CRBasic or Edlog, as developed by Campbell Scientific, Inc. for use with array or table-based dataloggers.

Meteorological Stations (MET1-MET4)—datalogger program for recording precipitation and near surface (2.5cm) soil moisture at these four stations. Program was modified for each station where sensor or site specific coefficients were required. Program also included measurements for additional variables collected as a larger research effort beyond the scope of this dissertation, and were therefore eliminated from the below code. Similar programming was done for ECOV1 and ECOV2 stations, including flux measurements of carbon dioxide and water vaper using eddy covariance methods.

The following data were collected using Campbell Scientific instrumentation at 60 second intervals, averaged and outputted every 15-minutes for this study, and as part of a larger study beyond the scope of this dissertation:

Instrument	Data Collected
HMP50	air temp/Rh
CS100	barometric pressure
034B	wind anemometer (wind speed/direction)
CS616	soil water content
TCAV	soil temperature
Rebs	soil heat flux
NR-Lite	net radiation
TE525	precipitation
LiCor7500	carbon and water vapor
CSAT	sonic anemometer
Li190B	PAR photosynthetically active radiation

```
;{CR23X-TD}MET1 Station Program
;Written by Mike Hansen at CSI and modified by Susan Howe and Mike Hansen:
Jan 25, 2006

*Table 1 Program
  01: 60        Execution Interval (seconds)
; Datalogger wiring instructions
;1H (SE1)    HMP50 Black
;1L (SE2)    HMP50 White
;AG          HMP50 Blue, 034B White, CS100 Yellow
;2H (SE3)    034B Green
;2L (SE4)    CS100 Blue
;3H (SE5)
;3L (SE6)    CS616 (1) Green  This is the sensor designated for the Heat
Flux measurement
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;AG
;4H (SE7)     TCAV-L Purple
;4L (SE8)     TCAV-L Red
;AG           TCAV-L Clear
;5H (SE9)     NR-Lite White
;5L (SE10)    NR-Lite Green with a jumper to AG
;AG           Jumper to 5L
;6H (SE11)
;6L (SE12)
;AG
;7H (SE13)    Rebs_1 Black
;7L (SE14)    Rebs_2 Black
;AG           Rebs_1 and Rebs_2 White
;8H (SE15)
;8L (SE16)
;AG
;9H (SE17)
;9L (SE18)
;AG
;10H (SE19)
;10L (SE20)
;AG
;11H (SE21)
;11L (SE22)
;AG
;12H (SE23)
;12L (SE24)
;AG
;12V       HMP50 Brown, CS100 Red, CS616 (1-4) Red
;12V
;G         CS100 Clear & Black
;G         CS616 (1) Clear & Black
;G
;C1        CS100 Green
;C2        CS616 (1) Orange
;C3
;C4
;C5
;C6
;C7
;C8
;E1        034B Blue
;E2
;E3
;P1        TE525 Black
;G         TE525 Clear & White; HMP50 Clear
;P2        034B Red
;G         034B Black
;-----------------------------------------------------------------------
1:  Batt Voltage (P10)
 1: 1        Loc [ Batt_Volt      ]


2:  Panel Temperature (P17)
```

```
 1: 38       Loc [ PTemp_C        ]


3:  If time is (P92)
 1: 0        Seconds into a
 2: 86400    Second interval
 3: 30       Then Do

    4:  Signature (P19)
     1: 2        Loc [ Prog_Sig       ]

5:  End (P95)

6:  Time (P18)
 1: 6        Store Mo,Day,Yr,Hr,Min,Sec in 6 consecutive locations
 2: 0000     Mod/By
 3: 96       Loc [ Month          ]

7:  Pulse (P3)
 1: 1        Reps
 2: 1        Pulse Channel 1
 3: 2        Switch Closure, All Counts
 4: 3        Loc [ Rain_mm        ]
 5: 0.254    Multiplier
 6: 0        Offset

;Rain event output based on 5 minute rain events
8:  Z=X+Y (P33)
 1: 3        X Loc [ Rain_mm        ]
 2: 102      Y Loc [ Rain_Event     ]
 3: 102      Z Loc [ Rain_Event     ]


9:  If time is (P92)
 1: 0        Seconds into a
 2: 300      Second interval
 3: 30       Then Do


    10:  If (X<=>F) (P89)
     1: 102      X Loc [ Rain_Event     ]
     2: 3        >=
     3: 0.01     F
     4: 12       Set Flag 2 High


11:  End (P95)

12:  Data Table (P84)^9022
 1: 0        Seconds into Interval
 2: -2       When Flag 2 is High
 3: 1440     (0 = auto allocate, -x = redirect to inloc x)
 4: Rain_5_min                Table Name
```

```
13:  Sample (P70)^1135
 1: 1        Reps
 2: 102      Loc [ Rain_Event     ]


;Reset rain event to 0 after it saves five minutes worth of rain data
14:  If Flag/Port (P91)
 1: 12       Do if Flag 2 is High
 2: 30       Then Do


     15:  Z=F x 10^n (P30)
      1: 0        F
      2: 1        n, Exponent of 10
      3: 102      Z Loc [ Rain_Event     ]


     16:  Do (P86)
      1: 22       Set Flag 2 Low

17:  End (P95)

;Take soil temp measurement with TCAV
49:  Thermocouple Temp (DIFF) (P14)
 1: 1        Reps
 2: 21       10 mV, 60 Hz Reject, Slow Range
 3: 4        DIFF Channel
 4: 2        Type E (Chromel-Constantan)
 5: 38       Ref Temp (Deg. C) Loc [ PTemp_C        ]
 6: 37       Loc [ T_Soil         ]
 7: 1.0      Multiplier
 8: 0.0      Offset

;Measure 1 CS616 sensors
52:  CS616 Water Content Reflectometer (P138)
 1: 1        Reps
 2: 6        SE Channel
 3: 12       All reps use C2
 4: 17       Loc [ PA_uS_1        ]
 5: 1        Multiplier
 6: 0        Offset

53:  Polynomial (P55)
 1: 1        Reps
 2: 17       X Loc [ PA_uS_1        ]
 3: 25       F(X) Loc [ VW_1           ]
 4: -0.5175  C0
 5: 0.0361   C1
 6: -0.0003  C2
 7: 0        C3
 8: 0        C4
 9: 0        C5
```

```
;Apply temperature correction to the volumetric water content
;Define a Constant of 20

54:  Z=F x 10^n (P30)
 1: 20       F
 2: 0        n, Exponent of 10
 3: 107      Z Loc [ Const20        ]

55:  Polynomial (P55)
 1: 1        Reps
 2: 17       X Loc [ PA_uS_1        ]
 3: 104      F(X) Loc [ TempCS616      ]
 4: 0.526    C0
 5: -0.052   C1
 6: 0.00136  C2
 7: 0.0      C3
 8: 0.0      C4
 9: 0.0      C5

56:  Z=X-Y (P35)
 1: 107      X Loc [ Const20        ]
 2: 37       Y Loc [ T_Soil         ]
 3: 105      Z Loc [ TFactor        ]

57:  Z=X*Y (P36)
 1: 105      X Loc [ TFactor        ]
 2: 104      Y Loc [ TempCS616      ]
 3: 104      Z Loc [ TempCS616      ]

58:  Z=X+Y (P33)
 1: 17       X Loc [ PA_uS_1        ]
 2: 104      Y Loc [ TempCS616      ]
 3: 108      Z Loc [ NewCS616       ]

59:  Polynomial (P55)
 1: 1        Reps
 2: 108      X Loc [ NewCS616       ]
 3: 109      F(X) Loc [ VW_1_T_Cor     ]
 4: -0.5175  C0
 5: 0.0361   C1
 6: -0.0003  C2
 7: 0.0      C3
 8: 0.0      C4
 9: 0.0      C5

;Store 15 minute values
60:  Data Table (P84)^12507
 1: 0        Seconds into Interval
 2: 900      Seconds Interval
 3: 0        (0 = auto allocate, -x = redirect to inloc x)
 4: T115                       Table Name

61:  Sample (P70)^10315
```

```
 1: 3        Reps
 2: 99       Loc [ Hour          ]

62:  Totalize (P72)^32183
 1: 1        Reps
 2: 3        Loc [ Rain_mm       ]

64:  Average (P71)^21878
 1: 1        Reps
 2: 17       Loc [ PA_uS_1       ]

65:  Average (P71)^9830
 1: 1        Reps
 2: 25       Loc [ VW_1          ]

66:  Sample (P70)^9248
 1: 1        Reps
 2: 109      Loc [ VW_1_T_Cor    ]

75:  Average (P71)^25182
 1: 1        Reps
 2: 37       Loc [ T_Soil        ]

76:  Average (P71)^4930
 1: 1        Reps
 2: 38       Loc [ PTemp_C       ]

;Store daily values
77:  Data Table (P84)^21102
 1: 0        Seconds into Interval
 2: 86400    Seconds Interval
 3: 0        (0 = auto allocate, -x = redirect to inloc x)
 4: Daily                     Table Name

78:  Sample (P70)^24720
 1: 5        Reps
 2: 96       Loc [ Month         ]

79:  Minimum (P74)^15463
 1: 1        Reps
 2: 0        Value Only
 3: 1        Loc [ Batt_Volt     ]

80:  Sample (P70)^20885
 1: 1        Reps
 2: 2        Loc [ Prog_Sig      ]

*Table 2 Program
  02: 0         Execution Interval (seconds)
*Table 3 Subroutines
```

Soil Moisture Stations (SF1-SF6)-- datalogger program for recording soil moisture and soil temperature at depths of 25,50, and 100cm. Program was modified for each station where sensor or site specific coefficients were required. Program also included measurementsof tree sap velocity collected as a larger research effort beyond the scope of this dissertation**.**

The following data were collected using Campbell Scientific and East 30 instrumentation at 60 second intervals, averaged and outputted every 15-minutes for this study, and as part of a larger study beyond the scope of this dissertation:

Instrument	Data Collected
T107	soil temperature
CS616	soil water content
Sapflow sensors	sap velocity via heat pulse method

```
----------------------------------------------------------------------

'CR1000  Program for SF 1 and SF2 stations
'Created by SCWIN (2.5 (beta))
'Created by Mike Hansen Campbell Scientific July 2006
----------------------------------------------------------------------
'All temperatures for SF TCs in 120 second loop are reported as
differences in temperature in degrees C from the initial pre- 4-second
heat pulse temperatures
'SF TC'S are type E
'Only one external battery source for all sensors and heater
'SF TCs are measured single ended across a 10:1 voltage divider
'All wiring to [AM 16/32 Multiplexor] is in 4 x 16 mode
----------------------------------------------------------------------
'CS616 below refers to soil moisture sensors at 25,50, and 100cm depths
'T107 below refers to soil temperature sensors at 25,50, and 100cm depths
'---------------------------------------------------------------------
'WIRING OF DATA LOGGER:

'1H T107(1)BG25cm Red              5H T107(9)IW100cm Red
'1L T107(2)BG50cm Red              5L single wire to multiplexor COM ODD L
(multiplexing outer TCs)
'Ground T107(1-4)Purple            Ground next to 5L single wire to COM
Signal Ground on multiplexor
'2H T107(3)BG100cm Red             6H single wire to multiplexor COM EVEN
H (multiplexing middle TCs)
'2L T107(4)PV25cm Red              6L single wire to multiplexor COM EVEN
L (multiplexing inner TCs)
'Ground T107(5-9)Purple            Ground
'3H T107(5)PV50cm Red              7H voltage divider on data logger to
'H' (+) on just 1 relay driver
'3L T107(6)PV100cm Red             7L voltage divider on data logger to
'signal ground'(-) on just 1 relay driver
'Ground
'4H T107(7)IW25cm Red              8H
'4L T107(8)IW50cm Red              8L

'Ground
'EX1 T107 (1-4)Black               EX2 T107 (5-9) Black
'Ground
      Ground
```

```
'Ground                         EX3
'P1
'P2
'G T107(1-4) Clear
'5V
'G T107(5-9) Clear
'SW-12
'12V  on data logger (outgoing port) single wire to 12V on multiplexor
'12V
'G   on data logger (outgoing port) single wire to G on multiplexor

'C1  on data logger single wire to RES on multiplexor
'C2  on data logger single wire to CLK on multiplexor
'C3  on data logger single wire to COM ODD H on multiplexor (controls
616s)
'C4  on data logger two wires from same C4 port, one to each 'C' CTRL on
each of the 2 SapFlow
'interface boards (i.e. the relay drivers)
'NEVER HAVE WIRES POWERED UP WITHOUT SAPFLOW SENSORS EMBEDDED IN TREES
'G   on data logger two wires from same G (use the one next to C4), one
wire goes to each
'Signal Ground port on each of the two heater interface boards (i.e. relay
drivers)
'C5
'C6
'C7
'C8
'G
-------------------------------------------------------------------
'EXTERNAL POWER SUPPLY WIRING:
-------------------------------------------------------------------
'WIRING OF [AM16/32 MULTIPLEXOR] IN 4x16 MODE:

'G         all CS616 Black
'12V       all CS616 Red
'***SF1 STATION ONLY***:
'1H odd
                                                           9H odd
'1L odd    SF TC(1-3) PAMI 1-1 Purple
     9L odd           SF TC(25-27)     OLTE 1-2 Purple
'Ground   SF TC(1-3) PAMI 1-1 Red
          Ground           SF TC(25-27)     OLTE 1-2 Red
'1H even  SF TC(1-3) PAMI 1-1 Yellow
     9H even    SF TC (25-27)    OLTE 1-2 Yellow
'1L even  SF TC(1-3) PAMI 1-1 Green
          9L even    SF TC (25-27)    OLTE 1-2 Green
'Ground   T107(5-8)  Purple
                     Ground
'2H odd
                                                           10H odd
'2L odd  SF TC(4-6) PAMI 1-1 Purple
          10L odd    SF TC(28-30)     OLTE 1-2 Purple
'Ground  SF TC(4-6) PAMI 1-1 Red
          Ground     SF TC (28-30)    OLTE 1-2 Red
```

```
'2H even SF TC(4-6) PAMI 1-1 Yellow
           10H even   SF TC(28-30)     OLTE 1-2 Yellow
'2L even SF TC(4-6) PAMI 1-1 Green
      10L even   SF TC (28-30)    OLTE 1-2 Green
'3H odd
                                                    11H odd
'3L odd  SF TC(7-9) PAMI 1-1RNT Purple
      11L odd          SF TC (31-33) PAMI 1-2RNT Purple
'Ground  SF TC(7-9) PAMI 1-1RNT Red
      Ground           TC (31-33)       PAMI 1-2RNT Red
'3H even SF TC(7-9) PAMI 1-1RNT Yellow
      11H even   SF TC (31-33)    PAMI 1-2RNT Yellow
'3L even SF TC(7-9) PAMI 1-1RNT Green
      11L even   SF TC (31-33)    PAMI 1-2RNT Green
'Ground
                                                    Ground
'4H odd
                                                    12H odd
'4L odd  SF TC(10-12) PAMI 1-2 Purple
      12L odd          SF TC (34-36)    PAMI 1-2RNT Blue
'Ground     SF TC(10-12) PAMI 1-2 Red
      Ground           SF TC (34-36)    PAMI 1-2RNT Pink
'4H even SF TC(10-12) PAMI 1-2 Yellow
      12H even   SF TC (34-36)    PAMI 1-2RNT White
'4L even SF TC(10-12) PAMI 1-2 Green
      12L even   SF TC (34-36)    PAMI 1-2RNT Orange
'5H odd
                                                    13H odd
'5L odd  SF TC(13-15) PAMI 1-2 Purple
      13L odd          SF TC (37-39) PAMI 1-1RNT Blue
'Ground  SF TC(13-15) PAMI 1-2 Red
      Ground           SF TC (37-39) PAMI 1-1RNT Pink
'5H even SF TC(13-15) PAMI 1-2 Yellow
      13H even   SF TC (37-39) PAMI 1-1RNT White
'5L even SF TC(13-15) PAMI 1-2 Green
      13L even   SF TC (37-39) PAMI 1-1RNT Orange
'Ground
                                                    Ground
'6H odd
                                                    14H odd    CS616(1-3)
BG25,50,100cm Orange
'6L odd  SF TC(16-18) OLTE 1-1 Purple
      14L odd    CS616(1)   BG25cm Green
'Ground  SF TC(16-18) OLTE 1-1 Red
      Ground           CS616(1-3) BG25,50,100cm Clear
'6H even SF TC(16-18) OLTE 1-1 Yellow
      14H even   CS616(2)   BG50cm Green
'6L even SF TC(16-18) OLTE 1-1 Green
      14L even   CS616(3)   BG100cm Green
'7H odd
                                                    15H odd    CS616(4-6)
PV25,50,100cm Orange
'7L odd  SF TC(19-21) OLTE 1-1 Purple
      15L odd    CS616(4)   PV25cm Green
```

```
'Ground  SF TC(19-21) OLTE 1-1 Red
      Ground           CS616(4-6) PV25,50,100cm Clear
'7H even SF TC(19-21) OLTE 1-1 Yellow
      15H even   CS616(5)   PV50cm Green
'7L even SF TC(19-21) OLTE 1-1 Green
      15L even   CS616(6)   PV100cm Green
'8H odd
                                                     16H odd    CS616(7-9)
IW25,50,100cm Orange
'8L odd  SF TC(22-24) OLTE 1-3 Purple
      16L odd    CS616(7)   IW25cm Green
'Ground  SF TC(22-24) OLTE 1-3 Red
      Ground           CS616(7-9) IW25,50,100cm Clear
'8H even SF TC(22-24) OLTE 1-3 Yellow
      16H even   CS616(8)   IW50cm Green
'8L even SF TC(22-24) OLTE 1-3 Green
      16L even   CS616(9)   IW100cm Green
-----------------------------------------------------------------------
'***SF2 STATION ONLY***:
'1H odd
                                                     9H odd
'1L odd    SF TC(1-3) PAMI 2-1 Purple
      9L odd           SF TC(25-27)     OLTE 2-2 Purple
'Ground   SF TC(1-3) PAMI 2-1 Red
            Ground           SF TC(25-27)     OLTE 2-2 Red
'1H even  SF TC(1-3) PAMI 2-1 Yellow
      9H even    SF TC (25-27)    OLTE 2-2 Yellow
'1L even  SF TC(1-3) PAMI 2-1 Green
            9L even    SF TC (25-27)    OLTE 2-2 Green
'Ground   T107(5-8)  Purple
                        Ground
'2H odd
                                                     10H odd
'2L odd  SF TC(4-6) PAMI 2-1 Purple
            10L odd    SF TC(28-30)     OLTE 2-2 Purple
'Ground  SF TC(4-6) PAMI 2-1 Red
            Ground     SF TC (28-30)    OLTE 2-2 Red
'2H even SF TC(4-6) PAMI 2-1 Yellow
            10H even   SF TC(28-30)     OLTE 2-2 Yellow
'2L even SF TC(4-6) PAMI 2-1 Green
      10L even   SF TC (28-30)    OLTE 2-2 Green
'3H odd
                                                     11H odd
'3L odd  SF TC(7-9) PAMI 2-1RNT Purple
      11L odd          SF TC (31-33) PAMI 2-2RNT Purple
'Ground  SF TC(7-9) PAMI 2-1RNT Red
      Ground           TC (31-33)       PAMI 2-2RNT Red
'3H even SF TC(7-9) PAMI 2-1RNT Yellow
      11H even   SF TC (31-33)    PAMI 2-2RNT Yellow
'3L even SF TC(7-9) PAMI 2-1RNT Green
      11L even   SF TC (31-33)    PAMI 2-2RNT Green
'Ground
                                                     Ground
```

```
'4H odd
                                                    12H odd
'4L odd  SF TC(10-12) PAMI 2-2 Purple
      12L odd          SF TC (34-36)    PAMI 2-2RNT Blue
'Ground     SF TC(10-12) PAMI 2-2 Red
      Ground           SF TC (34-36)    PAMI 2-2RNT Pink
'4H even SF TC(10-12) PAMI 2-2 Yellow
      12H even   SF TC (34-36)    PAMI 2-2RNT White
'4L even SF TC(10-12) PAMI 2-2 Green
      12L even   SF TC (34-36)    PAMI 2-2RNT Orange
'5H odd
                                                    13H odd
'5L odd  SF TC(13-15) PAMI 2-2 Purple
      13L odd          SF TC (37-39) PAMI 2-1RNT Blue
'Ground  SF TC(13-15) PAMI 2-2 Red
      Ground           SF TC (37-39) PAMI 2-1RNT Pink
'5H even SF TC(13-15) PAMI 2-2 Yellow
      13H even   SF TC (37-39) PAMI 2-1RNT White
'5L even SF TC(13-15) PAMI 2-2 Green
      13L even   SF TC (37-39) PAMI 2-1RNT Orange
'Ground
                                                    Ground
'6H odd
                                                    14H odd    CS616(1-3)
BG25,50,100cm Orange
'6L odd  SF TC(16-18) OLTE 2-1 Purple
      14L odd    CS616(1)   BG25 Green
'Ground  SF TC(16-18) OLTE 2-1 Red
      Ground           CS616(1-3) BG25,50,100cm Clear
'6H even SF TC(16-18) OLTE 2-1 Yellow
      14H even   CS616(2)   BG50cm Green
'6L even SF TC(16-18) OLTE 2-1 Green
      14L even   CS616(3)   BG100cm Green
'7H odd
                                                    15H odd    CS616(4-6)
PV25,50,100cm Orange
'7L odd  SF TC(19-21) OLTE 2-1 Purple
      15L odd    CS616(4)   PV25cm Green
'Ground  SF TC(19-21) OLTE 2-1 Red
      Ground           CS616(4-6) PV25,50,100cm Clear
'7H even SF TC(19-21) OLTE 2-1 Yellow
      15H even   CS616(5)   PV50cm Green
'7L even SF TC(19-21) OLTE 2-1 Green
      15L even   CS616(6)   PV100cm Green
'8H odd
                                                    16H odd    CS616(7-9)
IW25,50,100cm Orange
'8L odd  SF TC(22-24) OLTE 2-3 Purple
      16L odd    CS616(7)   IW25cm Green
'Ground  SF TC(22-24) OLTE 2-3 Red
      Ground           CS616(7-9) IW25,50,100cm Clear
'8H even SF TC(22-24) OLTE 2-3 Yellow
      16H even   CS616(8)   IW50cm Green
```

```
'8L even SF TC(22-24) OLTE 2-3 Green
      16L even   CS616(9)   IW100cm Green
--------------------------------------------------------------------
'PROGRAM:
'Declare Variables and Units
Dim LCount_13
Public Batt_Volt, PTemp_C, SF_Batt(2), SF_batt_sum(2), counter,
pulselength
Public T107_C(9)
Public VW(9)
Public PA_uS(9)
Public SapFloTC(39)
Public Flag(8) as boolean
'NEW VARIABLES
Public UnheatedTC(39),SapTCDiff(39)
Dim i
Public j
Public timevar(9)

Units Batt_Volt=Volts
Units T107_C()=Deg C
Units PA_uS()=uSec
Units SapFloTC()=Deg C
Units SF_Batt=Volts

'Define Data Tables

DataTable(Fifteen,True,800)
      DataInterval(14,15,Min,10)
      CardOut (0 ,16000)
      Average(9,T107_C(),FP2,False)
      Average(9,PA_uS(),FP2,False)
      Minimum(1,Batt_Volt,FP2,False,False)
EndTable

DataTable(SapFlow,True,13500)
      CardOut (0 ,500000)
      Sample (39,SapTCDiff(),FP2)
EndTable

'Main Program

BeginProg
      Scan(1,Min,1,0)  'The scan is the frequency the WCR and T107 probes
will be measured
            'Default Datalogger Battery Voltage measurement Batt_Volt
            Battery(Batt_Volt)

            '107 Temperature Probe measurement T107_C:
            Therm107(T107_C(),5,1,1,0,_60Hz,1.0,0.0)
            Therm107(T107_C(6),4,6,2,0,_60Hz,1.0,0.0)

            'Measure the CS616's
            PortSet(1,1)     'Turn AM16/32 Multiplexer On
```

```
            'Skip over empty groups of channels to get to CS616 sensors on
channels 14,15,and 16
            SubScan (0,uSec,13)
                  PulsePort(2,10000)
            NextSubScan
            LCount_13=1
            SubScan(0,uSec,3)
                  'Switch to next AM416 Multiplexer channel
                  PulsePort(2,10000)
                  'CS616(PA_uS(LCount_13),3,10,3,3,1,0)
                  PortSet(3, 1)     'turn ON probes
                  PeriodAvg(PA_uS(LCount_13),3,mV250,10,1,0,50,4,1,0) 'P27
Period Measurement
                  PortSet(3, 0) 'turn OFF probes
                  LCount_13=LCount_13+3
            NextSubScan
            For LCount_13=1 To 9
                  VW(LCount_13)=-0.0663+(-
0.0063*PA_uS(LCount_13))+(0.0007*PA_uS(LCount_13)^2)
            Next
            'Turn AM16/32 Multiplexer Off
            PortSet(1,0)

            'Call Data Tables and Store Data
            CallTable(Fifteen)
EndProg
```

Programming Code for Data Post-Processing: Data post-processing was done using MatLab® 7.10.0/R2010a, Excel 2010 (Microsoft, 2010), and R® 2.11.1/2010 computational software. Sample scripts are provided below for each of the station types, and were modified for each station and/or instrument that required site specific parameterization.

Script for post-processing precipitation and initial estimates of soil moisture from MET1-MET4 and SF1-SF6 stations: Data files for soil moisture were named SM1-SM6 in MatLab code to distinguish them from sapflow data files, which were collected at the same stations and kept the SF1-SF6 notation. Additional calculations originally in this script were part of a larger research effort that is beyond the scope of the dissertation, and were therefore omitted from the code. Similar code was developed for ECOV1 and ECOV2 data processing.

(*Source: MatLab® 7.10.0/R2010a*)

```
: %This script loads Met1 and SF3 soil moisture data and applies any needed
corrections and calculations.

load MET1_2010.mat
d = MET1_2010;
load SM3_2010.mat
s = SM3_2010;

%CS616 soil moisture sensor calibration (unique coefficients for each probe
and each station in this order:
%HFP3 2.5cm, BG25, BG50, BG100, PV25, PV50, PV100, IW25, IW50, IW100
smcal = [-0.0003, 0.0361, -0.5175;...
```

```
        1E-04, +0.0031, -0.0553;...
    0.0002, -0.0044, +0.0308;...
    6E-05, +0.006, -0.105;...
    -5E-05, +0.032, -0.4983;...
    -0.0019, +0.1068, -1.2663;...
    -0.0003, +0.0281, -0.3908;...
    -0.0009, +0.0676, -0.8299;...
    -0.0007, +0.0554, -0.7043;...
    -0.0009, +0.0658, -0.8242];
%Campbell Scientific factory default calibration values, commented out/not
used here
%smcal = ones(10,1)*[0.0007 -0.0063 -0.0663];

%% Make a new timestamp for both datasets
%pull out the timestamps from the 2 datasets and use them to make a new
%timestamp the encompasses both.  Each dataset will then be mapped to this
%new timestamp.
t1 = rndmin(datenum(d(:,1),d(:,2),d(:,3),d(:,4),d(:,5),0)-
datenum(d(:,1),1,0),15); %Met station time
t2 = rndmin(datenum(s(:,1),s(:,2),s(:,3),s(:,4),s(:,5),0)-
datenum(s(:,1),1,0),15); %Soil moisture station time
%Make the new timestamp
t = rndmin((min([t1;t2]):15/60/24:max([t1;t2]))',15);  %from the min of both
to the max of both by 15min.
[tf loc1] = ismember(t1,t); %gives the location of t1 in t
[tf loc2] = ismember(t2,t); %gives the location of t2 in t
%make empty datasets and them map them according to loc1 and loc2
D = zeros(length(t),length(d(1,:)))*NaN;
S = zeros(length(t),length(s(1,:)))*NaN;
D(loc1,:) = d;
S(loc2,:) = s;

%% Headers
%MET header (D):
%1 to 8
%Year, Month, Day, Hour, Min, Hour, Minutes, Seconds
%9 to 15
%Rain_mm_TOT, AirTC_AVG, RH_AVG, PA_uS_1_AVG, VW_1_AVG, VW_1_T_Cor, RH,
%16 to 20
%WS_ms_S_WVT, WindDir_D1_WVT, WindDir_SD1_WVT, NR_Wm2_AVG, CNR_Wm2_AVG,
%21 to 27
%BP_mbar_AVG, Sat_VP_AVG, VP_AVG, SHF_1_AVG, SHF_2_AVG, T_Soil_AVG,
PTemp_C_AVG

%Soil Moisture header (S):
%1 - 5
%Year, Month, Day, Hour, Min,
%6 - 14
%T107_C_Avg(1),T107_C_Avg(2),T107_C_Avg(3),T107_C_Avg(4),T107_C_Avg(5),T107_C
_Avg(6),T107_C_Avg(7),T107_C_Avg(8),T107_C_Avg(9),
%15 - 23
%PA_uS_Avg(1),PA_uS_Avg(2),PA_uS_Avg(3),PA_uS_Avg(4),PA_uS_Avg(5),PA_uS_Avg(6
),PA_uS_Avg(7),PA_uS_Avg(8),PA_uS_Avg(9),
%24
%Batt_Volt_Min
```

```
ppt = D(:,9);           %precipitation (mm)

%Soil moisture and soil temperature depths:
%2.5, BG25, BG50, BG100, PV25, PV50, PV100, IW25, IW50, IW100 cm
tsoil = [D(:,26) S(:,6:14)];        %soil temp (C)
dg = [2 5 8; 3 6 9; 4 7 10];        %depth groups for soil probes by number
%CS616 water content, same positions as tsoil probes in situ
per = [D(:,12) S(:,15:23)]; %period average of the water content
reflectometer (WCR)
%WCR estimates from MET station probe processed in data logger, not used
% wcru = D(:,13);       %uncorrected (temperature) Vol. Water Content
% wcr = D(:,14);        %temp. corrected vol. water content
vbat = S(:,24);         %battery voltage from soil datalogger

%% Apply CS616 temperature correction and probe specific calibration
perc = per + (20-tsoil).*(0.526-0.052*per+0.00136*per.^2);  %Campbell
Scientific factory soil temp correction for period average
wcr=[];
for i = 1:length(per(1,:))  %once for each probe
    wcr(:,i) = polyval(smcal(i,:),perc(:,i));
end
%estimate of vol. soil water content based on WCR measurement
w=wcr(:,1);         %shallow probe at MET station 2.5cm
```

Stepwise process for identifying and characterizing soil moisture events in response to precipitation:
(*Source: Visual Basic, Excel 2010; developed by Dave Dust, January 2012*)

The following stepwise procedure describes the process of deriving event-based variables from 15-minute soil moisture data:

(1) Read the first two days of 15-minute values.
(2) Find the 15-minute value of the diurnal peak for the first day in the time series.
(3) Compare 15-minute values for the next day until a value greater than the first days peak is identified using a user specified tolerance.
(4) If no value is found that is greater than the first day’s peak by at least the user speficied tolerance value, step forward one day and repeat steps 1-3 until a value is found that is greater than the first day’s peak value.
(4) When a value is found, log it with the time stamp as the start of an event.
(5) Find the peak value for each event by comparing subsequent values sequential to the start time value until the soil moisture value decreases. Log the value and time stamp identified one step prior to the decreasing value identified as the peak soil moisture for an event.
(6) Find the end of the event by comparing values after the peak against start values until the value is equal to the start time value. Log the value and start time and tag the event end type as ‘NPE’ (next peak encountered) to indicate the event did not reach antecedent moisture conditions before another soil moisture event began.
(7) If no value is found before the start of a subsequent event, log the value and end time of an event as the start time of the next event and tag the event end type as ‘EBS’ (end before start) to indicate antecedent moisture conditions were reached before another event began.

(8) For each soil moisture event identified, compute the change in volumetric soil moisture (event magnitude), event time length, and mean event soil moisture.
(9) Identify the precipitation associated with each event.

APPENDIX B

SOIL MOISTURE PROBE CALIBRATION PROCEDURE AND TEMPERATURE CORRECTION EQUATION

Response from the CS616 Soil Water Content Reflectometer (Campbell Scientific, Inc.) can be described by a quadratic calibration equation of the form:

$$\Theta(\tau) = C_0 + C_1 * \tau + C_2 * \tau^2$$

Where Θ is the volumetric water content in m^3/m^3, τ is the CS616 period output in microseconds (μsec), C_n the calibration coefficient.

The following equipment and procedures were used to developed laboratory calibrations for each soil a 616 probe was emplaced in:

(1) CS616 probes connected to a CS10X datalogger programmed to measure output period.
(2) PVC cylinders measuring 10cm x 36cm closed at one end for packing soil samples and inserting probes into
(3) Copper tubing 3cm x 5cm for packing soil samples for independent estimate of bulk density
(4) Analytical scale, oven, hood with temperature gage
(5) Soils were oven dried, then incrementally wetted at 50ml, 100ml, 250ml, and 500ml deionized water. With each increment, soils in each cylinder were covered to avoid evaporation, and allowed to equilibrate over a 24-hour period before output period readings were taken.
(6) A minimum of 20 readings at 10 second intervals over two minute periods per wetting increment were averaged for each probe, to develop the calibration curve relating output period to volumetric water content.
(7) To determine bulk density, three subsamples of each soil were obtained from each cylinder using 3cm x 5cm copper tubing inserted into the soil. Soils were weighed, dried, and reweighed. Gravimetric water content is calculated as:

$$\Theta_g = (m_{wet} - m_{dry}) / m_{dry}$$

And for the bulk density:

$$\rho_{bulk} = m_{dry} / v_{cylinder} \quad (g/cm^3)$$

(8) An independent estimate of volumetric water content was determined as the product of the gravimetric water content and the bulk specific gravity, with appropriate unit conversions to give:

$$\Theta_v = m^3/m^3$$

The following calibration equations and bulk densities were developed for each CS616 probe:

ECOV1 Lower Basin Terrace Station—1 sensor at 2.5 cm

BG2.5	y = 0.0006x^2-0.0167x+0.1124	
ρ_{bulk}	1.67	

ECOV2 Lower Basin Wash Station—1 sensor at 2.5 cm

BG2.5	y = -0.001x^2+0.0711x-0.9099
ρ_{bulk}	1.71

MET1 Mid-basin Terrace Station—1 sensor at 2.5 cm

BG2.5	y = -0.0003x^2+0.0361x-0.5175
ρ_{bulk}	1.60

MET2 Mid-basin Wash Station—1 sensor at 2.5 cm

BG2.5	y = -0.0012x^2+0.0786x-0.9753
ρ_{bulk}	1.62

MET3 Upper basin Wash Station—1 sensor at 2.5 cm

BG2.5	y = -0.0008x^2+0.0583x-0.7319
ρ_{bulk}	1.62

MET4 Upper basin Terrace Station—1 sensor at 2.5 cm

HFP6 2.5cm	y = 0.0004x^2-0.0141x+0.147
ρ_{bulk}	1.60

SF1 Lower Basin Terrace Station--9 sensors at 3 depths; 3 beneath bare ground (BG), 3 under *P.microphylla* (Foothill Palo Verde--PV), 3 beneath *O.tesota* (Ironwood--IW) at 25, 50, 100 cm.

BG25	y = 0.0002x^2 -0.0012x-0.0125	ρ_{bulk}	1.6
BG50	y = -7E-05x^2+0.0145x-0.2179	ρ_{bulk}	1.56
BG100	y = 0.0002x^2-0.0047x+0.0313	ρ_{bulk}	1.43
PV25	y = -0.0009x^2+0.0613x-0.778	ρ_{bulk}	1.50
PV50	y = -0.0002x^2+0.0246x-0.3465	ρ_{bulk}	1.51
PV100	y = -0.0002x^2+0.0263x-0.3553	ρ_{bulk}	1.56
IW25	y = -0.0008x^2+0.0664x-0.8613	ρ_{bulk}	1.49
IW50	y = -0.0005x^2+0.0473x-0.6344	ρ_{bulk}	1.47
IW100	y = -0.0001x^2+0.0207-0.302	ρ_{bulk}	1.48

SF2 Lower Basin Wash Station--9 sensors at 3 depths; 3 beneath bare ground (BG), 3 under *P.microphylla* (Foothill Palo Verde--PV), 3 beneath *O.tesota* (Ironwood--IW) at 25, 50, 100 cm.

BG25	y = -0.0008x^2+0.0571x-0.7255	ρ_{bulk}	1.57
BG50	y = -0.0004x^2+0.0406x-0.5569	ρ_{bulk}	1.72
BG100	y = -0.0003x^2+0.0398-0.5657	ρ_{bulk}	1.66
PV25	y = -0.0014x^2+0.088x-1.0814	ρ_{bulk}	1.80
PV50	y = -0.0008x^2+0.0619-0.8096	ρ_{bulk}	1.57
PV100	y = -0.0005x^2+0.045x-0.6203	ρ_{bulk}	1.69
IW25	y = -0.0003x^2+0.0355x-0.5027	ρ_{bulk}	1.62
IW50	y = -0.0009x^2+0.0613-0.768	ρ_{bulk}	1.65
IW100	y = -0.0009x^2+0.0637x-0.8054	ρ_{bulk}	1.63

SF3 Mid-basin Terrace Station--9 sensors at 3 depths; 3 beneath bare ground (BG), 3 under *P.microphylla* (Foothill Palo Verde--PV), 3 beneath *O.tesota* (Ironwood--IW) at 25, 50, 100 cm.

BG25	y = 1E-04x^2+0.0031x-0.0553	ρ_{bulk}	1. 45
BG50	y = 0.0002x^2-0.0044x+0.0308	ρ_{bulk}	1.52
BG100	y = 6E-05x^2+0.006x-0.105	ρ_{bulk}	1.65
PV25	y = -5E-05x^2+0.032x-0.4983	ρ_{bulk}	1.56
PV50	y = -0.0019x^2+0.1068x-1.2663	ρ_{bulk}	1.54
PV100	y = -0.0003x^2+0.0281x-0.3908	ρ_{bulk}	1. 47
IW25	y = -0.001x^2+0.069x-0.8436	ρ_{bulk}	1.44
IW50	y = -0.0013x^2+0.0784x-0.9363	ρ_{bulk}	1.49
IW100	y = -0.0009x^2+0.0658x-0.8242	ρ_{bulk}	1.52

SF4 Mid-basin Wash Station--9 sensors at 3 depths; 3 beneath bare ground (BG), 3 under *P.microphylla* (Foothill Palo Verde--PV), 3 beneath *O.tesota* (Ironwood--IW) at 25, 50, 100 cm.

BG25	y = -0.0004x^2+0.047x-0.6565	ρ_{bulk}	1.59
BG50	y = -0.0008x^2+0.0585x-0.76	ρ_{bulk}	1.58
BG100	y = -0.0002x^2+0.0345x-0.495	ρ_{bulk}	1.61
PV25	y = -0.0016x^2+0.0984x-1.1988	ρ_{bulk}	1.64
PV50	y = -0.0007x^2+0.0535x-0.6901	ρ_{bulk}	1.57
PV100	y = -0.0008x^2+0.0573x-0.73	ρ_{bulk}	1.58
IW25	y = -0.0006x^2+0.052x-0.6845	ρ_{bulk}	1.59
IW50	y = -0.0008x^2+0.0583x-0.7419	ρ_{bulk}	1.67
IW100	y = -0.0005x^2+0.0435x-0.5668	ρ_{bulk}	1.57

SF5 Station—Active Wash site; 9 sensors at 3 depths; 3 beneath bare ground, 3 under Palo Verde, 3 beneath Ironwood, at 25, 50, 100cm

BG25	y = -0.0017x^2+0.1026-1.2420	ρ_{bulk}	1.77
BG50	y = -0.001x^2+0.0726-0.9212	ρ_{bulk}	1.76
BG100	y = -0.0005x^2+0.0478-0.6595	ρ_{bulk}	1.74
PV25	y = -0.0013x^2+0.0861x-1.0619	ρ_{bulk}	1.65
PV50	y = 0.00008x^2+0.0228x-0.3956	ρ_{bulk}	1.73
PV100	y = -0.0006x^2+0.0519x-0.6926	ρ_{bulk}	1.61
IW25	y = -0.0005x^2+0.0479x-0.6679	ρ_{bulk}	1.78
IW50	y = -0.0004x^2+0.0411x-0.5837	ρ_{bulk}	1.75
IW100	y = -0.0008+0.06-0.7775	ρ_{bulk}	1.55

SF6 Station—Desert Pavement site; 9 sensors at 3 depths; 3 beneath bare ground, 3 under Palo Verde, 3 beneath Ironwood, at 25, 50, 100cm

BG25	y = 0.0002x^2-0.0008x-0.0231	ρ_{bulk}	1.61
BG50	y = 0.0001x^2+0.0055x-0.1133	ρ_{bulk}	1.58

BG100	y = 0.0001x^2+0.0055x-0.1133	ρ_{bulk}	1.64
PV25	y = 0.0008x^2-0.0086x-0.072	ρ_{bulk}	1.44
PV50	y = 0.0011x^2-0.0144x-0.036	ρ_{bulk}	1.52
PV100	y = -0.0004x^2+0.0413-0.5788	ρ_{bulk}	1.50
IW25	y = 0.0008x^2-0.0086x-0.72	ρ_{bulk}	1.47
IW50	y = 0.0011x^2-0.0144x-0.036	ρ_{bulk}	1.56
IW100	y = -0.0004+0.0413-0.5788	ρ_{bulk}	1.57

Soil excavation was impeded by considerable compaction and cementation at SF6 site, therefore rendering calibration problematic for SF6 PV50, SF6IW25, and SF6IW100 probes due to a lack of soil sample volume. Calibration equations for SF6IW50 were therefore substituted for SF5PV50, and SF6PV25 and SF6PV100 calibrations were substituted for SF6IW25 and SF6IW100 soils, which may have resulted in a degree of error in estimating volumetric soil moisture for these probes.

CSI Standard Factory Calibration curve y = 0.0007x^2-0.0063x-0.0663

Temperature Correction Equation to adjust readings to 20^{o}C, the approximate temperature under which the laboratory calibration procedure was conducted:

period avg + (20-soil temp)* (0.526-0.052*period avg+0.00136*(period avg^2))

APPENDIX C

PROGRAMMING CODE: STATISTICAL ANALYSIS OF PRECIPITATION AND SOIL MOISTURE

(Source: R® 2.11.1/2010; code developed by Natalie Kramer and edited by Susan Howe, 2012)

****

Precipitation Data File Generation Code: this code imports precipitation data files and creates the .RData files used in data analysis scripts for precipitation.

****

Script_DataRead_ppt.R:

```
setwd("C:\\Users\\showe\\YumaWash\\precipitation\\CURRENT")
getwd()
#The precipitation data for all stns is in units of mm.
#The time stamps are in Julian Days.
#The Cont.Time is the continuous time measurement since initiation and Time resets each year.
#select which precip data to generate a dataset for:
#for daily totals
pptall=read.csv("Data_ppt.csv", header=T, na.strings="NaN")
pptall=pptall[1:1339,1:8]
#for intensity means
pptall=read.csv("Data_ppt_int_mean.csv", header=T, na.strings="NaN")
pptall=pptall[1:1339,1:8]
#for intensity max
pptall=read.csv("Data_ppt_int_max.csv", header=T, na.strings="NaN")
pptall=pptall[1:1339,1:8]
#selects so that dataset includes only days with at least one station recording ppt>0
pptna=pptall[apply(pptall[3:8],1,sum, na.rm=T)!=0,]
#The next section adds categorical variables corresponding with site location,
#depth, geomorphic surface,season and vegetation
ppt2=pptna[3:8]
names(ppt2)
ppt2[8:9, "precip"]= NA
ppt2[9:10, "location"]=NA
ppt2[10:11, "stn"]=NA
ppt2[12:13, "geo"]=NA
ppt2[13:14, "seas"]=NA
ppt2[14:15, "seasyr"]=NA
ppt2[15:16, "yr"]=NA
ppt2[16:17, "ContTime"]=NA
names(ppt2)

#Next code creates a dataset for each unique station with categorical
```

```
#variables, and fills in the season categories
#Sets Seasonal Breaks by year
seasyr=(cut(pptna$Cont.Time, breaks=c(min(pptna$Cont.Time), 274, 335, 456, 547,
         639, 700, 821, 912, 1004, 1065, 1187, 1278, 1370, 1431,
          max(pptna$Cont.Time)), right=FALSE, include.lowest=TRUE))
levels(seasyr)=c("Su06", "Fa06", "Wi06-07", "Sp07", "Su07", "Fa07", "Wi07-08",
          "Sp08", "Su08", "Fa08", "Wi08-09", "Sp09", "Su09", "Fa09", "Wi09-10")
#Breaks by season
seas=(cut(pptna$Cont.Time, breaks=c(min(pptna$Cont.Time), 274, 335, 456, 547, 639,
          700, 821, 912, 1004, 1065, 1187, 1278, 1370, 1431, max(pptna$Cont.Time)),
         right=FALSE, include.lowest=TRUE))
levels(seas)=c("Summer", "Fall", "Winter", "Spring", "Summer", "Fall",
         "Winter", "Spring", "Summer", "Fall", "Winter", "Spring", "Summer",
         "Fall", "Winter")
#Breaks by Year
yr=(cut(pptna$Cont.Time, breaks=c(min(pptna$Cont.Time), 366.0000, 730.9892,
         1096.9892, 1461.9892, max(pptna$Cont.Time)),
         right=FALSE, include.lowest=TRUE))
levels(yr)=c("2006", "2007", "2008", "2009", "2010")
ppt2$seas=seas
ppt2$seasyr=seasyr
ppt2$yr=yr
ppt2$ContTime=pptna$Cont.Time
#fills in the rest of the categories
s1na=data.frame(ppt2[,7:14])
s1na$stn="ECOV1"
s1na$geo="Terrace"
s1na$precip=ppt2$ECOV1
s1na$location="Lower"
s2na=data.frame(ppt2[,7:14])
s2na$stn="ECOV2"
s2na$geo="Wash"
s2na$precip=ppt2$ECOV2
s2na$location="Lower"
s3na=data.frame(ppt2[,7:14])
s3na$stn="MET1"
s3na$geo="Terrace"
s3na$precip=ppt2$MET1
s3na$location="Middle"
s4na=data.frame(ppt2[,7:14])
s4na$stn="MET2"
s4na$geo="Wash"
s4na$precip=ppt2$MET2
s4na$location="Middle"

s5na=data.frame(ppt2[,7:14])
```

```
s5na$stn="MET3"
s5na$geo="Wash"
s5na$precip=ppt2$MET3
s5na$location="Upper"
s6na=data.frame(ppt2[,7:14])
s6na$stn="MET4"
s6na$geo="Terrace"
s6na$precip=ppt2$MET4
s6na$location="Upper"
pptstnsna=rbind(s1na,s2na,s3na,s4na, s5na, s6na)
pptstnsna=data.frame(pptstnsna[,1],factor(pptstnsna[,2]),
          factor(pptstnsna[,3]),factor(pptstnsna[,4]),factor(pptstnsna[,5]),
          factor(pptstnsna[,6]),factor(pptstnsna[,7]),pptstnsna[,8])
names(pptstnsna)=c("precip", "location", "stn", "geo", "seas", "seasyr", "yr", "ContTime")
str(pptstnsna)
# Makes Datasets without NA values called ppt.
ppt=na.omit(pptna)
#Next section adds categorical variables corresponding with site location, depth, geomorphic surface,season and vegetation
ppt2=ppt[3:8]
names(ppt2)
ppt2[8:9, "precip"]= NA
ppt2[9:10, "location"]=NA
ppt2[10:11, "stn"]=NA
ppt2[12:13, "geo"]=NA
ppt2[13:14, "seas"]=NA
ppt2[14:15, "seasyr"]=NA
ppt2[15:16, "yr"]=NA
ppt2[16:17, "ContTime"]=NA
names(ppt2)
#This next code creates a dataset for each unique station with categorical
#variables
#fills in the season categories
#Sets Seasonal Breaks by year
seasyr=(cut(ppt$Cont.Time, breaks=c(min(ppt$Cont.Time), 274, 335, 456, 547,
          639, 700, 821, 912, 1004, 1065, 1187, 1278, 1370, 1431,
           max(ppt$Cont.Time)), right=FALSE, include.lowest=TRUE))
levels(seasyr)=c("Su06", "Fa06", "Wi06-07", "Sp07", "Su07", "Fa07", "Wi07-08",
           "Sp08", "Su08", "Fa08", "Wi08-09", "Sp09", "Su09", "Fa09", "Wi09-10")
#Breaks by season
seas=(cut(ppt$Cont.Time, breaks=c(min(ppt$Cont.Time), 274, 335, 456, 547, 639,
           700, 821, 912, 1004, 1065, 1187, 1278, 1370, 1431, max(ppt$Cont.Time)),
          right=FALSE, include.lowest=TRUE))
levels(seas)=c("Summer", "Fall", "Winter", "Spring", "Summer", "Fall",
          "Winter", "Spring", "Summer", "Fall", "Winter", "Spring", "Summer",
          "Fall", "Winter")
```

```
#Breaks by Year
yr=(cut(ppt$Cont.Time, breaks=c(min(ppt$Cont.Time), 366.0000, 730.9892,
        1096.9892, 1461.9892, max(ppt$Cont.Time)),
        right=FALSE, include.lowest=TRUE))
levels(yr)=c("2006", "2007", "2008", "2009", "2010")
ppt2$seas=seas
ppt2$seasyr=seasyr
ppt2$yr=yr
ppt2$ContTime=ppt$Cont.Time
#fills in the rest of the categories
s1=data.frame(ppt2[,7:14])
s1$stn="ECOV1"
s1$geo="Terrace"
s1$precip=ppt2$ECOV1
s1$location="Lower"
s2=data.frame(ppt2[,7:14])
s2$stn="ECOV2"
s2$geo="Wash"
s2$precip=ppt2$ECOV2
s2$location="Lower"
s3=data.frame(ppt2[,7:14])
s3$stn="MET1"
s3$geo="Terrace"
s3$precip=ppt2$MET1
s3$location="Middle"
s4=data.frame(ppt2[,7:14])
s4$stn="MET2"
s4$geo="Wash"
s4$precip=ppt2$MET2
s4$location="Middle"
s5=data.frame(ppt2[,7:14])
s5$stn="MET3"
s5$geo="Wash"
s5$precip=ppt2$MET3
s5$location="Upper"
s6=data.frame(ppt2[,7:14])
s6$stn="MET4"
s6$geo="Terrace"
s6$precip=ppt2$MET4
s6$location="Upper"
pptstns=rbind(s1,s2,s3,s4, s5, s6)
pptstns=data.frame(pptstns[,1],factor(pptstns[,2]),
        factor(pptstns[,3]),factor(pptstns[,4]),factor(pptstns[,5]),
        factor(pptstns[,6]),factor(pptstns[,7]),pptstns[,8])
names(pptstns)=c("precip", "location", "stn", "geo", "seas", "seasyr", "yr", "ContTime")
str(pptstns)
```

```
#The below code makes the ppt.RData Files that will be used henceforth in analyses.
#select which to save based on dataset
#for daily totals:
save(s1, s2, s3, s4,s5,s6, s1na, s2na, s3na, s4na, s5na, s6na, pptstns, pptstnsna, pptna, ppt, pptall,
file="ppt.RData")
#for intensity means
save(s1, s2, s3, s4,s5,s6, s1na, s2na, s3na, s4na, s5na, s6na, pptstns, pptstnsna, pptna, ppt, pptall,
file="pptintmean.RData")
#for intensity max
save(s1, s2, s3, s4,s5,s6, s1na, s2na, s3na, s4na, s5na, s6na, pptstns, pptstnsna, pptna, ppt, pptall,
file="pptintmax.RData")
```

****

Precipitation Univariate and Bivariate Analysis Code: this code is for univariate and bivariate analysis and plots of precipitation event totals, mean and maximum intensities. Code was truncated to avoid redundancy and reduce length of appendices.

****

Script_Precip.R:

```
setwd("C:\\Users\\showe\\YumaWash\\precipitation\\CURRENT")
library(stringr)
library(gplots)
library(car) #load this package
source("Func_plots.R")
source("Func_sumtables.R")
#Select Precipitation Data Type:

load("ppt.RData")
label=expression(paste(Precipitation, "  ", "(mm)"))
datalabel="ppt"
datatitle="Precipitation Event Totals"

load("pptintmean.RData")
label=expression(paste(Precipitation, " ", Mean," ",Intensity, "  ", "(mm/hr)"))
datalabel="pptintmean"
datatitle="Precipitation Event Mean Intensity"

load("pptintmax.RData")
label=expression(paste(Precipitation, " ", Max," ", Intensity, "  ", "(mm/hr)"))
datalabel="pptintmax"
datatitle="Precipitation Event Maximum Intensity"
getwd() # lists the working directory you are using
# precipitation files below are defined as follows:
# ppt=41 events with > 0 ppt recorded at at least one station, and all 6 stations were operative (no
NAs)
```

ppt13na=54 events with > 0 ppt recorded at at least one station, and only 1 station was inoperative (few NAs); this file is made below by adding 13 events listed below back into the ppt file
pptna=71 events with > 0 ppt recorded at at least one station, and more than 1 station had NAs
pptstns=precipitation file with no NAs designed for by factor analysis
pptstns13na=precipitation with 13 NAs file designed for by factor analysis
pptstnsna=precipitation with all NAs file designed for by factor analysis

```
attach(pptstnsna)
pptstns13na=rbind(
pptstnsna[ContTime==249,],
pptstnsna[ContTime==250,],
pptstnsna[ContTime==297,],
pptstnsna[ContTime==608,],
pptstnsna[ContTime==639,],
pptstnsna[ContTime==699,],
pptstnsna[ContTime==737,],
pptstnsna[ContTime==1134,],
pptstnsna[ContTime==1344,],
pptstnsna[ContTime==1437,],
pptstnsna[ContTime==1498,],
pptstnsna[ContTime==1502,],
pptstnsna[ContTime==1512,],
pptstns
)
attach(pptna)
ppt13na=rbind(
pptna[Cont.Time==249,],
pptna[Cont.Time==250,],
pptna[Cont.Time==297,],
pptna[Cont.Time==608,],
pptna[Cont.Time==639,],
pptna[Cont.Time==699,],
pptna[Cont.Time==737,],
pptna[Cont.Time==1134,],
pptna[Cont.Time==1344,],
pptna[Cont.Time==1437,],
pptna[Cont.Time==1498,],
pptna[Cont.Time==1502,],
pptna[Cont.Time==1512,],
ppt
)
```

need a period b/w Cont and Time in above just for pptna file because of the way the csv file was read in. Do NOT need the period in code above for pptstnsna

#data=pptstns #sets data to include only events > 0 at at least one station, with no NAs at other stations, includes zeros

```
#nalabel="no NAs"
#data=pptstnsna #sets data to include events > 0 at at least one station, but includes events when NAs occur at inoperative stations, includes zeros
#nalabel="all NAs"
data=pptstns13na  #sets data to include events > 0 at at least one station and no NAs EXCEPT 13 additional events where significant ppt occured and only 1 station was inoperative, so includes some NAs, includes zeros
nalabel="13 NAs"
data=pptstns13na  #sets data to include events > 0 at at least one station and no NAs EXCEPT 13 additional events where significant ppt
#occured and only 1 station was inoperative, so includes some NAs, but no zeros
nalabel="13 NAs"
n0=data[data$precip>0,]
data=n0
#UNIVARIATE ANALYSIS AND PLOTS
#attach(ppt) #uncomment and run to view 41 events with no NAs (when at least 1 station recorded >0 ppt and all stations were operative
#attach(pptna) #uncomment and run to view 71 events with NAs (when at least 1 station recorded >0 ppt but several stations may have been inoperative)
attach(ppt13na) #uncomment and run to view 54 events with a few NAs during 13 of them (when at least 1 station recorded >0 ppt but only 1 station was inoperative)
data=pptstns13na  #sets data to include events > 0 at at least one station and no NAs except 13 additional events where significant ppt occurred and only 1 station was inoperative, so includes a few NAs
nalabel="13 NAs"
n0=data[data$precip>0,]
data=n0

#HISTOGRAMS, CDFS, AND QQ'S BY FACTOR:
BY STATION
png(str_c(datalabel, "Hist CDF QQ by Station (Terraces)", nalabel, ".png"), height=900,width=580)
par(mfrow=c(3,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(data,3,"ECOV1",label, "ECOV1: Histogram")
hist3factor(data,3,"MET1",label, "MET1: Histogram")
hist3factor(data,3,"MET4",label, "MET4: Histogram")
title(str_c(datatitle, " by Station (Terraces)"), outer=TRUE)
dev.off()
png(str_c(datalabel, "Hist CDF QQ by Station (Washes)", nalabel, ".png"), height=900,width=580)
par(mfrow=c(3,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(data,3,"ECOV2",label, "ECOV2: Histogram")
hist3factor(data,3,"MET2",label, "MET2: Histogram")
hist3factor(data,3,"MET3",label, "MET3: Histogram")
title(str_c(datatitle, " by Station (Washes)"), outer=TRUE)
dev.off()
```

BY LOCATION
png(str_c(datalabel, "Hist CDF QQ by Basin Location", nalabel, ".png"), height=900,width=580)
par(mfrow=c(3,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(data,2,"Lower",label, "Lower: Histogram")
hist3factor(data,2,"Middle",label, "Middle: Histogram")
hist3factor(data,2,"Upper",label, "Upper: Histogram")
title(str_c(datatitle, " by Basin Location"), outer=TRUE)
dev.off()
BY GEOMORPHIC SURFACE
png(str_c(datalabel," Hist CDF QQ by Geomorphic Surface", nalabel, ".png"), height=600,width=580)
par(mfrow=c(2,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(data,4,"Terrace",label, "Terrace: Histogram")
hist3factor(data,4,"Wash",label, "Wash: Histogram")
title(str_c(datatitle, " by Geomorphic Surface"), outer=TRUE)
dev.off()
BY SEASON
png(str_c(datalabel, "Hist CDF QQ by Season", nalabel,".png"), height=900,width=580)
par(mfrow=c(4,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(data,5,"Summer",label, "Summer: Histogram")
hist3factor(data,5,"Fall",label, "Fall: Histogram")
hist3factor(data,5,"Winter",label, "Winter: Histogram")
hist3factor(data,5,"Spring",label, "Spring: Histogram")
title(str_c(datatitle, " by Season"), outer=TRUE)
dev.off()
#BOXBLOTS BY FACTOR:
#For data with zeros included
data=pptstns #41 events where at least 1 station recorded > 0 ppt, and no NA values (includes zeros)
nalabel="no NAs"
data=pptstnsna #71 events where at least 1 station recorded > 0 ppt, and NA values may have occurred at inoperative stations (includes zeros)
nalabel="all NAs"
data=pptstns13na #54 events where at least 1 station recorded > 0 ppt, and some NA values occurred for 13 events at 1 or 2 stations (includes zeros)
nalabel="13 NAs"
#For data with no zeros using 'data=pptstns13na'; CODE: 'n0 data[data$precip>0,]' and 'data=n0' removes all zeros from 'pptstns13na' dataset
data=pptstns13na #54 events where at least 1 station recorded > 0 ppt, and some NA values occurred for 13 events at 1 station (includes zeros)
nalabel="13 NAs"
n0=data[data$precip>0,]
data=n0
ymin=0
ymax=100 #use for event totals
ymax=50 #use for ppt mean intensities

```
ymax=160 #use for ppt max intensities
BY STATION
png(str_c(datalabel, "Boxplots by Station", nalabel, ".png"), width=480, height=480)
par(mfrow=c(1,1), oma=c(0,0,2,0), cex=1.0, las=1)
boxplot.n(data$precip~factor(data$stn), ylab=label, ylim=range(ymin,ymax),top=T)
#text(c(1,2,3,4,5,6), c(rep(80,6)),pos=2,cex=1, labels=c(rep("n=",6)))
#text(c(1,2,3,4,5,6), c(rep(80,6)),pos=2,cex=1, offset=-.7, labels=c(
        #length(data[data$stn=="ECOV1",1]),length(data[data$stn=="ECOV2",1]),
         #length(data[data$stn=="MET1",1]),length(data[data$stn=="MET2",1]),
         #length(data[data$stn=="MET3",1]),length(data[data$stn=="MET4",1])
        #))
title(str_c(datatitle," by Station"))
dev.off()
BY LOCATION
png(str_c(datalabel, "Boxplots by Basin Location ", nalabel, ".png"), width=480, height=480)
par(mfrow=c(1,1), oma=c(0,0,2,0), cex=1.0, las=1)
boxplot.n(data$precip~factor(data$location), ylab=label, ylim=range(ymin,ymax), top=T)
#text(c(1,2,3,4,5,6), c(rep(80,6)),pos=2,cex=1, labels=c(rep("n=",6)))
#text(c(1,2,3,4,5,6), c(rep(80,6)),pos=2,cex=1, offset=-.7, labels=c(
        #length(data[data$location=="Lower",1]),length(data[data$location=="Middle",1]),
         # length(data[data$location=="Upper",1])
        #))
title(str_c(datatitle, " by Basin Location"))
dev.off()
BY GEOMORPHIC SURFACE
png(str_c(datalabel, "Boxplots by Geomorphic Surface ", nalabel, ".png"), width=480,
height=480)
par(mfrow=c(1,1), oma=c(0,0,2,0), cex=1.0, las=1)
boxplot.n(data$precip~factor(data$geo), ylab=label, ylim=range(ymin,ymax),top=T)
#text(c(1,2,3,4,5,6), c(rep(80,6)),pos=2,cex=1, labels=c(rep("n=",6)))
#text(c(1,2,3,4,5,6), c(rep(80,6)),pos=2,cex=1, offset=-0.7, labels=c(
#       length(data[data$geo=="Terrace",1]),length(data[data$geo=="Wash",1])
#       ))
title(str_c(datatitle, " by Geomorphic Surface"))
dev.off()
BY SEASON
png(str_c(datalabel, "Boxplots by Season ", nalabel, ".png"), width=480, height=480)
par(mfrow=c(1,1), oma=c(0,0,2,0), cex=1.0, las=1)
boxplot.n(data$precip~factor(data$seas), ylab=label, ylim=range(ymin,ymax),top=T)
#text(c(1,2,3,4,5,6), c(rep(80,6)),pos=2,cex=1, labels=c(rep("n=",6)))
#text(c(1,2,3,4,5,6), c(rep(80,6)),pos=2,cex=1, offset=-0.7, labels=c(
#       length(data[data$geo=="Terrace",1]),length(data[data$geo=="Wash",1])
#       ))
title(str_c(datatitle," by Season"))
dev.off()
#BARPLOTS BY FACTOR:
```

```
#data=pptstns
#nalabel="no NAs"
#data=pptstnsna
#nalabel="all NAs"
#data=pptstns13na
#nalabel="13 NAs"
data=pptstns13na
nalabel="13 NAs"
n0=data[data$precip>0,]
data=n0
#Run the following when changing datasets
#Eliminates specific data from datasets when they were not working, etc.
yr06=data[data$yr==2006,]
        yr06.o=yr06[yr06$stn!="MET1",]
#there are no 2006 values when you don't have any NA values
yr07=data[data$yr==2007,]
        yr07.o=yr07[yr07$stn!="ECOV1",]
yr08=data[data$yr==2008,]
yr09=data[data$yr==2009,]
#       yr09.o=yr09[yr09$stn!="MET2",]
yr10=data[data$yr==2010,]
data.o=rbind(yr06.o, yr07.o, yr08,yr09, yr10)
sumstn=yuma.pptsummary(data$precip,data$stn)
sumloc=yuma.pptsummary(data$precip,data$location)
sumgeo=yuma.pptsummary(data$precip,data$geo)
sumseas=yuma.pptsummary(data$precip,data$seas)
sumsyr=yuma.pptsummary(data$precip,data$seasyr)
sumyr=yuma.pptsummary(data$precip,data$yr)#data.o now removed, but originally was used so
certain stations eliminated for 'by year' analyses
names(sumstn)
#Median=5
#Mean=7
#GMean=6
stat=5
statlabel="Median"
#stat=7
#statlabel="Mean"
stat=9
statlabel="Max"

# RUN FOR EVENT PRECIPITATION PLOTS
png(str_c(statlabel,datalabel, "Barplots by Factor1", " ",nalabel, ".png"), width=800, height=800)
ymin=0
ymax=25
par(mfrow=c(2,2), oma=c(0,0,2,0))
barplot(sumloc[,stat], ylim=range(ymin:ymax), ylab=label)
```

```
text(c(0.7,1.9,3.1), sumloc[,stat], sumloc$Obs, pos=3)
barplot(sumgeo[,stat], ylim=range(ymin:ymax), ylab=label)
text(c(0.7,1.9), sumgeo[,stat], sumgeo$Obs, pos=3)
barplot(sumseas[,stat], ylim=range(ymin:ymax), ylab=label)
text(c(0.7,1.9,3.1,4.3), sumseas[,stat], sumseas$Obs, pos=3)
barplot(sumyr[,stat], ylim=range(ymin:ymax), ylab=label)
text(c(0.7,1.9,3.1,4.3,5.6), sumyr[,stat], sumyr$Obs, pos=3)
title(str_c(statlabel, datatitle, "by Factor", sep=" "), outer=TRUE)
dev.off()
png(str_c(statlabel, datalabel, "Barplots by Factor2", " ",nalabel, ".png"), width=800, height=800)
ymin=0
ymax=25
par(mfrow=c(2,1), oma=c(0,0,2,0), las=2)
barplot(sumstn[,stat], ylim=range(ymin:ymax), ylab=label)
text(c(0.7,1.9,3.1,4.3,5.5,6.7), sumstn[,stat], sumstn$Obs, pos=3)
barplot(sumsyr[,stat], ylim=range(ymin:ymax), ylab=label)
text(seq(0.7,length(sumsyr[,1])+3,1.2), sumsyr[,stat], sumsyr$Obs, pos=3)
title(str_c(statlabel, datatitle, " by Factor", sep=" "), outer=TRUE)
dev.off()
# RUN FOR PRECIPITATION MEAN INTENSITY PLOTS
png(str_c(statlabel,datalabel, "Barplots by Factor1", " ",nalabel, ".png"), width=800, height=800)
ymin=0
ymax=20
par(mfrow=c(2,2), oma=c(0,0,2,0))
barplot(sumloc[,stat], ylim=range(ymin:ymax), ylab=label)
text(c(0.7,1.9,3.1), sumloc[,stat], sumloc$Obs, pos=3)
barplot(sumgeo[,stat], ylim=range(ymin:ymax), ylab=label)
text(c(0.7,1.9), sumgeo[,stat], sumgeo$Obs, pos=3)
barplot(sumseas[,stat], ylim=range(ymin:ymax), ylab=label)
text(c(0.7,1.9,3.1,4.3), sumseas[,stat], sumseas$Obs, pos=3)
barplot(sumyr[,stat], ylim=range(ymin:ymax), ylab=label)
text(c(0.7,1.9,3.1,4.3,5.6), sumyr[,stat], sumyr$Obs, pos=3)
title(str_c(statlabel, "of the", datatitle, "by Factor", sep=" "), outer=TRUE)
dev.off()
png(str_c(statlabel, datalabel, "Barplots by Factor2", " ",nalabel, ".png"), width=800, height=800)
ymin=0
ymax=20
par(mfrow=c(2,1), oma=c(0,0,2,0), las=2)
barplot(sumstn[,stat], ylim=range(ymin:ymax), ylab=label)
text(c(0.7,1.9,3.1,4.3,5.5,6.7), sumstn[,stat], sumstn$Obs, pos=3)
barplot(sumsyr[,stat], ylim=range(ymin:ymax), ylab=label)
text(seq(0.7,length(sumsyr[,1])+3,1.2), sumsyr[,stat], sumsyr$Obs, pos=3)
title(str_c(statlabel, "of the", datatitle, " by Factor", sep=" "), outer=TRUE)
dev.off()
```

```
# RUN FOR PRECIPITATION MAXIMUM INTENSITY PLOTS
png(str_c(statlabel, datalabel, "Barplots by Factor1", " ",nalabel, ".png"), width=800, height=800)
ymin=0
ymax=70
par(mfrow=c(2,2), oma=c(0,0,2,0))
barplot(sumloc[,stat], ylim=range(ymin:ymax), ylab=label)
text(c(0.7,1.9,3.1), sumloc[,stat], sumloc$Obs, pos=3)
barplot(sumgeo[,stat], ylim=range(ymin:ymax), ylab=label)
text(c(0.7,1.9), sumgeo[,stat], sumgeo$Obs, pos=3)
barplot(sumseas[,stat], ylim=range(ymin:ymax), ylab=label)
text(c(0.7,1.9,3.1,4.3), sumseas[,stat], sumseas$Obs, pos=3)
barplot(sumyr[,stat], ylim=range(ymin:ymax), ylab=label)
text(c(0.7,1.9,3.1,4.3,5.6), sumyr[,stat], sumyr$Obs, pos=3)
title(str_c(statlabel, "of the", datatitle, "by Factor", sep=" "), outer=TRUE)
dev.off()
png(str_c(statlabel, datalabel, "Barplots by Factor2", " ",nalabel, ".png"), width=800, height=800)
ymin=0
ymax=100
par(mfrow=c(2,1), oma=c(0,0,2,0), las=2)
barplot(sumstn[,stat], ylim=range(ymin:ymax), ylab=label)
text(c(0.7,1.9,3.1,4.3,5.5,6.7), sumstn[,stat], sumstn$Obs, pos=3)
barplot(sumsyr[,stat], ylim=range(ymin:ymax), ylab=label)
text(seq(0.7,length(sumsyr[,1])+3,1.2), sumsyr[,stat], sumsyr$Obs, pos=3)
title(str_c(statlabel, "of the", datatitle, " by Factor", sep=" "), outer=TRUE)
dev.off()
#DESCRIPTIVE (SUMMARY) STATISTICS--scatter plots; type file name 'pptsum13na' in console to get tabular data for export
#Creates Summary Tables from ppt data by factor
#data=pptstns
#data=pptstnsna
#data=pptstns13na
data=pptstns13na
n0=data[data$precip>0,]
data=n0
sumstn=yuma.pptsummary(data$precip,data$stn)
sumloc=yuma.pptsummary(data$precip,data$location)
sumgeo=yuma.pptsummary(data$precip,data$geo)
sumseas=yuma.pptsummary(data$precip,data$seas)
sumsyr=yuma.pptsummary(data$precip,data$seasyr)
sumyr=yuma.pptsummary(data.o$precip,data.o$yr)
pptsum=rbind(sumstn,sumloc,sumgeo,sumseas,sumsyr, sumyr) #combines data into one table
pptsumna=rbind(sumstn, sumloc, sumgeo, sumseas, sumsyr, sumyr)
pptsum13na=rbind(sumstn, sumloc, sumgeo, sumseas, sumsyr, sumyr)
#data=pptsum
```

```
#nalabel="no NA"
#data=pptsumna
#nalabel="all NA"
data=pptsum13na
nalabel="13 NA"
# above pptsum13na now has NO ZEROS as long as you run 'n0' code at the beginning of this section
names(data)
#you can set the ymin and max to be whatever you want in the code below
#it is by default set to the below code for min or max
#typing 'data' into the console gives you all of the descriptive stats as a table you can export
xmin=1  #sets the lower bound for the x data to include
        #1=start of station data (1-6)
        #7=start location (7-9)
        #10=start geo (10-11)
        #12=start of season (12-15)
        #16=start seasyr (16-29)
        #30=start of year(30-34)
xmax=15 #set the upper bound for the x data to include
        # xmax=11 to not include seasonal data, xmax=15 to include
#These mins and maxs only set it for the centrality stats (ex median/CVR mean/CV, gmean/GCV)
ymin=0 #min(wcrfsummary[,stat]) stat refers to the column number of the stat you are interested in
ymax=10 #max(wcrfsummary[,stat]) stat refers to the column number of the stat you are interested in
yCVmin=80
yCVmax=250
#To change to Means and CV or Gmeans and GCV simply change all titles and
#change the number in function to reflect appropriate column.
#5=median
#6=gmean
#7=mean
#13=CV
#14=CVR
#18=GCV
#Median and CVR
png(str_c(datalabel, " Medians and CVR by factor", nalabel, ".png"), height=480, width=480)
par(mfrow=c(1,1))
scatterbyfppt(data, 5, label, xmin, xmax, ymin,ymax)
title("Median Event Precipitation by Factor")
dev.off()
scatterbyfppt(data, 13 ,"CV (%)",xmin, xmax, yCVmin, yCVmax)
title(str_c(datatitle,": CV by Factor", " ", nalabel))
dev.off()
#skew and Kurt
```

```
png(str_c(datalabel, "Skew and Kurt by factor", nalabel, ".png"), height=480, width=960)
par(mfrow=c(1,2))
scatterbyfppt(data, 15,"Standardized Skewness", xmin, xmax, min(data[xmin:xmax,15]), max(data[xmin:xmax,15]))
abline(h=c(2,-2), lty=2)
text(3,c(2,-2), c("extreme right skew", "extreme left skew"))
title("Precipitation Totals: Skewness by Factor")
scatterbyfppt(data, 16 ,"Standardized Kurtosis", xmin, xmax, min(data[xmin:xmax,16]), max(data[xmin:xmax,16]))
abline(h=c(2,-2), lty=2)
text(3,c(2,-2), c("extreme heavy tail", "extremely centered"))
title(str_c(datatitle, ": Kurtosis by Factor", " ", nalabel))
dev.off()
#NA and Observations
png(str_c(datalabel, "Obs and NaN by factor", nalabel, ".png"), height=480, width=960)
par(mfrow=c(1,2))
scatterbyfppt(data, 1,"# of Observations", xmin, xmax, min(data[,1]), max(data[,1]))
title("Volumetric Water Content: #Obs by Factor")
scatterbyfppt(data, 2 ,"% Missing Values",xmin, xmax, min(data[,2]), max(data[,2]))
title(str_c(datatitle, ": %NaN by Factor", " ", nalabel))
dev.off()
#SCATTERPLOT MATRICES AND CORRELATIONS BY STATION WITH ALL DATA, AND BY STATION BY SEASON
#data=ppt
#nalabel="no NAs"
#data=pptna
#nalabel="all NAs"
data=ppt13na
nalabel="13 NAs"
ppt13na_nozero=as.data.frame(replace(as.matrix(ppt13na), which(ppt13na==0), NaN))
#the above line of code removes all ZEROS from ppt13na to run scatterplot matrices, correlations, and Shiprio Wilks on 13na dataset without zeros.
data=ppt13na_nozero
par(las=1)

#Breaks by season
seas=(cut(data$Cont.Time, breaks=c(min(data$Cont.Time), 274, 335, 456, 547, 639,
     700, 821, 912, 1004, 1065, 1187, 1278, 1370, 1431, max(data$Cont.Time)),
    right=FALSE, include.lowest=TRUE))
levels(seas)=c("Summer", "Fall", "Winter", "Spring", "Summer", "Fall",
    "Winter", "Spring", "Summer", "Fall", "Winter", "Spring", "Summer",
    "Fall", "Winter")
data$seas=seas
head(data)
# RUN FOR PRECIPITATION EVENT DATA
#All Seasons by Station
```

```
png(str_c(datalabel,"scatterplot all seas stations" ,nalabel, ".png"))
pairs(data[3:8], diag.panel=panel.hist, upper.panel=panel.cor, main="Correlation of Precipitation Event Totals")
title(sub=label)
dev.off()
#these next two lines give you table format of Spearmans rho and R^2
cor(data[,3:8], y = NULL, use = "pairwise.complete.obs", method = c("spearman"))#spearman
(cor(data[,3:8], y = NULL, use = "pairwise.complete.obs"))^2 #r squared
# Summer by Station
png(str_c(datalabel,"scatterplot Summer by stations", nalabel, ".png"))
pairs(subset(data[3:8],seas=="Summer"), diag.panel=panel.hist, upper.panel=panel.cor, main="Correlation of Summer Precipitation Event Totals")
title(sub=label)
dev.off()
cor(data[data$seas=="Summer",3:8], y=NULL, use = "pairwise.complete.obs", method = c("spearman")) # Spearmans
(cor(data[data$seas=="Summer",3:8], y = NULL, use = "pairwise.complete.obs"))^2 #for pearsons r sq
# Fall by Station--not enough paired data when zeros removed to run scatterplot matrix for fall
png(str_c(datalabel,"scatterplot Fall by stations" ,nalabel, ".png"))
pairs(subset(data[3:8],seas=="Fall"), diag.panel=panel.hist, upper.panel=panel.cor, main="Correlation of Fall Precipitation Event Totals")
title(sub=label)
dev.off()
cor(data[data$seas=="Fall",3:8], y = NULL, use = "pairwise.complete.obs", method = c("spearman"))
(cor(data[data$seas=="Fall",3:8], y = NULL, use = "pairwise.complete.obs"))^2 #for pearsons r sq
# Winter by Station
png(str_c(datalabel,"scatterplot Winter by stations" ,nalabel, ".png"))
pairs(subset(data[3:8],seas=="Winter"), diag.panel=panel.hist, upper.panel=panel.cor, main="Correlation of Winter Precipitation Event Totals")
title(sub=label)
dev.off()
cor(data[data$seas=="Winter",3:8], y = NULL, use = "pairwise.complete.obs", method = c("spearman"))
(cor(data[data$seas=="Winter",3:8], y = NULL, use = "pairwise.complete.obs"))^2 #for pearsons r sq
# Spring by Station
png(str_c(datalabel,"scatterplot Spring by stations", nalabel, ".png"))
pairs(subset(data[3:8],seas=="Spring"), diag.panel=panel.hist, upper.panel=panel.cor, main="Correlation of Spring Precipitation Event Totals")
title(sub=label)
dev.off()
cor(data[data$seas=="Spring",3:8], y = NULL, use = "pairwise.complete.obs", method = c("spearman"))
```

```
(cor(data[data$seas=="Spring",3:8], y = NULL, use = "pairwise.complete.obs"))^2 #for pearsons r sq
# RUN FOR PPT MEAN INTENSITY DATA
#All Seasons by Station
png(str_c(datalabel,"scatterplot all seas stations" ,nalabel, ".png"))
pairs(data[3:8], diag.panel=panel.hist, upper.panel=panel.cor, main="Correlation of Precipitation Event Mean Intensities")
title(sub=label)
dev.off()
#these next two lines give you table format of Spearmans rho and R^2
cor(data[,3:8], y = NULL, use = "pairwise.complete.obs", method = c("spearman"))#spearman
(cor(data[,3:8], y = NULL, use = "pairwise.complete.obs"))^2 #r squared
# Summer by Station
png(str_c(datalabel,"scatterplot Summer by stations", nalabel, ".png"))
pairs(subset(data[3:8],seas=="Summer"), diag.panel=panel.hist, upper.panel=panel.cor, main="Correlation of Summer Precipitation Event Mean Intensities")
title(sub=label)
dev.off()
cor(data[data$seas=="Summer",3:8], y=NULL, use = "pairwise.complete.obs", method = c("spearman")) # Spearmans
(cor(data[data$seas=="Summer",3:8], y = NULL, use = "pairwise.complete.obs"))^2 #for pearsons r sq
# Fall by Station-- not enough paired data when zeros removed to run scatterplot matrix for fall
png(str_c(datalabel,"scatterplot Fall by stations" ,nalabel, ".png"))
pairs(subset(data[3:8],seas=="Fall"), diag.panel=panel.hist, upper.panel=panel.cor, main="Correlation of Fall Precipitation Event Mean Intensities")
title(sub=label)
dev.off()
cor(data[data$seas=="Fall",3:8], y = NULL, use = "pairwise.complete.obs", method = c("spearman"))
(cor(data[data$seas=="Fall",3:8], y = NULL, use = "pairwise.complete.obs"))^2 #for pearsons r sq
# Winter by Station
png(str_c(datalabel,"scatterplot Winter by stations" ,nalabel, ".png"))
pairs(subset(data[3:8],seas=="Winter"), diag.panel=panel.hist, upper.panel=panel.cor, main="Correlation of Winter Precipitation Event Mean Intensities")
title(sub=label)
dev.off()
cor(data[data$seas=="Winter",3:8], y = NULL, use = "pairwise.complete.obs", method = c("spearman"))
(cor(data[data$seas=="Winter",3:8], y = NULL, use = "pairwise.complete.obs"))^2 #for pearsons r sq
# Spring by Station
png(str_c(datalabel,"scatterplot Spring by stations", nalabel, ".png"))
pairs(subset(data[3:8],seas=="Spring"), diag.panel=panel.hist, upper.panel=panel.cor, main="Correlation of Spring Precipitation Event Mean Intensities")
```

```
title(sub=label)
dev.off()
cor(data[data$seas=="Spring",3:8], y = NULL, use = "pairwise.complete.obs", method = c("spearman"))
(cor(data[data$seas=="Spring",3:8], y = NULL, use = "pairwise.complete.obs"))^2 #for pearsons r sq
##  RUN FOR PPT MAXIMUM INTENSITY DATA
#All Seasons by Station
png(str_c(datalabel,"scatterplot all seas stations" ,nalabel, ".png"))
pairs(data[3:8], diag.panel=panel.hist, upper.panel=panel.cor, main="Correlation of Precipitation Event Maximum Intensities")
title(sub=label)
dev.off()
#these next two lines give you table format of Spearmans rho and R^2
cor(data[,3:8], y = NULL, use = "pairwise.complete.obs", method = c("spearman"))#spearman
(cor(data[,3:8], y = NULL, use = "pairwise.complete.obs"))^2 #r squared
# Summer by Station
png(str_c(datalabel,"scatterplot Summer by stations", nalabel, ".png"))
pairs(subset(data[3:8],seas=="Summer"), diag.panel=panel.hist, upper.panel=panel.cor, main="Correlation of Summer Precipitation Event Maximum Intensities")
title(sub=label)
dev.off()
cor(data[data$seas=="Summer",3:8], y=NULL, use = "pairwise.complete.obs", method = c("spearman")) # Spearmans
(cor(data[data$seas=="Summer",3:8], y = NULL, use = "pairwise.complete.obs"))^2 #for pearsons r sq
# Fall by Station--not enough paired data when zeros removed to run scatterplot matrix for fall

png(str_c(datalabel,"scatterplot Fall by stations" ,nalabel, ".png"))
pairs(subset(data[3:8],seas=="Fall"), diag.panel=panel.hist, upper.panel=panel.cor, main="Correlation of Fall Precipitation Event Maximum Intensities")
title(sub=label)
dev.off()
cor(data[data$seas=="Fall",3:8], y = NULL, use = "pairwise.complete.obs", method = c("spearman"))
(cor(data[data$seas=="Fall",3:8], y = NULL, use = "pairwise.complete.obs"))^2 #for pearsons r sq
# Winter by Station
png(str_c(datalabel,"scatterplot Winter by stations" ,nalabel, ".png"))
pairs(subset(data[3:8],seas=="Winter"), diag.panel=panel.hist, upper.panel=panel.cor, main="Correlation of Winter Precipitation Event Maximum Intensities")
title(sub=label)
dev.off()
cor(data[data$seas=="Winter",3:8], y = NULL, use = "pairwise.complete.obs", method = c("spearman"))
```

```
(cor(data[data$seas=="Winter",3:8], y = NULL, use = "pairwise.complete.obs"))^2 #for pearsons r sq
# Spring by Station
png(str_c(datalabel,"scatterplot Spring by stations", nalabel, ".png"))
pairs(subset(data[3:8],seas=="Spring"), diag.panel=panel.hist, upper.panel=panel.cor, main="Correlation of Spring Precipitation Event Maximum Intensities")
title(sub=label)
dev.off()
cor(data[data$seas=="Spring",3:8], y = NULL, use = "pairwise.complete.obs", method = c("spearman"))
(cor(data[data$seas=="Spring",3:8], y = NULL, use = "pairwise.complete.obs"))^2 #for pearsons r sq
#BIVARIATE ANALYSIS AND PLOTS--- BY SEASON/YR THEN BY FACTOR
#data=pptstns
#nalabel="no NAs"    #without na, with zeros
#data=pptstnsna   #all na, with zeros
#nalabel="all NAs"
#data=pptstns13na  #13na data, with zeros
#nalabel="13 NAs"
data=pptstns13na   #13na data, NO ZEROS
nalabel="13 NAs"
n0=data[data$precip>0,]
data=n0
yr06=data[data$yr==2006,]
	yr06.o=yr06[yr06$stn!="MET1",]
		#there are no 2006 values when you don't have any NA values
yr07=data[data$yr==2007,]
	yr07.o=yr07[yr07$stn!="ECOV1",]
yr08=data[data$yr==2008,]
yr09=data[data$yr==2009,]
#	yr09.o=yr09[yr09$stn!="MET2",]
yr10=data[data$yr==2010,]
data.o=rbind(yr06.o, yr07.o, yr08,yr09, yr10)
seassummary=rbind(
yuma.fSsummary(data[data$location=="Lower",]$precip, data[data$location=="Lower",]$seas, NA , "Lower")
,yuma.fSsummary(data[data$location=="Middle",]$precip,
data[data$location=="Middle",]$seas,NA , "Middle")
,yuma.fSsummary(data[data$location=="Upper",]$precip,
data[data$location=="Upper",]$seas,NA , "Upper")
,yuma.fSsummary(data[data$geo=="Terrace",]$precip, data[data$geo=="Terrace",]$seas, NA, "Terrace")
,yuma.fSsummary(data[data$geo=="Wash",]$precip, data[data$geo=="Wash",]$seas, NA, "Wash")
,yuma.fSsummary(data[data$stn=="ECOV1",]$precip, data[data$stn=="ECOV1",]$seas, NA, "ECOV1")
```

```
,yuma.fSsummary(data[data$stn=="ECOV2",]$precip, data[data$stn=="ECOV2",]$seas, NA,
"ECOV2")
,yuma.fSsummary(data[data$stn=="MET1",]$precip, data[data$stn=="MET1",]$seas, NA,
"MET1")
,yuma.fSsummary(data[data$stn=="MET2",]$precip, data[data$stn=="MET2",]$seas, NA,
"MET2")
,yuma.fSsummary(data[data$stn=="MET3",]$precip, data[data$stn=="MET3",]$seas, NA,
"MET3")
,yuma.fSsummary(data[data$stn=="MET4",]$precip, data[data$stn=="MET4",]$seas, NA,
"MET4")
)
seassummary$i=c(1,2,3,4)
labelseas=c("Summer","Fall","Winter","Spring")
seassummary$F1=labelseas
seasyrsummary=rbind(
yuma.fSsummary(data[data$location=="Lower",]$precip,
data[data$location=="Lower",]$seasyr, NA , "Lower")
,yuma.fSsummary(data[data$location=="Middle",]$precip,
data[data$location=="Middle",]$seasyr,NA , "Middle")
,yuma.fSsummary(data[data$location=="Upper",]$precip,
data[data$location=="Upper",]$seasyr,NA , "Upper")
,yuma.fSsummary(data[data$geo=="Terrace",]$precip, data[data$geo=="Terrace",]$seasyr, NA,
"Terrace")
,yuma.fSsummary(data[data$geo=="Wash",]$precip, data[data$geo=="Wash",]$seasyr, NA,
"Wash")
,yuma.fSsummary(data[data$stn=="ECOV1",]$precip, data[data$stn=="ECOV1",]$seasyr, NA,
"ECOV1")
,yuma.fSsummary(data[data$stn=="ECOV2",]$precip, data[data$stn=="ECOV2",]$seasyr, NA,
"ECOV2")
,yuma.fSsummary(data[data$stn=="MET1",]$precip, data[data$stn=="MET1",]$seasyr, NA,
"MET1")
,yuma.fSsummary(data[data$stn=="MET2",]$precip, data[data$stn=="MET2",]$seasyr, NA,
"MET2")
,yuma.fSsummary(data[data$stn=="MET3",]$precip, data[data$stn=="MET3",]$seasyr, NA,
"MET3")
,yuma.fSsummary(data[data$stn=="MET4",]$precip, data[data$stn=="MET4",]$seasyr, NA,
"MET4")
)
yrsummary=rbind(
yuma.fSsummary(data[data$location=="Lower",]$precip, data[data$location=="Lower",]$yr,
NA , "Lower")
,yuma.fSsummary(data[data$location=="Middle",]$precip,
data[data$location=="Middle",]$yr,NA , "Middle")
,yuma.fSsummary(data[data$location=="Upper",]$precip,
data[data$location=="Upper",]$yr,NA , "Upper")
```

```
,yuma.fSsummary(data[data$geo=="Terrace",]$precip,    data[data$geo=="Terrace",]$yr,    NA,
"Terrace")
,yuma.fSsummary(data[data$geo=="Wash",]$precip,       data[data$geo=="Wash",]$yr,       NA,
"Wash")
,yuma.fSsummary(data[data$stn=="ECOV1",]$precip,    data[data$stn=="ECOV1",]$yr,    NA,
"ECOV1")
,yuma.fSsummary(data[data$stn=="ECOV2",]$precip,    data[data$stn=="ECOV2",]$yr,    NA,
"ECOV2")
,yuma.fSsummary(data[data$stn=="MET1",]$precip,       data[data$stn=="MET1",]$yr,       NA,
"MET1")
,yuma.fSsummary(data[data$stn=="MET2",]$precip,       data[data$stn=="MET2",]$yr,       NA,
"MET2")
,yuma.fSsummary(data[data$stn=="MET3",]$precip,       data[data$stn=="MET3",]$yr,       NA,
"MET3")
,yuma.fSsummary(data[data$stn=="MET4",]$precip,       data[data$stn=="MET4",]$yr,       NA,
"MET4")
)
#FOR DATA=pptstns13na with zeros, or pptstns13na with NO ZEROS (i.e. data=n0), run this
section:
 yrsummary$i=c(1,2,3,4,5)
labelyr=c("2006", "2007", "2008", "2009", "2010")
yrsummary$F1=labelyr
seasyrsummary$i=c(1,2,3,4,5,6,7,8,9,10,11,13,14,15)
labelsyr=c("Su06", "Fa06", "Wi06-07", "Sp07", "Su07","Fa07", "Wi07-08","Sp08",
                  "Su08", "Fa08", "Wi08-09","Su09", "Fa09", "Wi09-10")
seasyrsummary$F1=labelsyr
#BOXPLOTS--BIVARIATE FACTORS--USE FOR PPT EVENT TOTALS
#BY SEASON, BY YEAR, AND BY SEAS/YR
png(str_c(datalabel, "  Boxplots by Season, Year, and SeasYr II", nalabel, ".png"), width=900,
height=900)
ymin=0
ymax=100
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=5, las=1)
layout(rbind(c(1,2), c(3,3)))
boxplot.n(data$precip~factor(data$seas), ylim=range(ymin,ymax), ylab=label, top=T) #
title("")
boxplot.n(data$precip~factor(data$yr),   ylim=range(ymin,ymax),   ylab=label,   top=T)      #,
col=(c("grey100","grey70", "grey51" ,"grey90")))
title("")
boxplot.n(data$precip~factor(data$seasyr),   ylim=range(ymin,ymax),   ylab=label,   top=T)   #,
col=(c("grey100","grey70", "grey51" ,"grey90")))
title("")
title(str_c(" Precipitation Event Totals by Season and by Year ", sep=" "), outer=TRUE)
dev.off()
BY SEASON AND BY STATION
```

```
png(str_c(datalabel, "  Boxplots by Season and Station ", nalabel, ".png"), width=600, height=480)
ymin=0
ymax=100
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7, las=1)
summer=data[factor(data$seas)=="Summer",]
boxplot.n(summer$precip~summer$stn, ylim=range(ymin,ymax), ylab=label, main="Summer", top=T) #
fall=data[factor(data$seas)=="Fall",]
boxplot.n(fall$precip~fall$stn, ylim=range(ymin,ymax), ylab=label, main="Fall", top=T)  #, col=(c("grey100","grey70", "grey51" ,"grey90")))
winter=data[factor(data$seas)=="Winter",]
boxplot.n(winter$precip~winter$stn, ylim=range(ymin,ymax), ylab=label, main="Winter", top=T) #, col=(c("grey100","grey70", "grey51" ,"grey90")))
spring=data[factor(data$seas)=="Spring",]
boxplot.n(spring$precip~spring$stn, ylim=range(ymin,ymax), ylab=label, main="Spring", top=T) #
title(str_c(" Precipitation Event Totals by Season and by Station ",sep=" "), outer=TRUE)
dev.off()
BY SEASON AND BY YEAR
png(str_c(datalabel, "  Boxplots by Season and Year ", nalabel, ".png"), width=480, height=480)
ymin=0
ymax=100
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7, las=2)
summer=data[factor(data$seas)=="Summer",]
boxplot.n(summer$precip~summer$yr, ylim=range(ymin,ymax), ylab=label, main="Summer", top=T) #
fall=data[factor(data$seas)=="Fall",]
boxplot.n(fall$precip~fall$yr, ylim=range(ymin,ymax), ylab=label, main="Fall", top=T)  #, col=(c("grey100","grey70", "grey51" ,"grey90")))
winter=data[factor(data$seas)=="Winter",]
boxplot.n(winter$precip~winter$yr, ylim=range(ymin,ymax), ylab=label, main="Winter", top=T) #, col=(c("grey100","grey70", "grey51" ,"grey90")))
spring=data[factor(data$seas)=="Spring",]
boxplot.n(spring$precip~spring$yr, ylim=range(ymin,ymax), ylab=label, main="Spring", top=T) #
title(str_c(" Precipitation Event Totals by Season and Year ",sep=" "), outer=TRUE)
dev.off()
BY SEASON AND BY GEOMORPHIC SURFACE
png(str_c(datalabel, "  Boxplots by Season and Geo", nalabel, ".png"), width=480, height=480)
ymin=0
ymax=100
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7, las=2)
summer=data[factor(data$seas)=="Summer",]
boxplot.n(summer$precip~summer$geo, ylim=range(ymin,ymax), ylab=label, main="Summer", top=T) #
```

```
fall=data[factor(data$seas)=="Fall",]
boxplot.n(fall$precip~fall$geo, ylim=range(ymin,ymax), ylab=label, main="Fall", top=T) #, col=(c("grey100","grey70", "grey51" ,"grey90")))
winter=data[factor(data$seas)=="Winter",]
boxplot.n(winter$precip~winter$geo, ylim=range(ymin,ymax), ylab=label, main="Winter", top=T) #, col=(c("grey100","grey70", "grey51" ,"grey90")))
spring=data[factor(data$seas)=="Spring",]
boxplot.n(spring$precip~spring$geo, ylim=range(ymin,ymax), ylab=label, main="Spring", top=T) #
title(str_c(" Precipitation Event Totals by Season and by Geomorphic Surface ",sep=" "), outer=TRUE)
dev.off()
BY SEASON AND BY LOCATION
png(str_c(datalabel, "  Boxplots by Season and Loc", nalabel, ".png"), width=480, height=480)
ymin=0
ymax=100
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7, las=2)
summer=data[factor(data$seas)=="Summer",]
boxplot.n(summer$precip~summer$loc, ylim=range(ymin,ymax), ylab=label, main="Summer", top=T) #
fall=data[factor(data$seas)=="Fall",]
boxplot.n(fall$precip~fall$loc, ylim=range(ymin,ymax), ylab=label, main="Fall", top=T) #, col=(c("grey100","grey70", "grey51" ,"grey90")))
winter=data[factor(data$seas)=="Winter",]
boxplot.n(winter$precip~winter$loc, ylim=range(ymin,ymax), ylab=label, main="Winter", top=T) #, col=(c("grey100","grey70", "grey51" ,"grey90")))
spring=data[factor(data$seas)=="Spring",]
boxplot.n(spring$precip~spring$loc, ylim=range(ymin,ymax), ylab=label, main="Spring", top=T) #
title(str_c(" Precipitation Event Totals by Season and by Basin Location ",sep=" "), outer=TRUE)
dev.off()
```

****

Precipitation: Statistical Tests Code

****

```
setwd("C:\\Users\\showe\\YumaWash\\precipitation\\CURRENT")
library(pgirmess) #install the pgirmess package first
library(stringr)
library(gplots)
library(car)
source("Func_testtables.R")
#Select precipitation data type:

load("ppt.RData")
label=expression(paste(Precipitation, "  ", "(mm)"))
```

```
datalabel="ppt"
datatitle="Daily Precipitation Totals"

load("pptintmean.RData")
label=expression(paste(Mean," ",Intensity, "  ", "(mm/hr)"))
datalabel="pptintmean"
datatitle="Mean Precipitation Intensity"

load("pptintmax.RData")
label=expression(paste(Max," ", Intensity, "  ", "(mm/hr)"))
datalabel="pptintmax"
datatitle="Maximum Precipitation Intensity"

attach(pptstnsna)
pptstns13na=rbind(
pptstnsna[ContTime==249,],
pptstnsna[ContTime==250,],
pptstnsna[ContTime==297,],
pptstnsna[ContTime==608,],
pptstnsna[ContTime==639,],
pptstnsna[ContTime==699,],
pptstnsna[ContTime==737,],
pptstnsna[ContTime==1134,],
pptstnsna[ContTime==1344,],
pptstnsna[ContTime==1437,],
pptstnsna[ContTime==1498,],
pptstnsna[ContTime==1502,],
pptstnsna[ContTime==1512,],
pptstns
)
PPTSTNS13na dataset has been adjusted below to remove all zeros.
#data=pptstns
#data=pptstnsna
data=pptstns13na
n0=data[data$precip>0,]
data=n0
#Makes sure that all the categorical variables are reading like factors for each depth.
data=data.frame(data[,1],factor(data[,2]),
factor(data[,3]),factor(data[,4]),factor(data[,5]), factor(data[,6])
,factor(data[,7]), data[,8])
names(data)=c("precip", "loc", "stn", "geo", "seas", "seasyr", "yr", "ContTime")
str(data)
Summer=subset(data, data$seas=="Summer")
Fall=subset(data, data$seas=="Fall")
Winter=subset(data, data$seas=="Winter")
Spring=subset(data, data$seas=="Spring")
```

```
yr06=data[data$yr==2006,]
	yr06.o=yr06[yr06$stn!="MET1",]
		#there are no 2006 values when you don't have any NA values
yr07=data[data$yr==2007,]
	yr07.o=yr07[yr07$stn!="ECOV1",]
yr08=data[data$yr==2008,]
yr09=data[data$yr==2009,]
#	yr09.o=yr09[yr09$stn!="MET2",]
yr10=data[data$yr==2010,]
data.o=rbind(yr06.o, yr07.o, yr08,yr09, yr10)
Summer.o=subset(data, data$seas=="Summer")
Fall.o=subset(data, data$seas=="Fall")
Winter.o=subset(data, data$seas=="Winter")
Spring.o=subset(data, data$seas=="Spring")
#ANOVA- Tests if there are any significant differences among groups.
allseas=data.o
summary(aov(allseas$precip~allseas[,5]))
# above F test shows if there is significance by season
seas=summary(aov(allseas$precip~allseas$seas))
allseas=data
stn=ftest.ppttable(3, stn)
loc=ftest.ppttable(2, loc)
geo=ftest.ppttable(4, geo)
#seasyr=ftest.ppttable(6,seasyr) omitted test
allseas=data.o
yr=ftest.ppttable(7, yr)
F.test=list(seas, stn, loc, geo, yr)
names(F.test)=c("seas","stn", "loc", "geo", "yr")
F.test
#Pairwise T-test comparisons for groups with statistical differences.
#Multiple comparison with Tukey HSD for multiple comparisons.
allseas=data.o
TukeyHSD(aov(data$precip~data$seas))
#TukeyHSD(aov(allseas$precip~allseas$seasyr))
TukeyHSD(aov(allseas$precip~allseas$stn))
TukeyHSD(aov(allseas$precip~allseas$yr))
TukeyHSD(aov(Summer.o$precip~Summer.o$loc))# this one is for ppt, and max int
TukeyHSD(aov(Fall.o$precip~Fall.o$loc))# this one is for mean ppt int
TukeyHSD(aov(Winter.o$precip~Winter.o$loc))# this one is for mean ppt int
TukeyHSD(aov(Summer.o$precip~Summer.o$yr))
TukeyHSD(aov(Fall.o$precip~Fall.o$yr))
TukeyHSD(aov(Spring.o$precip~Spring.o$yr))
TukeyHSD(aov(Winter.o$precip~Winter.o$yr))

#Formal Boxplot with export to PNG is at end of script
#boxplot(data$precip~data$seas)
```

```
#boxplot(allseas$precip~allseas$seasyr)
#boxplot(allseas$precip~allseas$yr)
#boxplot(Fall$precip~Fall$yr)
#boxplot(Summer$precip~Summer$yr)
#boxplot(Winter$precip~Winter$yr)
#boxplot(Spring$precip~Spring$yr)
# KRUSKAL-WALLACE:
allseas=data.o
kruskal.test(allseas$precip~allseas[,5])
# the above line of code is the non-parametric equivalent to what we added on 9/17/12 for seasonal above in the parametric section
seas=kruskal.test(allseas$precip~allseas$seas)
allseas=data
stn=kruskal.ppttable(3, stn)
loc=kruskal.ppttable(2, loc)
geo=kruskal.ppttable(4, geo)
#seasyr=kruskal.ppttable(6,seasyr)
allseas=data.o
yr=kruskal.ppttable(7, yr)
KW.test=list(seas, stn, loc, geo, yr)
names(KW.test)=c("seas","stn", "loc", "geo", "yr")
KW.test
#MANN-WHITNEY WILCOXON:
#Sum_Location Mann Whitney test for Max Intensity
data=Summer.o
suloc=rbind(
wilcox.test(subset(data$precip, data$loc=="Upper"), subset(data$precip, data$loc=="Middle"))[1:3],
wilcox.test(subset(data$precip, data$loc=="Middle"), subset(data$precip, data$loc=="Lower"))[1:3],
wilcox.test(subset(data$precip, data$loc=="Lower"), subset(data$precip, data$loc=="Upper"))[1:3]
)
colnames(suloc)=c("W", "par", "p.test")
rownames(suloc)=c("Upper-Middle","Middle-Lower","Lower-Upper")
suloc
data=allseas
years=rbind(
wilcox.test(subset(data$precip, data$yr=="2006"), subset(data$precip, data$yr=="2007"))[1:3],
wilcox.test(subset(data$precip, data$yr=="2006"), subset(data$precip, data$yr=="2008"))[1:3],
wilcox.test(subset(data$precip, data$yr=="2006"), subset(data$precip, data$yr=="2009"))[1:3],
wilcox.test(subset(data$precip, data$yr=="2006"), subset(data$precip, data$yr=="2010"))[1:3],
wilcox.test(subset(data$precip, data$yr=="2007"), subset(data$precip, data$yr=="2008"))[1:3],
wilcox.test(subset(data$precip, data$yr=="2007"), subset(data$precip, data$yr=="2009"))[1:3],
wilcox.test(subset(data$precip, data$yr=="2007"), subset(data$precip, data$yr=="2010"))[1:3],
wilcox.test(subset(data$precip, data$yr=="2008"), subset(data$precip, data$yr=="2009"))[1:3],
```

```
wilcox.test(subset(data$precip, data$yr=="2008"), subset(data$precip, data$yr=="2010"))[1:3],
wilcox.test(subset(data$precip, data$yr=="2009"), subset(data$precip, data$yr=="2010"))[1:3]
)
colnames(years)=c("W", "par", "p.test")
#rownames(years)=c("07-08","07-09","07-10","08-09","08-10", "09-10")
rownames(years)=c("06-07","06-08","06-09","06-10","07-08","07-09","07-10","08-09","08-10",
"09-10")# for na
years
seasons=rbind(
wilcox.test(subset(data$precip, data$seas=="Summer"), subset(data$precip,
data$seas=="Fall"))[1:3],
wilcox.test(subset(data$precip, data$seas=="Summer"), subset(data$precip,
data$seas=="Winter"))[1:3],
wilcox.test(subset(data$precip, data$seas=="Summer"), subset(data$precip,
data$seas=="Spring"))[1:3],
wilcox.test(subset(data$precip, data$seas=="Fall"), subset(data$precip,
data$seas=="Winter"))[1:3],
wilcox.test(subset(data$precip, data$seas=="Fall"), subset(data$precip,
data$seas=="Spring"))[1:3],
wilcox.test(subset(data$precip, data$seas=="Winter"), subset(data$precip,
data$seas=="Spring"))[1:3]
)
colnames(seasons)=c("W", "par", "p.test")
rownames(seasons)=c("Su-Fa","Su-Wi","Su-Sp","Fa-Wi","Fa-Sp","Wi-Sp")
seasons
data=Summer.o
su=rbind(
wilcox.test(subset(data$precip, data$yr=="2006"), subset(data$precip, data$yr=="2007"))[1:3],
#for na
wilcox.test(subset(data$precip, data$yr=="2006"), subset(data$precip, data$yr=="2008"))[1:3],
#for na
wilcox.test(subset(data$precip, data$yr=="2006"), subset(data$precip, data$yr=="2009"))[1:3],
#for na
wilcox.test(subset(data$precip, data$yr=="2007"), subset(data$precip, data$yr=="2008"))[1:3],
wilcox.test(subset(data$precip, data$yr=="2007"), subset(data$precip, data$yr=="2009"))[1:3],
wilcox.test(subset(data$precip, data$yr=="2008"), subset(data$precip, data$yr=="2009"))[1:3]
)
colnames(su)=c("W", "par", "p.test")
#rownames(su)=c("07-08","07-09","08-09")
rownames(su)=c("06-07", "06-08", "06-09","07-08","07-09","08-09")# for na
data=Fall.o
fa=rbind(
wilcox.test(subset(data$precip, data$yr=="2006"), subset(data$precip, data$yr=="2007"))[1:3],
#for na
wilcox.test(subset(data$precip, data$yr=="2006"), subset(data$precip, data$yr=="2008"))[1:3],
#for na
```

```
wilcox.test(subset(data$precip, data$yr=="2006"), subset(data$precip, data$yr=="2009"))[1:3],
#for na
wilcox.test(subset(data$precip, data$yr=="2007"), subset(data$precip, data$yr=="2008"))[1:3],
#for na, no data 2007 with na
wilcox.test(subset(data$precip, data$yr=="2007"), subset(data$precip, data$yr=="2009"))[1:3],
#for na, no data 2009 with na
wilcox.test(subset(data$precip, data$yr=="2008"), subset(data$precip, data$yr=="2009"))[1:3]
)
colnames(fa)=c("W", "par", "p.test")
#rownames(fa)=c("08-09")
rownames(fa)=c("06-07", "06-08", "06-09","07-08","07-09","08-09")# for na
#this next code lets you know how many n-values are in the comparison
(subset(data$precip, data$yr=="2006"))
length(subset(data$precip, data$yr=="2006"))
(subset(data$precip, data$yr=="2007"))
length(subset(data$precip, data$yr=="2007"))
(subset(data$precip, data$yr=="2008"))
length(subset(data$precip, data$yr=="2008"))
(subset(data$precip, data$yr=="2009"))
length(subset(data$precip, data$yr=="2009"))
data=Winter.o
wi=rbind(
wilcox.test(subset(data$precip, data$yr=="2007"), subset(data$precip, data$yr=="2008"))[1:3],
wilcox.test(subset(data$precip, data$yr=="2007"), subset(data$precip, data$yr=="2009"))[1:3],
wilcox.test(subset(data$precip, data$yr=="2007"), subset(data$precip, data$yr=="2010"))[1:3],
wilcox.test(subset(data$precip, data$yr=="2008"), subset(data$precip, data$yr=="2009"))[1:3],
wilcox.test(subset(data$precip, data$yr=="2008"), subset(data$precip, data$yr=="2010"))[1:3],
wilcox.test(subset(data$precip, data$yr=="2009"), subset(data$precip, data$yr=="2010"))[1:3]
)
colnames(wi)=c("W", "par", "p.test")
#rownames(wi)=c("07-08","07-09","07-10","08-09","08-10", "09-10")
rownames(wi)=c("07-08","07-09","07-10","08-09","08-10", "09-10")# for na
data=Spring.o
sp=rbind(
wilcox.test(subset(data$precip, data$yr=="2007"), subset(data$precip, data$yr=="2008"))[1:3]
#,
#wilcox.test(subset(data$precip, data$yr=="2007"), subset(data$precip, data$yr=="2009"))[1:3],
#for na, not enough data in 2009 with na
#wilcox.test(subset(data$precip, data$yr=="2008"), subset(data$precip, data$yr=="2009"))[1:3]
#for na, not enough data in 2009 with na
)
colnames(sp)=c("W", "par", "p.test")
rownames(sp)=c("07-08")
#rownames(sp)=c("07-08","07-09","08-09")# for na
fa
wi
```

```
sp
su
#ADDITIONAL TESTS:  KOLMGOROV SMIRNOV, SPEARMANS RHO, SHAPIRO WILK:
data=pptstns13na
nalabel="13 NAs"
n0=data[data$precip>0,]
data=n0
#KOLMGOROV SMIRNOV
#Tests if two datasets come from the same distribution
ks.all=ks.ppttable(data, all)
ks.Su=ks.ppttable(Summer, summer)
ks.Fa=ks.ppttable(Fall, fall)
ks.Wi=ks.ppttable(Winter, winter)
ks.Sp=ks.ppttable(Spring, spring)
KS.test=list(ks.all, ks.Su, ks.Fa, ks.Wi, ks.Sp)
names(KS.test)=c("allseas","Summer","Fall","Winter","Spring")
KS.test
#SPEARMANS RHO
# Spearmans are already computed in Script_Precip but repeated here with different format
data=ppt13na
nalabel="13 NAs"
ppt13na_nozero=as.data.frame(replace(as.matrix(ppt13na), which(ppt13na==0), NaN))
#the above line of code removes all ZEROS from ppt13na so I can run scatterplot matrices, correlations, and Shiprio Wilks
#on 13na dataset without zeros.
data=ppt13na_nozero
#Breaks by season
seas=(cut(data$Cont.Time, breaks=c(min(data$Cont.Time), 274, 335, 456, 547, 639,
           700, 821, 912, 1004, 1065, 1187, 1278, 1370, 1431, max(data$Cont.Time)),
          right=FALSE, include.lowest=TRUE))
levels(seas)=c("Summer", "Fall", "Winter", "Spring", "Summer", "Fall",
          "Winter", "Spring", "Summer", "Fall", "Winter", "Spring", "Summer",
          "Fall", "Winter")
data$seas=seas
head(data)
Summer=subset(data,seas=="Summer")
Fall=subset(data,seas=="Fall")
Winter=subset(data,seas=="Winter")
Spring=subset(data,seas=="Spring")
cor.all=cor.ppttable(data, Spearmans.All)
cor.Su=cor.ppttable(Summer, Spearmans.All)
cor.Fa=cor.ppttable(Fall, Spearmans.All)
cor.Wi=cor.ppttable(Winter, Spearmans.All)
cor.Sp=cor.ppttable(Spring, Spearmans.All)
cor.test=list(cor.all, cor.Su, cor.Fa, cor.Wi, cor.Sp)
names(cor.test)=c("allseas","Summer","Fall","Winter","Spring")
```

```
cor.test
#SHAPRIO WILK:
data=ppt13na
nalabel="13 NAs"
ppt13na_nozero=as.data.frame(replace(as.matrix(ppt13na), which(ppt13na==0), NaN))
#the above line of code removes all ZEROS from ppt13na to run scatterplot matrices, correlations, and Shiprio Wilks on 13na dataset without zeros.
data=ppt13na_nozero
#Breaks by season
seas=(cut(data$Cont.Time, breaks=c(min(data$Cont.Time), 274, 335, 456, 547, 639,
        700, 821, 912, 1004, 1065, 1187, 1278, 1370, 1431, max(data$Cont.Time)),
        right=FALSE, include.lowest=TRUE))
levels(seas)=c("Summer", "Fall", "Winter", "Spring", "Summer", "Fall",
        "Winter", "Spring", "Summer", "Fall", "Winter", "Spring", "Summer",
        "Fall", "Winter")
data$seas=seas
head(data)
Summer=subset(data,seas=="Summer")
Fall=subset(data,seas=="Fall")
Winter=subset(data,seas=="Winter")
Spring=subset(data,seas=="Spring")
sh.all=t(sapply(data[,3:8], shapiro.test))
sh.Su=t(sapply(Summer[,3:8], shapiro.test))
sh.Fa=t(sapply(Fall[,4:8], shapiro.test)) #NOT ENOUGH DATA POINTS (n<3)FOR ECOV1 FALL TEST WHEN ZEROS ARE REMOVED
sh.Wi=t(sapply(Winter[,3:8], shapiro.test))
sh.Sp=t(sapply(Spring[,3:8], shapiro.test))
sh.test=list(sh.all, sh.Su, sh.Fa, sh.Wi, sh.Sp)
names(sh.test)=c("allseas","Summer","Fall","Winter","Spring")
```

****

Soil Moisture Data File Generation Code: this code imports soil moisture and soil temperature data files and creates the .RData files used in data analysis scripts for soil moisture.

```
#R code by Natalie K. Anderson. nettleus@gmail.com. 530-722-5789.
#This code creates the wcr.RData file for soil moisture (wcr) used in other scripts.
setwd("C:\\Users\\showe\\YumaWash\\soilmoisture\\CURRENT3")
getwd()
#The soil moisture data for all stns is in units % m^3/m^3
#The Time Stamps are in Julian Days.  The ContTime is the continuous
#Time measurement since initiation and Time resets each year.
wcr=read.csv("Data_wcr.csv", header=T, na.strings="NA")
names(wcr)
wcr[37610,33]=NA
#eliminates a single bad data point 0.654453 in SF6_IW25
#The next section adds categorical variables corresponding with site location,
```

```
#depth, geomorphic surface,season and vegetation
#first adds new empty columns. soil is the column where the soil moisture data will go.
wcr2=wcr[4:63]
names(wcr2)
wcr2[60:61, "soil"]= NA
wcr2[61:62, "probe"]=NA
wcr2[62:63, "location"]=NA
wcr2[63:64, "stn"]=NA
wcr2[64:65, "depth"]=NA
wcr2[66:67, "veg"]=NA
wcr2[67:68, "geo"]=NA
wcr2[68:69, "seas"]=NA
wcr2[69:70, "seasyr"]=NA
wcr2[70:71, "yr"]=NA
names(wcr2)
#Next create a dataset for each unique station with categorical variables with form sxdxAB, where sx represents locations s1-s6, dx represents depth 1-4, d1=2.5cm, d2=25cm, d3=50cm and d4=100cm. AB is the veg ID's, PV=Palo Verde, IW=Ironwood and BG=Bare Ground
#These datasets also include the seasons, and Time Stamps from previous
#Fills in the season categories
#Sets Seasonal Breaks by year
seasyr=(cut(wcr$ContTime, breaks=c(min(wcr$ContTime), 274, 335, 456, 547,
          639, 700, 821, 912, 1004, 1065, 1187, 1278, 1370, 1431,
           max(wcr$ContTime)), right=FALSE, include.lowest=TRUE))
levels(seasyr)=c("Su06", "Fa06", "Wi06-07", "Sp07", "Su07", "Fa07", "Wi07-08",
           "Sp08", "Su08", "Fa08", "Wi08-09", "Sp09", "Su09", "Fa09", "Wi09-10")
#Pools by season
seas=(cut(wcr$ContTime, breaks=c(min(wcr$ContTime), 274, 335, 456, 547, 639,
           700, 821, 912, 1004, 1065, 1187, 1278, 1370, 1431, max(wcr$ContTime)),
          right=FALSE, include.lowest=TRUE))
levels(seas)=c("Summer", "Fall", "Winter", "Spring", "Summer", "Fall",
          "Winter", "Spring", "Summer", "Fall", "Winter", "Spring", "Summer",
          "Fall", "Winter")
yr=(cut(wcr$ContTime, breaks=c(min(wcr$ContTime), 366.0000, 730.9892,
          1096.9892, 1461.9892, max(wcr$ContTime)),
          right=FALSE, include.lowest=TRUE))
levels(yr)=c("2006", "2007", "2008", "2009", "2010")
wcr2$seas=seas
wcr2$seasyr=seasyr
wcr2$yr=yr
#fills in the rest of the categories
#2.5 cm Probes
s1d1BG=data.frame(wcr2[,61:70])
s1d1BG$depth=2.5
s1d1BG$stn="ECOV1"
s1d1BG$geo="Terrace"
```

```
s1d1BG$veg="BG"
s1d1BG$soil=wcr2$ECOV1_BG2.5
s1d1BG$probe="ECOV1_BG2.5"
s1d1BG$location="Lower"
s2d1BG=data.frame(wcr2[,61:70])
s2d1BG$depth=2.5
s2d1BG$stn="ECOV2"
s2d1BG$geo="Wash"
s2d1BG$veg="BG"
s2d1BG$soil=wcr2$ECOV2_BG2.5
s2d1BG$probe="ECOV2_BG2.5"
s2d1BG$location="Lower"
s3d1BG=data.frame(wcr2[,61:70])
s3d1BG$depth=2.5
s3d1BG$stn="MET1"
s3d1BG$geo="Terrace"
s3d1BG$veg="BG"
s3d1BG$soil=wcr2$MET1_BG2.5
s3d1BG$probe="MET1_BG2.5"
s3d1BG$location="Middle"
s4d1BG=data.frame(wcr2[,61:70])
s4d1BG$depth=2.5
s4d1BG$stn="MET2"
s4d1BG$geo="Wash"
s4d1BG$veg="BG"
s4d1BG$soil=wcr2$MET2_BG2.5
s4d1BG$probe="MET2_BG2.5"
s4d1BG$location="Middle"
s5d1BG=data.frame(wcr2[,61:70])
s5d1BG$depth=2.5
s5d1BG$stn="MET3"
s5d1BG$geo="Wash"
s5d1BG$veg="BG"
s5d1BG$soil=wcr2$MET3_BG2.5
s5d1BG$probe="MET3_BG2.5"
s5d1BG$location="Upper"
s6d1BG=data.frame(wcr2[,61:70])
s6d1BG$depth=2.5
s6d1BG$stn="MET4"
s6d1BG$geo="Terrace"
s6d1BG$veg="BG"
s6d1BG$soil=wcr2$MET4_BG2.5
s6d1BG$probe="MET4_BG2.5"
s6d1BG$location="Upper"

#all stations depth 25
```

```
#Palo Verde
s1d2PV=data.frame(wcr2[,61:70])
s1d2PV$depth=25
s1d2PV$stn="SF1"
s1d2PV$geo="Terrace"
s1d2PV$veg="PV"
s1d2PV$soil=wcr2$SF1_PV25
s2d2PV=data.frame(wcr2[,61:70])
s2d2PV$depth=25
s2d2PV$stn="SF2"
s2d2PV$geo="Wash"
s2d2PV$veg="PV"
s2d2PV$soil=wcr2$SF2_PV25
s3d2PV=data.frame(wcr2[,61:70])
s3d2PV$depth=25
s3d2PV$stn="SF3"
s3d2PV$geo="Terrace"
s3d2PV$veg="PV"
s3d2PV$soil=wcr2$SF3_PV25
s4d2PV=data.frame(wcr2[,61:70])
s4d2PV$depth=25
s4d2PV$stn="SF4"
s4d2PV$geo="Wash"
s4d2PV$veg="PV"
s4d2PV$soil=wcr2$SF4_PV25
s5d2PV=data.frame(wcr2[,61:70])
s5d2PV$depth=25
s5d2PV$stn="SF5"
s5d2PV$geo="Wash"
s5d2PV$veg="PV"
s5d2PV$soil=wcr2$SF5_PV25
s6d2PV=data.frame(wcr2[,61:70])
s6d2PV$depth=25
s6d2PV$stn="SF6"
s6d2PV$geo="Terrace"
s6d2PV$veg="PV"
s6d2PV$soil=wcr2$SF6_PV25
#Ironwood
s1d2IW=data.frame(wcr2[,61:70])
s1d2IW$depth=25
s1d2IW$stn="SF1"
s1d2IW$geo="Terrace"
s1d2IW$veg="IW"
s1d2IW$soil=wcr2$SF1_IW25
s2d2IW=data.frame(wcr2[,61:70])
s2d2IW$depth=25
```

```
s2d2IW$stn="SF2"
s2d2IW$geo="Wash"
s2d2IW$veg="IW"
s2d2IW$soil=wcr2$SF2_IW25
s3d2IW=data.frame(wcr2[,61:70])
s3d2IW$depth=25
s3d2IW$stn="SF3"
s3d2IW$geo="Terrace"
s3d2IW$veg="IW"
s3d2IW$soil=wcr2$SF3_IW25
s4d2IW=data.frame(wcr2[,61:70])
s4d2IW$depth=25
s4d2IW$stn="SF4"
s4d2IW$geo="Wash"
s4d2IW$veg="IW"
s4d2IW$soil=wcr2$SF4_IW25
s5d2IW=data.frame(wcr2[,61:70])
s5d2IW$depth=25
s5d2IW$stn="SF5"
s5d2IW$geo="Wash"
s5d2IW$veg="IW"
s5d2IW$soil=wcr2$SF5_IW25
s6d2IW=data.frame(wcr2[,61:70])
s6d2IW$depth=25
s6d2IW$stn="SF6"
s6d2IW$geo="Terrace"
s6d2IW$veg="IW"
s6d2IW$soil=wcr2$SF6_IW25
#Bare Ground
s1d2BG=data.frame(wcr2[,61:70])
s1d2BG$depth=25
s1d2BG$stn="SF1"
s1d2BG$geo="Terrace"
s1d2BG$veg="BG"
s1d2BG$soil=wcr2$SF1_BG25
s2d2BG=data.frame(wcr2[,61:70])
s2d2BG$depth=25
s2d2BG$stn="SF2"
s2d2BG$geo="Wash"
s2d2BG$veg="BG"
s2d2BG$soil=wcr2$SF2_BG25
s3d2BG=data.frame(wcr2[,61:70])
s3d2BG$depth=25
s3d2BG$stn="SF3"
s3d2BG$geo="Terrace"
s3d2BG$veg="BG"
```

```
s3d2BG$soil=wcr2$SF3_BG25
s4d2BG=data.frame(wcr2[,61:70])
s4d2BG$depth=25
s4d2BG$stn="SF4"
s4d2BG$geo="Wash"
s4d2BG$veg="BG"
s4d2BG$soil=wcr2$SF4_BG25
s5d2BG=data.frame(wcr2[,61:70])
s5d2BG$depth=25
s5d2BG$stn="SF5"
s5d2BG$geo="Wash"
s5d2BG$veg="BG"
s5d2BG$soil=wcr2$SF5_BG25
s6d2BG=data.frame(wcr2[,61:70])
s6d2BG$depth=25
s6d2BG$stn="SF6"
s6d2BG$geo="Terrace"
s6d2BG$veg="BG"
s6d2BG$soil=wcr2$SF6_BG25
s1d2BG$probe="SF1_BG25"
s1d2BG$location="Lower"
s2d2BG$probe="SF2_BG25"
s2d2BG$location="Lower"
s3d2BG$probe="SF3_BG25"
s3d2BG$location="Middle"
s4d2BG$probe="SF4_BG25"
s4d2BG$location="Middle"
s5d2BG$probe="SF5_BG25"
s5d2BG$location="Upper"
s6d2BG$probe="SF6_BG25"
s6d2BG$location="Upper"
s1d2PV$probe="SF1_PV25"
s1d2PV$location="Lower"
s2d2PV$probe="SF2_PV25"
s2d2PV$location="Lower"
s3d2PV$probe="SF3_PV25"
s3d2PV$location="Middle"
s4d2PV$probe="SF4_PV25"
s4d2PV$location="Middle"
s5d2PV$probe="SF5_PV25"
s5d2PV$location="Upper"
s6d2PV$probe="SF6_PV25"
s6d2PV$location="Upper"
s1d2IW$probe="SF1_IW25"
s1d2IW$location="Lower"
s2d2IW$probe="SF2_IW25"
```

```
s2d2IW$location="Lower"
s3d2IW$probe="SF3_IW25"
s3d2IW$location="Middle"
s4d2IW$probe="SF4_IW25"
s4d2IW$location="Middle"
s5d2IW$probe="SF5_IW25"
s5d2IW$location="Upper"
s6d2IW$probe="SF6_IW25"
s6d2IW$location="Upper"
#All stations 50cm
#Palo Verde
s1d3PV=data.frame(wcr2[,61:70])
s1d3PV$depth=50
s1d3PV$stn="SF1"
s1d3PV$geo="Terrace"
s1d3PV$veg="PV"
s1d3PV$soil=wcr2$SF1_PV50

s2d3PV=data.frame(wcr2[,61:70])
s2d3PV$depth=50
s2d3PV$stn="SF2"
s2d3PV$geo="Wash"
s2d3PV$veg="PV"
s2d3PV$soil=wcr2$SF2_PV50
s3d3PV=data.frame(wcr2[,61:70])
s3d3PV$depth=50
s3d3PV$stn="SF3"
s3d3PV$geo="Terrace"
s3d3PV$veg="PV"
s3d3PV$soil=wcr2$SF3_PV50
s4d3PV=data.frame(wcr2[,61:70])
s4d3PV$depth=50
s4d3PV$stn="SF4"
s4d3PV$geo="Wash"
s4d3PV$veg="PV"
s4d3PV$soil=wcr2$SF4_PV50
s5d3PV=data.frame(wcr2[,61:70])
s5d3PV$depth=50
s5d3PV$stn="SF5"
s5d3PV$geo="Wash"
s5d3PV$veg="PV"
s5d3PV$soil=wcr2$SF5_PV50
s6d3PV=data.frame(wcr2[,61:70])
s6d3PV$depth=50
s6d3PV$stn="SF6"
s6d3PV$geo="Terrace"
```

```
s6d3PV$veg="PV"
s6d3PV$soil=wcr2$SF6_PV50
#Ironwood
s1d3IW=data.frame(wcr2[,61:70])
s1d3IW$depth=50
s1d3IW$stn="SF1"
s1d3IW$geo="Terrace"
s1d3IW$veg="IW"
s1d3IW$soil=wcr2$SF1_IW50
s2d3IW=data.frame(wcr2[,61:70])
s2d3IW$depth=50
s2d3IW$stn="SF2"
s2d3IW$geo="Wash"
s2d3IW$veg="IW"
s2d3IW$soil=wcr2$SF2_IW50
s3d3IW=data.frame(wcr2[,61:70])
s3d3IW$depth=50
s3d3IW$stn="SF3"
s3d3IW$geo="Terrace"
s3d3IW$veg="IW"
s3d3IW$soil=wcr2$SF3_IW50
s4d3IW=data.frame(wcr2[,61:70])
s4d3IW$depth=50
s4d3IW$stn="SF4"
s4d3IW$geo="Wash"
s4d3IW$veg="IW"
s4d3IW$soil=wcr2$SF4_IW50
s5d3IW=data.frame(wcr2[,61:70])
s5d3IW$depth=50
s5d3IW$stn="SF5"
s5d3IW$geo="Wash"
s5d3IW$veg="IW"
s5d3IW$soil=wcr2$SF5_IW50
s6d3IW=data.frame(wcr2[,61:70])
s6d3IW$depth=50
s6d3IW$stn="SF6"
s6d3IW$geo="Terrace"
s6d3IW$veg="IW"
s6d3IW$soil=wcr2$SF6_IW50
#Bare Ground
s1d3BG=data.frame(wcr2[,61:70])
s1d3BG$depth=50
s1d3BG$stn="SF1"
s1d3BG$geo="Terrace"
s1d3BG$veg="BG"
s1d3BG$soil=wcr2$SF1_BG50
```

```
s2d3BG=data.frame(wcr2[,61:70])
s2d3BG$depth=50
s2d3BG$stn="SF2"
s2d3BG$geo="Wash"
s2d3BG$veg="BG"
s2d3BG$soil=wcr2$SF2_BG50
s3d3BG=data.frame(wcr2[,61:70])
s3d3BG$depth=50
s3d3BG$stn="SF3"
s3d3BG$geo="Terrace"
s3d3BG$veg="BG"
s3d3BG$soil=wcr2$SF3_BG50
s4d3BG=data.frame(wcr2[,61:70])
s4d3BG$depth=50
s4d3BG$stn="SF4"
s4d3BG$geo="Wash"
s4d3BG$veg="BG"
s4d3BG$soil=wcr2$SF4_BG50
s5d3BG=data.frame(wcr2[,61:70])
s5d3BG$depth=50
s5d3BG$stn="SF5"
s5d3BG$geo="Wash"
s5d3BG$veg="BG"
s5d3BG$soil=wcr2$SF5_BG50
s6d3BG=data.frame(wcr2[,61:70])
s6d3BG$depth=50
s6d3BG$stn="SF6"
s6d3BG$geo="Terrace"
s6d3BG$veg="BG"
s6d3BG$soil=wcr2$SF6_BG50
s1d3BG$probe="SF1_BG50"
s1d3BG$location="Lower"
s2d3BG$probe="SF2_BG50"
s2d3BG$location="Lower"
s3d3BG$probe="SF3_BG50"
s3d3BG$location="Middle"
s4d3BG$probe="SF4_BG50"
s4d3BG$location="Middle"
s5d3BG$probe="SF5_BG50"
s5d3BG$location="Upper"
s6d3BG$probe="SF6_BG50"
s6d3BG$location="Upper"
s1d3PV$probe="SF1_PV50"
s1d3PV$location="Lower"
s2d3PV$probe="SF2_PV50"
s2d3PV$location="Lower"
```

```
s3d3PV$probe="SF3_PV50"
s3d3PV$location="Middle"
s4d3PV$probe="SF4_PV50"
s4d3PV$location="Middle"
s5d3PV$probe="SF5_PV50"
s5d3PV$location="Upper"
s6d3PV$probe="SF6_PV50"
s6d3PV$location="Upper"
s1d3IW$probe="SF1_IW50"
s1d3IW$location="Lower"
s2d3IW$probe="SF2_IW50"
s2d3IW$location="Lower"
s3d3IW$probe="SF3_IW50"
s3d3IW$location="Middle"
s4d3IW$probe="SF4_IW50"
s4d3IW$location="Middle"
s5d3IW$probe="SF5_IW50"
s5d3IW$location="Upper"
s6d3IW$probe="SF6_IW50"
s6d3IW$location="Upper"
#All stations 100 cm
#Palo Verde
s1d4PV=data.frame(wcr2[,61:70])
s1d4PV$depth=100
s1d4PV$stn="SF1"
s1d4PV$geo="Terrace"
s1d4PV$veg="PV"
s1d4PV$soil=wcr2$SF1_PV100
s2d4PV=data.frame(wcr2[,61:70])
s2d4PV$depth=100
s2d4PV$stn="SF2"
s2d4PV$geo="Wash"
s2d4PV$veg="PV"
s2d4PV$soil=wcr2$SF2_PV100
s3d4PV=data.frame(wcr2[,61:70])
s3d4PV$depth=100
s3d4PV$stn="SF3"
s3d4PV$geo="Terrace"
s3d4PV$veg="PV"
s3d4PV$soil=wcr2$SF3_PV100
s4d4PV=data.frame(wcr2[,61:70])
s4d4PV$depth=100
s4d4PV$stn="SF4"
s4d4PV$geo="Wash"
s4d4PV$veg="PV"
s4d4PV$soil=wcr2$SF4_PV100
```

```
s5d4PV=data.frame(wcr2[,61:70])
s5d4PV$depth=100
s5d4PV$stn="SF5"
s5d4PV$geo="Wash"
s5d4PV$veg="PV"
s5d4PV$soil=wcr2$SF5_PV100
s6d4PV=data.frame(wcr2[,61:70])
s6d4PV$depth=100
s6d4PV$stn="SF6"
s6d4PV$geo="Terrace"
s6d4PV$veg="PV"
s6d4PV$soil=wcr2$SF6_PV100
#Ironwood
s1d4IW=data.frame(wcr2[,61:70])
s1d4IW$depth=100
s1d4IW$stn="SF1"
s1d4IW$geo="Terrace"
s1d4IW$veg="IW"
s1d4IW$soil=wcr2$SF1_IW100
s2d4IW=data.frame(wcr2[,61:70])
s2d4IW$depth=100
s2d4IW$stn="SF2"
s2d4IW$geo="Wash"
s2d4IW$veg="IW"
s2d4IW$soil=wcr2$SF2_IW100
s3d4IW=data.frame(wcr2[,61:70])
s3d4IW$depth=100
s3d4IW$stn="SF3"
s3d4IW$geo="Terrace"
s3d4IW$veg="IW"
s3d4IW$soil=wcr2$SF3_IW100
s4d4IW=data.frame(wcr2[,61:70])
s4d4IW$depth=100
s4d4IW$stn="SF4"
s4d4IW$geo="Wash"
s4d4IW$veg="IW"
s4d4IW$soil=wcr2$SF4_IW100
s5d4IW=data.frame(wcr2[,61:70])
s5d4IW$depth=100
s5d4IW$stn="SF5"
s5d4IW$geo="Wash"
s5d4IW$veg="IW"
s5d4IW$soil=wcr2$SF5_IW100
s6d4IW=data.frame(wcr2[,61:70])
s6d4IW$depth=100
s6d4IW$stn="SF6"
```

```
s6d4IW$geo="Terrace"
s6d4IW$veg="IW"
s6d4IW$soil=wcr2$SF6_IW100
#Bare Ground
s1d4BG=data.frame(wcr2[,61:70])
s1d4BG$depth=100
s1d4BG$stn="SF1"
s1d4BG$geo="Terrace"
s1d4BG$veg="BG"
s1d4BG$soil=wcr2$SF1_BG100
s2d4BG=data.frame(wcr2[,61:70])
s2d4BG$depth=100
s2d4BG$stn="SF2"
s2d4BG$geo="Wash"
s2d4BG$veg="BG"
s2d4BG$soil=wcr2$SF2_BG100
s3d4BG=data.frame(wcr2[,61:70])
s3d4BG$depth=100
s3d4BG$stn="SF3"
s3d4BG$geo="Terrace"
s3d4BG$veg="BG"
s3d4BG$soil=wcr2$SF3_BG100
s4d4BG=data.frame(wcr2[,61:70])
s4d4BG$depth=100
s4d4BG$stn="SF4"
s4d4BG$geo="Wash"
s4d4BG$veg="BG"
s4d4BG$soil=wcr2$SF4_BG100
s5d4BG=data.frame(wcr2[,61:70])
s5d4BG$depth=100
s5d4BG$stn="SF5"
s5d4BG$geo="Wash"
s5d4BG$veg="BG"
s5d4BG$soil=wcr2$SF5_BG100
s6d4BG=data.frame(wcr2[,61:70])
s6d4BG$depth=100
s6d4BG$stn="SF6"
s6d4BG$geo="Terrace"
s6d4BG$veg="BG"
s6d4BG$soil=wcr2$SF6_BG100
s1d4BG$probe="SF1_BG100"
s1d4BG$location="Lower"
s2d4BG$probe="SF2_BG100"
s2d4BG$location="Lower"
s3d4BG$probe="SF3_BG100"
s3d4BG$location="Middle"
```

```
s4d4BG$probe="SF4_BG100"
s4d4BG$location="Middle"
s5d4BG$probe="SF5_BG100"
s5d4BG$location="Upper"
s6d4BG$probe="SF6_BG100"
s6d4BG$location="Upper"
s1d4PV$probe="SF1_PV100"
s1d4PV$location="Lower"
s2d4PV$probe="SF2_PV100"
s2d4PV$location="Lower"
s3d4PV$probe="SF3_PV100"
s3d4PV$location="Middle"
s4d4PV$probe="SF4_PV100"
s4d4PV$location="Middle"
s5d4PV$probe="SF5_PV100"
s5d4PV$location="Upper"
s6d4PV$probe="SF6_PV100"
s6d4PV$location="Upper"
s1d4IW$probe="SF1_IW100"
s1d4IW$location="Lower"
s2d4IW$probe="SF2_IW100"
s2d4IW$location="Lower"
s3d4IW$probe="SF3_IW100"
s3d4IW$location="Middle"
s4d4IW$probe="SF4_IW100"
s4d4IW$location="Middle"
s5d4IW$probe="SF5_IW100"
s5d4IW$location="Upper"
s6d4IW$probe="SF6_IW100"
s6d4IW$location="Upper"
save(s1d1BG,    s1d2BG,    s1d2IW,    s1d2PV
,s1d3BG,    s1d3IW,    s1d3PV,    s1d4BG
,s1d4IW,    s1d4PV,    s2d1BG,    s2d2BG
,s2d2IW,    s2d2PV,    s2d3BG,    s2d3IW
,s2d3PV,    s2d4BG,    s2d4IW,    s2d4PV
,s3d1BG,    s3d2BG,    s3d2IW,    s3d2PV
,s3d3BG,    s3d3IW,    s3d3PV,    s3d4BG
,s3d4IW,    s3d4PV,    s4d1BG,    s4d2BG
,s4d2IW,    s4d2PV,    s4d3BG,    s4d3IW
,s4d3PV,    s4d4BG,    s4d4IW,    s4d4PV
,s5d1BG,    s5d2BG,    s5d2IW,    s5d2PV
,s5d3BG,    s5d3IW,    s5d3PV,    s5d4BG
,s5d4IW,    s5d4PV,    s6d1BG,    s6d2BG
,s6d2IW,    s6d2PV,    s6d3BG,    s6d3IW
,s6d3PV,    s6d4BG,    s6d4IW,    s6d4PV, file="wcrprobes.RData")
save(wcr, file="wcr.RData")
```

```
#Makes Datasets combining by depths
d1=rbind(s1d1BG, s2d1BG, s3d1BG, s4d1BG, s5d1BG, s6d1BG)
d2=rbind(
s1d2PV, s2d2PV, s3d2PV, s4d2PV, s5d2PV, s6d2PV,
s1d2IW, s2d2IW,          s4d2IW, s5d2IW, s6d2IW,
s1d2BG, s2d2BG, s3d2BG,      s5d2BG, s6d2BG
)#s4d2BG, s3d2IW omitted probes
d3=rbind(
       s2d3PV, s3d3PV, s4d3PV, s5d3PV, s6d3PV,
s1d3IW, s2d3IW, s3d3IW, s4d3IW, s5d3IW, s6d3IW,
s1d3BG, s2d3BG,               s4d3BG, s5d3BG, s6d3BG
)#s1d3PV,s3d3BG omitted probes
d4=rbind(
s1d4PV, s2d4PV, s3d4PV, s4d4PV, s5d4PV, s6d4PV,
s1d4IW, s2d4IW, s3d4IW,      s5d4IW, s6d4IW,
s1d4BG, s2d4BG, s3d4BG, s4d4BG, s5d4BG, s6d4BG
) #s4d4IW omitted probes
save(d1,d2,d3,d4, file="wcrdepth.RData")
load("wcrprobes.RData")
#Combines datasets pooling by Depth and Loc, bad probes omitted
          d1L=rbind(s1d1BG, s2d1BG)
          d1M=rbind(s3d1BG, s4d1BG)
          d1U=rbind(s5d2BG, s6d1BG)
          d2L=rbind(s1d2BG, s2d2BG, s1d2PV, s2d2PV, s1d2IW, s2d2IW)
          d2M=rbind(s3d2BG,    s3d2PV, s4d2PV,        s4d2IW)#s4d2BG,s3d2IW
          d2U=rbind(s5d2BG, s6d2BG, s5d2PV, s6d2PV, s5d2IW, s6d2IW)
          d3L=rbind(s1d3BG,   s2d3BG,        s2d3PV, s1d3IW, s2d3IW)#s1d3PV,
          d3M=rbind(               s4d3BG, s3d3PV, s4d3PV, s3d3IW, s4d3IW)#s3d3BG,
          d3U=rbind(s5d3BG, s6d3BG, s5d3PV, s6d3PV, s5d3IW, s6d3IW)
          d4L=rbind(s1d4BG,   s2d4BG, s1d4PV, s2d4PV, s1d4IW, s2d4IW)
          d4M=rbind(s3d4BG, s4d4BG, s3d4PV, s4d4PV, s3d4IW      )#s4d4IW
          d4U=rbind(s5d4BG, s6d4BG, s5d4PV, s6d4PV, s5d4IW, s6d4IW)
save(d1L, d1M, d1U, d2L, d2M, d2U, d3L, d3M, d3U, d4L, d4M, d4U,
          file="wcrdepthloc.RData")
#Makes datasets holding depth and veg constant:
d1BG=rbind(s1d1BG, s2d1BG, s3d1BG, s4d1BG, s5d1BG, s6d1BG)
d2BG=rbind(s1d2BG, s2d2BG, s3d2BG,              s5d2BG, s6d2BG)#s4d2BG
d2IW=rbind(s1d2IW, s2d2IW,            s4d2IW, s5d2IW, s6d2IW)#s3d2IW
d2PV=rbind(s1d2PV, s2d2PV, s3d2PV, s4d2PV, s5d2PV, s6d2PV)
d3BG=rbind(s1d3BG, s2d3BG,            s4d3BG, s5d3BG, s6d3BG)#s3d3BG
d3IW=rbind(s1d3IW, s2d3IW, s3d3IW, s4d3IW, s5d3IW, s6d3IW)
d3PV=rbind(        s2d3PV, s3d3PV, s4d3PV, s5d3PV, s6d3PV)#s1d3PV
d4BG=rbind(s1d4BG, s2d4BG, s3d4BG, s4d4BG, s5d4BG, s6d4BG)
d4IW=rbind(s1d4IW, s2d4IW, s3d4IW,            s5d4IW, s6d4IW)#s4d4IW
d4PV=rbind(s1d4PV, s2d4PV, s3d4PV, s4d4PV, s5d4PV, s6d4PV)
```

```
save(d1BG, d2BG, d2PV, d2IW, d3BG, d3PV, d3IW, d4BG, d4PV, d4IW,
        file="wcrdepthveg.RData")
#Makes datasets holding depth and geo constant:
d1T=rbind(s1d1BG,s3d1BG,s6d1BG)
d1W=rbind(s2d1BG,s4d1BG,s5d1BG)
d2T=rbind(s1d2BG,s3d2BG,s6d2BG,s1d2PV,s3d2PV,s6d2PV,s1d2IW,
        s6d2IW)#s3d2IW
d2W=rbind(s2d2BG,
        s5d2BG,s2d2PV,s4d2PV,s5d2PV,s2d2IW,s4d2IW,s5d2IW)#s4d2BG,
d3T=rbind(s1d3BG,        s6d3BG,
s3d3PV,s6d3PV,s1d3IW,s3d3IW,s6d3IW)#s3d3BG,s1d3PV
d3W=rbind(s2d3BG,s4d3BG,s5d3BG,s2d3PV,s4d3PV,s5d3PV,s2d3IW,s4d3IW,s5d3IW)
d4T=rbind(s1d4BG,s3d4BG,s6d4BG,s1d4PV,s3d4PV,s6d4PV,s1d4IW,s3d4IW,s6d4IW)
d4W=rbind(s2d4BG,s4d4BG,s5d4BG,s2d4PV,s4d4PV,s5d4PV,s2d4IW,
        s5d4IW)#s4d4IW,
save(d1T, d1W, d2T, d2W, d3T, d3W, d4T, d4W,
        file="wcrdepthgeo.RData")
```
****

Soil Moisture Univariate, Bivariate, and Trivariate Analysis Code: this code is for analysis and plots of soil moisture and soil temperature.

Script_Summary by Probe_wcr.R

```
#Need to run these lines of code - up to the Hist QQ and CDF plots section before running any code in this script

setwd("C:\\Users\\showe\\YumaWash\\soilmoisture\\CURRENT3")
load("wcr.RData")
load("wcrdepth.RData")
source("Func_plots.R")
label=expression(paste(theta, "  ", "(", m^3/m^3, ")"))
wcrsummary=read.csv("wcrsummary.csv", header=T)
head(wcrsummary)

#HISTOGRAMS, QQ and CDF Plots
attach(wcr)
hist3by3(ECOV1_BG2.5,"ECOV1/BG2.5", MET1_BG2.5, "MET1/BG2.5", MET4_BG2.5, "MET4/BG2.5","Volumetric Water Content at 2.5cm beneath Bare Ground--Terrace Probes.png", label)
hist3by3(ECOV2_BG2.5, "ECOV2/BG2.5", MET2_BG2.5, "MET2/BG2.5", MET3_BG2.5, "MET3/BG2.5", "Volumetric Water Content at 2.5cm beneath Bare Ground--Wash Probes.png", label)
hist3by3(SF1_BG25, "SF1/BG25",SF3_BG25,"SF3/BG25", SF6_BG25,"SF6/BG25", "Volumetric Water Content at 25cm beneath Bare Ground--Terrace Probes.png", label)
hist3by3(SF1_PV25, "SF1/PV25",SF3_PV25,"SF3/PV25", SF6_PV25,"SF6/PV25", "Volumetric Water Content at 25cm beneath Parkinsonia microphylla--Terrace Probes.png", label)
```

```
hist3by3(SF1_IW25, "SF1/IW25",SF3_IW25,"SF3/IW25-Bad Probe", SF6_IW25,"SF6/IW25", "Volumetric Water Content at 25cm beneath Olneya tesota--Terrace Probes.png", label)
hist3by3(SF2_BG25, "SF2/BG25",SF4_BG25, "SF4/BG25-Bad Probe",SF5_BG25,"SF5/BG25","Volumetric Water Content at 25cm beneath Bare Ground--Wash Probes.png", label)
hist3by3(SF2_PV25, "SF2/PV25",SF4_PV25,"SF4/PV25", SF5_PV25,"SF5/PV25", "Volumetric Water Content at 25cm beneath Parkinsonia microphylla--Wash Probes.png", label)
hist3by3(SF2_IW25, "SF2/IW25",SF4_IW25,"SF4/IW25", SF5_IW25,"SF5/IW25", "Volumetric Water Content at 25cm beneath Olneya tesota--Wash Probes.png", label)
hist3by3(SF1_BG50, "SF1/BG50",SF3_BG50,"SF3/BG50-Bad Probe", SF6_BG50,"SF6/BG50", "Volumetric Water Content at 50cm beneath Bare Ground--Terrace Probes.png", label)
hist3by3(SF1_PV50, "SF1/PV50-Bad Probe",SF3_PV50,"SF3/PV50", SF6_PV50,"SF6/PV50", "Volumetric Water Content at 50cm beneath Parkinsonia microphylla--Terrace Probes.png", label)
hist3by3(SF1_IW50, "SF1/IW50",SF3_IW50,"SF3/IW50", SF6_IW50,"SF6/IW50", "Volumetric Water Content at 50cm beneath Olneya tesota--Terrace Probes.png", label)
hist3by3(SF2_BG50, "SF2/BG50",SF4_BG50,"SF4/BG50", SF5_BG50,"SF5/BG50", "Volumetric Water Content at 50cm beneath Bare Ground--Wash Probes.png", label)
hist3by3(SF2_PV50, "SF2/PV50",SF4_PV50,"SF4/PV50", SF5_PV50,"SF5/PV50", "Volumetric Water Content at 50cm beneath Parkinsonia microphylla--Wash Probes.png", label)
hist3by3(SF2_IW50, "SF2/IW50",SF4_IW50,"SF4/IW50", SF5_IW50,"SF5/IW50", "Volumetric Water Content at 50cm beneath Olneya tesota--Wash Probes.png", label)
hist3by3(SF1_BG100, "SF1/BG100",SF3_BG100,"SF3/BG100", SF6_BG100,"SF6/BG100", "Volumetric Water Content at 100cm beneath Bare Ground--Terrace Probes.png", label)
hist3by3(SF1_PV100, "SF1/PV100",SF3_PV100,"SF3/PV100", SF6_PV100,"SF6/PV100", "Volumetric Water Content at 100cm beneath Parkinsonia microphylla--Terrace Probes.png", label)
hist3by3(SF1_IW100, "SF1/IW100",SF3_IW100,"SF3/IW100", SF6_IW100,"SF6/IW100", "Volumetric Water Content at 100cm beneath Olneya tesota--Terrace Probes.png", label)
hist3by3(SF2_BG100, "SF2/BG100",SF4_BG100, "SF4/BG100-Bad Probe",SF5_BG100,"SF5/BG100", "Volumetric Water Content at 100cm beneath Bare Ground--Wash Probes.png", label)
hist3by3(SF2_PV100, "SF2/PV100",SF4_PV100, "SF4/PV100",SF5_PV100,"SF5/PV100", "Volumetric Water Content at 100cm beneath Parkinsonia microphylla--Wash Probes.png", label)
hist3by3(SF2_IW100, "SF2/IW100",SF4_IW100, "SF4/IW100-Bad Probe",SF5_IW100,"SF5/IW100", "Volumetric Water Content at 100cm beneath Olneya tesota--Wash Probes.png", label)

#BOXBLOT BY PROBE
dev.new()
png("Volumetric Water Content by Probe.png", width=2000, height=1200)
ymin=0
ymax=0.7
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=1.5, las=2)
```

```
boxplot(d1$soil~factor(d1$probe), ylab=label, ylim=range(ymin,ymax))
boxplot(d2$soil~factor(d2$probe), ylab=label, ylim=range(ymin,ymax))
boxplot(d3$soil~factor(d3$probe), ylab=label, ylim=range(ymin,ymax))
boxplot(d4$soil~factor(d4$probe), ylab=label, ylim=range(ymin,ymax))
title("Volumetric Water Content by Probe and by Depth", outer=TRUE)
dev.off()

#SCATTER PLOTS
#Creates new datasets without bad probes
wcrsummary.o=wcrsummary
wcrsummary.o1=wcrsummary.o[wcrsummary.o$X!="SF4_BG25",]
wcrsummary.o2=wcrsummary.o1[wcrsummary.o1$X!="SF3_IW25",]
wcrsummary.o3=wcrsummary.o2[wcrsummary.o2$X!="SF4_IW100",]
wcrsummary.o4=wcrsummary.o3[wcrsummary.o3$X!="SF1_PV50",]
wcrsummary.o5=wcrsummary.o4[wcrsummary.o4$X!="SF3_BG50",]
#wcrsummary.o6=wcrsummary.o5[wcrsummary.o5$X!="SF1_BG100",]

#If you want to see all bad probes from the plots below, replace wcrsummary.o6 with wcrsummary.o (or wcrsummary.o1 through wcrsummary.o4 to see just some of them) Make sure that when you do the replace you don't change the code above. or if you do, you change it back.

ymin=0
ymax=0.3
yCVmin=0
yCVmax=70
names(wcrsummary)
#To change to Means and CV or Gmeans and GCV simply change all titles and change
#the number in function to reflect appropriate column.
#6= median  15=CVR
#7= gmean   14=CV
#8= mean

#BY VEG
#medians and CVR
png("wcr Medians and CVR by veg.png", height=480, width=960)
par(mfrow=c(1,2))
scatterveg(wcrsummary.o6,6,label, ymin, ymax)
title("Volumetric Water Content: Medians by Cover")
scatterveg(wcrsummary.o6, 15, "CVR (%)", yCVmin, yCVmax)
legend(50, 55, legend=c(levels(factor(wcrsummary.o6$veg))),pch=c(16,2,3))
title("Volumetric Water Content: CVR by Cover")
dev.off()
#skewness and kurtosis
png("wcr Skew and Kurt by veg.png", height=480, width=960)
par(mfrow=c(1,2))
```

```
scatterveg(wcrsummary.o6, 16,"Standardized Skewness", min(wcrsummary.o6[,16]), max(wcrsummary.o6[,16]))
abline(h=c(2,-2), lty=2)
text(9,c(2,-2), c("extreme right skew", "extreme left skew"))
title("Volumetric Water Content: Skewness by Cover")
scatterveg(wcrsummary.o6, 17,"Standardized Kurtosis", min(wcrsummary.o6[,17]), max(wcrsummary.o6[,17]))
abline(h=c(2,-2), lty=2)
text(9,c(2,-2), c("extreme heavy tail", "extremely centered"))
legend(50, 24, legend=c(levels(factor(wcrsummary.o6$veg))),pch=c(16,2,3))
title("Volumetric Water Content: Kurtosis by Cover")
dev.off()
#For obs and NAN
png("wcr Obs and NaN by veg.png", height=480, width=960)
par(mfrow=c(1,2))
scatterveg(wcrsummary.o6,2,"# of Observations Used", min(wcrsummary.o6[,2]), max(wcrsummary.o6[,2]))
title("Volumetric Water Content: # Observations by Cover")
scatterveg(wcrsummary.o6, 3, "% Missing Values", min(wcrsummary.o6[,3]), max(wcrsummary.o6[,3]))
legend(45, 25, legend=c(levels(factor(wcrsummary.o6$veg))),pch=c(16,2,3))
title("Volumetric Water Content: %NaN by Cover")
dev.off()
#BY GEO
#medians and CVR
png("wcr Medians and CVR by geo.png", height=480, width=960)
par(mfrow=c(1,2))
scattergeo(wcrsummary.o6,6,label, ymin, ymax)
title("Volumetric Water Content: Medians by Geomorphic Surface")
scattergeo(wcrsummary.o6, 15, "CVR (%)", yCVmin,yCVmax)
legend(50, 55, legend=c(levels(factor(wcrsummary.o6$geo))),pch=c(16,2,3))
title("Volumetric Water Content: CVR by Geomorphic Surface")
dev.off()
#skewness and Kurtosis
png("wcr Skew and Kurt by geo.png", height=480, width=960)
par(mfrow=c(1,2))
scattergeo(wcrsummary.o6, 16,"Standardized Skewness", min(wcrsummary.o6[,16]), max(wcrsummary.o6[,16]))
abline(h=c(2,-2), lty=2)
text(9,c(2,-2), c("extreme right skew", "extreme left skew"))
title("Volumetric Water Content: Skewness by Geomorphic Surface")
scattergeo(wcrsummary.o6, 17,"Standardized Kurtosis", min(wcrsummary.o6[,17]), max(wcrsummary.o6[,17]))
abline(h=c(2,-2), lty=2)
text(9,c(2,-2), c("extreme heavy tail", "extremely centered"))
legend(50, 24, legend=c(levels(factor(wcrsummary.o6$geo))),pch=c(16,2,3))
```

```
title("Volumetric Water Content: Kurtosis by Geomorphic Surface")
dev.off()
#For obs and NAN
png("wcr Obs and NaN by geo.png", height=480, width=960)
par(mfrow=c(1,2))
scattergeo(wcrsummary.o6,2,"# of Observations Used",min(wcrsummary.o6[,2]),
max(wcrsummary.o6[,2]))
title("Volumetric Water Content: #Observations by Geomorphic Surface")
scattergeo(wcrsummary.o6, 3, "% Missing Values",min(wcrsummary.o6[,3]),
max(wcrsummary.o6[,3]))
legend(45, 25, legend=c(levels(factor(wcrsummary.o6$geo))),pch=c(16,2,3))
title("Volumetric Water Content: %NaN by Geomorphic Surface")
dev.off()
#FOR LOCATION
#medians and CVR
png("wcr Medians and CVR by location.png", height=480, width=960)
par(mfrow=c(1,2))
scatterloc(wcrsummary.o6,6,label, ymin, ymax)
title("Volumetric Water Content: Medians by Location")
scatterloc(wcrsummary.o6, 15, "CVR (%)", yCVmin,yCVmax)
legend(45, 55, legend=c(levels(factor(wcrsummary.o6$location))),pch=c(16,2,3))
title("Volumetric Water Content: CVR by Location")
dev.off()
#skewness and kurtosis
png("wcr Skew and Kurt by location.png", height=480, width=960)
par(mfrow=c(1,2))
scatterloc(wcrsummary.o6, 16,"Standardized Skewness", min(wcrsummary.o6[,16]),
max(wcrsummary.o6[,16]))
abline(h=c(2,-2), lty=2)
text(9,c(2,-2), c("extreme right skew", "extreme left skew"))
title("Volumetric Water Content: Skewness by Location")
scatterloc(wcrsummary.o6, 17,"Standardized Kurtosis", min(wcrsummary.o6[,17]),
max(wcrsummary.o6[,17]))
abline(h=c(2,-2), lty=2)
text(9,c(2,-2), c("extreme heavy tail", "extremely centered"))
legend(50, 24, legend=c(levels(factor(wcrsummary.o6$location))),pch=c(16,2,3))
title("Volumetric Water Content: Kurtosis by Location")
dev.off()
#For obs and NAN
png("wcr Obs and NaN by location.png", height=480, width=960)
par(mfrow=c(1,2))
scatterloc(wcrsummary.o6,2,"# of Observations Used", min(wcrsummary.o6[,2]),
max(wcrsummary.o6[,2]))
title("Volumetric Water Content: # Observations by Location")
scatterloc(wcrsummary.o6, 3, "% Missing Values", min(wcrsummary.o6[,3]),
max(wcrsummary.o6[,3]))
```

```
legend(45, 25, legend=c(levels(factor(wcrsummary.o6$location))),pch=c(16,2,3))
title("Volumetric Water Content: %NaN by Location")
```
****

Script_Summary by Factor_wcr.R

```
#Need to run these lines of code - up to Hist QQ CDF plot section before running any Factor code in this script
setwd("C:\\Users\\showe\\YumaWash\\soilmoisture\\CURRENT3")
load("wcrdepth.RData") #bad probes are now eliminated from this RData file; DataRead file creates dataset by omitting bad probes
source("Func_plots.R")

label=expression(paste(theta, "  ", "(", m^3/m^3, ")"))
wcrfsummary=read.csv("wcrfsummary.csv", header=T)
head(wcrfsummary)
#Hist QQ CDF by Factor
#FOR VEG
png("wcr 2.5cm Hist CDF QQ by Veg.png", height=700,width=580)
par(mfrow=c(3,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(d1,6,"BG",label, "BG: Histogram")
title("Volumetric Water Content at 2.5cm by Cover", outer=TRUE)
dev.off()
png("wcr 25cm Hist CDF QQ by Veg.png", height=700,width=580)
par(mfrow=c(3,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(d2,6,"BG",label, "BG: Histogram")
hist3factor(d2,6,"IW",label, "IW: Histogram")
hist3factor(d2,6,"PV",label, "PV: Histogram")
title("Volumetric Water Content at 25cm by Cover", outer=TRUE)
dev.off()
png("wcr 50cm Hist CDF QQ by Veg.png", height=700,width=580)
par(mfrow=c(3,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(d3,6,"BG",label, "BG: Histogram")
hist3factor(d3,6,"IW",label, "IW: Histogram")
hist3factor(d3,6,"PV",label, "PV: Histogram")
title("Volumetric Water Content at 50cm by Cover", outer=TRUE)
dev.off()
png("wcr 100cm Hist CDF QQ by Veg.png", height=700,width=580)
par(mfrow=c(3,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(d4,6,"BG",label, "BG: Histogram")
hist3factor(d4,6,"IW",label, "IW: Histogram")
hist3factor(d4,6,"PV",label, "PV: Histogram")
title("Volumetric Water Content at 100cm by Cover", outer=TRUE)
dev.off()
#FOR LOCATION
png("wcr 2.5cm Hist CDF QQ by Loc.png", height=700,width=580)
par(mfrow=c(3,3), oma=c(0,0,2,0), cex=0.7)
```

```
hist3factor(d1,3,"Lower",label, "Lower: Histogram")
hist3factor(d1,3,"Middle",label, "Middle: Histogram")
hist3factor(d1,3,"Upper",label, "Upper: Histogram")
title("Volumetric Water Content at 2.5cm by Location", outer=TRUE)
dev.off()
png("wcr 25cm Hist CDF QQ by Loc.png", height=700,width=580)
par(mfrow=c(3,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(d2,3,"Lower",label, "Lower: Histogram")
hist3factor(d2,3,"Middle",label, "Middle: Histogram")
hist3factor(d2,3,"Upper",label, "Upper: Histogram")
title("Volumetric Water Content at 25cm by Location", outer=TRUE)
dev.off()
png("wcr 50cm Hist CDF QQ by Loc.png", height=700,width=580)
par(mfrow=c(3,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(d3,3,"Lower",label, "Lower: Histogram")
hist3factor(d3,3,"Middle",label, "Middle: Histogram")
hist3factor(d3,3,"Upper",label, "Upper: Histogram")
title("Volumetric Water Content at 50cm by Location", outer=TRUE)
dev.off()
png("wcr 100cm Hist CDF QQ by Loc.png", height=700,width=580)
par(mfrow=c(3,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(d4,3,"Lower",label, "Lower: Histogram")
hist3factor(d4,3,"Middle",label, "Middle: Histogram")
hist3factor(d4,3,"Upper",label, "Upper: Histogram")
title("Volumetric Water Content at 100cm by Location", outer=TRUE)
dev.off()
#FOR GEOMORPHIC SURFACE
png("wcr 2.5cm Hist CDF QQ by Geo.png", height=700,width=580)
par(mfrow=c(2,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(d1,7,"Terrace",label, "Terrace: Histogram")
hist3factor(d1,7,"Wash",label, "Wash: Histogram")
title("Volumetric Water Content at 2.5cm by Geomorphic Surface", outer=TRUE)
dev.off()
png("wcr 25cm Hist CDF QQ by Geo.png", height=700,width=580)
par(mfrow=c(2,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(d2,7,"Terrace",label, "Terrace: Histogram")
hist3factor(d2,7,"Wash",label, "Wash: Histogram")
title("Volumetric Water Content at 25cm by Geomorphic Surface", outer=TRUE)
dev.off()
png("wcr 50cm Hist CDF QQ by Geo.png", height=700,width=580)
par(mfrow=c(2,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(d3,7,"Terrace",label, "Terrace: Histogram")
hist3factor(d3,7,"Wash",label, "Wash: Histogram")
title("Volumetric Water Content at 50cm by Geomorphic Surface", outer=TRUE)
dev.off()
png("wcr 100cm Hist CDF QQ by Geo.png", height=700,width=580)
```

```
par(mfrow=c(2,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(d4,7,"Terrace",label, "Terrace: Histogram")
hist3factor(d4,7,"Wash",label, "Wash: Histogram")
title("Volumetric Water Content at 100cm by Geomorphic Surface", outer=TRUE)
dev.off()
#BOXPLOTS BY FACTORS
ymin=0
ymax=0.6
dev.new()
png("wcr 2.5cm Boxplots by Factor.png", width=620, height=750)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7, las=0)
boxplot(d1$soil~factor(d1$seas), ylab=label, ylim=range(ymin,ymax),  ylim=range(ymin,ymax))
boxplot(d1$soil~factor(d1$location), ylim=range(ymin,ymax))
boxplot(d1$soil~factor(d1$veg), xlab="BG", ylab=label, ylim=range(ymin,ymax), ylim=range(ymin,ymax))
boxplot(d1$soil~factor(d1$geo), ylim=range(ymin,ymax))
title("Volumetric Water Content at 2.5cm by Factor", outer=TRUE)
dev.off()
png("wcr 25cm Boxplots by Factor.png", width=620, height=750)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7, las=0)
boxplot(d2$soil~factor(d2$seas), ylab=label, ylim=range(ymin,ymax))
boxplot(d2$soil~factor(d2$location), ylim=range(ymin,ymax))
boxplot(d2$soil~factor(d2$veg), ylab=label, ylim=range(ymin,ymax))
boxplot(d2$soil~factor(d2$geo), ylim=range(ymin,ymax))
title("Volumetric Water Content at 25cm by Factor", outer=TRUE)
dev.off()
png("wcr 50cm Boxplots by Factor.png", width=620, height=750)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7, las=0)
boxplot(d3$soil~factor(d3$seas), ylab=label, ylim=range(ymin,ymax))
boxplot(d3$soil~factor(d3$location), ylim=range(ymin,ymax))
boxplot(d3$soil~factor(d3$veg), ylab=label, ylim=range(ymin,ymax))
boxplot(d3$soil~factor(d3$geo), ylim=range(ymin,ymax))
title("Volumetric Water Content at 50cm by Factor", outer=TRUE)
dev.off()
png("wcr 100cm Boxplots by Factor.png", width=620, height=750)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7, las=0)
boxplot(d4$soil~factor(d4$seas), ylab=label, ylim=range(ymin,ymax))
boxplot(d4$soil~factor(d4$location), ylim=range(ymin,ymax))
boxplot(d4$soil~factor(d4$veg), ylab=label, ylim=range(ymin,ymax))
boxplot(d4$soil~factor(d4$geo), ylim=range(ymin,ymax))
title("Volumetric Water Content at 100cm by Factor", outer=TRUE)
dev.off()
png("wcr Boxplots by Season All Depths.png", width=620, height=750)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7, las=0)
boxplot(d1$soil~factor(d1$seas), ylab=label, ylim=range(0,0.6), xlab="2.5cm")
boxplot(d2$soil~factor(d2$seas), ylab=label, ylim=range(0,0.6),xlab="25cm" )
```

```
boxplot(d3$soil~factor(d3$seas), ylab=label, ylim=range(0,0.6), xlab="50cm")
boxplot(d4$soil~factor(d4$seas), ylab=label, ylim=range(0,0.6),xlab="100cm")
title("Volumetric Water Content by Season and by Depth", outer=TRUE)
dev.off()
png("wcr Boxplots by Location All Depths.png", width=620, height=750)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7, las=0)
boxplot(d1$soil~factor(d1$location), ylab=label, ylim=range(0,0.6), xlab="2.5cm")
boxplot(d2$soil~factor(d2$location), ylab=label, ylim=range(0,0.6),xlab="25cm" )
boxplot(d3$soil~factor(d3$location), ylab=label, ylim=range(0,0.6), xlab="50cm")
boxplot(d4$soil~factor(d4$location), ylab=label, ylim=range(0,0.6),xlab="100cm")
title("Volumetric Water Content by Location and by Depth", outer=TRUE)
dev.off()
png("wcr Boxplots by Vegetation All Depths.png", width=620, height=750)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7, las=0)
boxplot(d1$soil, xlab="2.5 cm", ylab=label, ylim=range(0,0.6))
axis(1,at=1,labels="BG")#these prior two lines of code is to get both BG and 2.5cm on the x-axis as separate labels with BG above 2.5cm
#boxplot(d1$soil~factor(d1$veg), ylab=label, ylim=range(0,0.6), xlab="BG 2.5cm")
boxplot(d2$soil~factor(d2$veg), ylab=label, ylim=range(0,0.6),xlab="25cm" )
boxplot(d3$soil~factor(d3$veg), ylab=label, ylim=range(0,0.6), xlab="50cm")
boxplot(d4$soil~factor(d4$veg), ylab=label, ylim=range(0,0.6),xlab="100cm")
title("Volumetric Water Content by Cover and by Depth", outer=TRUE)
dev.off()
png("wcr Boxplots by Geomorphic Surface All Depths.png", width=620, height=750)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7, las=0)
boxplot(d1$soil~factor(d1$geo), ylab=label, ylim=range(0,0.6), xlab="2.5cm")
boxplot(d2$soil~factor(d2$geo), ylab=label, ylim=range(0,0.6),xlab="25cm" )
boxplot(d3$soil~factor(d3$geo), ylab=label, ylim=range(0,0.6), xlab="50cm")
boxplot(d4$soil~factor(d4$geo), ylab=label, ylim=range(0,0.6),xlab="100cm")
title("Volumetric Water Content by Geomorphic Surface and by Depth", outer=TRUE)
dev.off()
#Boxplots by Station
png("wcr Boxplots by Station for all depths.png", width=700, height=375)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7, las=2)
boxplot(d1$soil~factor(d1$stn), ylab=label, ylim=range(ymin,ymax), xlab="2.5cm", ylim=range(0,0.6))
boxplot(d2$soil~factor(d2$stn), ylab=label, ylim=range(ymin,ymax), xlab="25cm", ylim=range(0,0.6))
boxplot(d3$soil~factor(d3$stn), ylab=label, ylim=range(ymin,ymax), xlab="50cm", ylim=range(0,0.6))
boxplot(d4$soil~factor(d4$stn), ylab=label, ylim=range(ymin,ymax), xlab="100cm", ylim=range(0,0.6))
title("Volumetric Water Content by Station and by Depth", outer=TRUE)
dev.off()
#pooled data from each depth, Boxplot by depth- all data
png("wcr Boxplots by Depth.png", height=375, width=310)
```

```
par(mfrow=c(1,1), oma=c(0,0,2,0), cex=0.7, las=0)
boxplot(d1$soil, d2$soil, d3$soil, d4$soil, names=c("2.5cm", "25cm", "50cm", "100cm"),
ylab=label, ylim=range(ymin,ymax))
title("Volumetric Water Content by Depth",outer=TRUE)
dev.off()
#SCATTERPLOTS BY FACTOR
names(wcrfsummary)
#you can set the ymin and max to be whatever you want.  In the code below it is by default se to
the below code for min or max

xmin=1  #sets the lower bound for the x data to include
        #1=start of station data (1-6)
        #7=start location (7-9)
        #10=start veg (10-12)
        #13=start of geo (13-14)
        #15=start Season (15-18)
xmax=14 #set the upper bound for the x data to include
        # xmax=14 to not include seasonal data, xmax=18 to include
#These mins and maxs only set it for the centrality stats (ex median/CVR mean/CV, gmean/GCV
ymin=0 #min(wcrfsummary[,stat]) stat refers to the column number of the stat you are interested
in ymax=0.25 #max(wcrfsummary[,stat]) stat refers to the column number of the stat you are
interested in
yCVmin=10
yCVmax=80
names(wcrfsummary)
#To change to Means and CV or Gmeans and GCV simply change all titles and
#change the number in function to reflect appropriate column.
#7=median
#8=gmean
#9=mean
#15=CV
#16=CVR
#20=GCV
#Median and CVR
png("wcr Medians and CVR by factor.png", height=480, width=960)
par(mfrow=c(1,2))
scatterbyf(wcrfsummary, 7, label, xmin, xmax, ymin,ymax)
legend(8, ymax, legend=c("2.5cm", "25cm", "50cm", "100cm"),pch=c(1,2,3,4))
title("wcr Medians by Factor")
scatterbyf(wcrfsummary, 16 ,"CVR (%)",xmin, xmax, yCVmin, yCVmax)
title("Volumetric Water Content: CVR by Factor")
dev.off()
#skew and Kurt
png("wcr Skew and Kurt by factor.png", height=480, width=960)
par(mfrow=c(1,2))
```

```
scatterbyf(wcrfsummary, 17,"Standardized Skewness", xmin, xmax, min(wcrfsummary[xmin:xmax,17]), max(wcrfsummary[xmin:xmax,17]))
abline(h=c(2,-2), lty=2)
text(3,c(2,-2), c("extreme right skew", "extreme left skew"))
title("Volumetric Water Content: Skewness by Factor")
scatterbyf(wcrfsummary, 18 ,"Standardized Kurtosis", xmin, xmax, min(wcrfsummary[xmin:xmax,18]), max(wcrfsummary[xmin:xmax,18]))
abline(h=c(2,-2), lty=2)
text(3,c(2,-2), c("extreme heavy tail", "extremely centered"))
legend(10, 12, legend=c("2.5cm", "25cm", "50cm", "100cm"),pch=c(1,2,3,4))
title("Volumetric Water Content: Kurtosis by Factor")
dev.off()
#NA and Observations
png("wcr Obs and NaN by factor.png", height=480, width=960)
par(mfrow=c(1,2))
scatterbyf(wcrfsummary, 3,"# of Observations", xmin, xmax, min(wcrfsummary[,3]), max(wcrfsummary[,3]))
legend(2, max(wcrfsummary[,3]), legend=c("2.5cm", "25cm", "50cm", "100cm"),pch=c(1,2,3,4))
title("Volumetric Water Content: #Obs by Factor")
scatterbyf(wcrfsummary, 4 ,"% Missing Values",xmin, xmax, min(wcrfsummary[,4]), max(wcrfsummary[,4]))
title("Volumetric Water Content: %NaN by Factor")
dev.off()
```

Script_Summary by Season_wcr_tc.R

```
#Need to run these lines of code - up to the summary by factory section before running any Factor code in this script
setwd("C:\\Users\\showe\\YumaWash\\soilmoisture\\CURRENT3")
source("Func_plots.R")
library(stringr)
#TO RUN WCR DATA
load("wcr.RData")
load("wcrdepth.RData")
seasyrfile="wcrfSsummary.csv"
seasfile="wcrfSeassummary.csv"
yrfile="wcrfyrsummary.csv"
label=expression(paste(theta, "  ", "(", m^3/m^3, ")"))
datalabel="wcr"
datatitle="Volumetric Water Content"
#TO RUN TC DATA
load("tc.RData")
load("tcdepth.RData")
seasyrfile="tcfSsummary.csv"
seasfile="tcfSeassummary.csv"
yrfile="tcfyrsummary.csv"
```

```
label=expression(paste("soil temp"," ","(",degree,C,")"))
datalabel="tc"
datatitle="Temperature"
#TO RUN PRECIP DATA---IGNORE; PPT RUN IN SEPARATE CODE ALTOGETHER
#load("ppt.RData")
#seasyrfile="pptfsyrsummary.csv"
#seasfile="pptfseassummary.csv"
#yrfile="pptfyrsummary.csv"
#label=expression(paste("precipitation", " ", " (",mm,")"))
#datalable="ppt"
#datatitle="Daily Precipitation Totals"
#RUN THIS NEXT
seasyrsummary=read.csv(seasyrfile, header=T)
seasyrsummary$X=factor(c("Su06", "Fa06", "Wi06-07", "Sp07", "Su07", "Fa07", "Wi07-
08","Sp08", "Su08", "Fa08", "Wi08-09", "Sp09", "Su09", "Fa09", "Wi09-10"))
head(seasyrsummary)
seassummary=read.csv(seasfile, header=T)
seassummary$X=factor(c("Summer", "Fall", "Winter", "Spring"))
head(seassummary)
yrsummary=read.csv(yrfile, header=T)
yrsummary$X=factor(c("2006", "2007", "2008", "2009", "2010"))
head(yrsummary)

#Hist QQ CDF BY SEASONS
png(str_c(datalabel,"_", "2.5cm Hist CDF by Seas.png"), height=900,width=580)
par(mfrow=c(4,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(d1,8,"Summer",label, "Summer: Histogram")
hist3factor(d1,8,"Fall",label, "Fall: Histogram")
hist3factor(d1,8,"Winter",label, "Winter: Histogram")
hist3factor(d1,8,"Spring",label, "Spring: Histogram")
title(str_c(datatitle, "at 2.5cm by Season", sep=" "), outer=TRUE)
dev.off()
png(str_c(datalabel, "_", "25cm Hist CDF by Seas.png"), height=900,width=580)
par(mfrow=c(4,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(d2,8,"Summer",label, "Summer: Histogram")
hist3factor(d2,8,"Fall",label, "Fall: Histogram")
hist3factor(d2,8,"Winter",label, "Winter: Histogram")
hist3factor(d2,8,"Spring",label, "Spring: Histogram")
title(str_c(datatitle, "at 25cm by Season", sep=" "), outer=TRUE)
dev.off()
png(str_c(datalabel,"_", "50cm Hist CDF by Seas.png"), height=900,width=580)
par(mfrow=c(4,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(d3,8,"Summer",label, "Summer: Histogram")
hist3factor(d3,8,"Fall",label, "Fall: Histogram")
hist3factor(d3,8,"Winter",label, "Winter: Histogram")
hist3factor(d3,8,"Spring",label, "Spring: Histogram")
```

```
title(str_c(datatitle, "at 50cm by Season", sep=" "), outer=TRUE)
dev.off()
png(str_c(datalabel,"_", "100cm Hist CDF by Seas.png"), height=900,width=580)
par(mfrow=c(4,3), oma=c(0,0,2,0), cex=0.7)
hist3factor(d4,8,"Summer",label, "Summer: Histogram")
hist3factor(d4,8,"Fall",label, "Fall: Histogram")
hist3factor(d4,8,"Winter",label, "Winter: Histogram")
hist3factor(d4,8,"Spring",label, "Spring: Histogram")
title(str_c(datatitle, "at 100cm by Season", sep=" "), outer=TRUE)
dev.off()
#BOXPLOTS BY SEASON AND YEAR
#for wcr
ymin=0
ymax=0.6
#for tc
ymin=0
ymax=70
png(str_c(datalabel, "_", "Boxplots by season.png"), width=900, height=900)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7)
boxplot(d1$soil~factor(d1$seas), ylim=range(ymin,ymax), ylab=label,
col=(c("grey100","grey70", "grey51" ,"grey90")))
title("2.5cm")
boxplot(d2$soil~factor(d2$seas), ylim=range(ymin,ymax),ylab=label,
col=(c("grey100","grey70", "grey51" ,"grey90")))
title("25cm")
boxplot(d3$soil~factor(d3$seas), ylim=range(ymin,ymax), ylab=label,
col=(c("grey100","grey70", "grey51" ,"grey90")))
title("50cm")
boxplot(d4$soil~factor(d4$seas), ylim=range(ymin,ymax), ylab=label,
col=(c("grey100","grey70", "grey51" ,"grey90")))
title("100cm")
title(str_c(datatitle, "by Depth and by Season", sep=" "), outer=TRUE)
dev.off()
#WITHOUT COLOR IN BOXES
png(str_c(datalabel, "_", "Boxplots by season.png"), width=900, height=900)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7)
boxplot(d1$soil~factor(d1$seas), ylim=range(ymin,ymax), ylab=label)
title("2.5cm")
boxplot(d2$soil~factor(d2$seas), ylim=range(ymin,ymax),ylab=label)
title("25cm")
boxplot(d3$soil~factor(d3$seas), ylim=range(ymin,ymax), ylab=label)
title("50cm")
boxplot(d4$soil~factor(d4$seas), ylim=range(ymin,ymax), ylab=label)
title("100cm")
title(str_c(datatitle, "by Depth and by Season", sep=" "), outer=TRUE)
dev.off()
```

```
png(str_c(datalabel,"_", "Boxplots by season through time.png"), width=1500, height=900)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=1.5, las=2)
boxplot(d1$soil~factor(d1$seasyr), ylim=range(ymin,ymax), ylab=label,
col=(c("grey100","grey70", "grey51" ,"grey90")))
title("2.5cm")
boxplot(d2$soil~factor(d2$seasyr), ylim=range(ymin,ymax),ylab=label,
col=(c("grey100","grey70", "grey51" ,"grey90")))
title("25cm")
boxplot(d3$soil~factor(d3$seasyr), ylim=range(ymin,ymax), ylab=label,
col=(c("grey100","grey70", "grey51" ,"grey90")))
title("50cm")
boxplot(d4$soil~factor(d4$seasyr), ylim=range(ymin,ymax), ylab=label,
col=(c("grey100","grey70", "grey51" ,"grey90")))
title("100cm")
title(str_c(datatitle, " by Depth and by Season/Year ", sep=" "), outer=TRUE)
dev.off()
png(str_c(datalabel,"_" ,"Boxplots by year.png"), width=1500, height=900)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=1.5, las=2)
boxplot(d1$soil~factor(d1$yr), ylim=range(ymin,ymax), ylab=label, col=(c("grey100","grey70",
"grey51" ,"grey90")))
title("2.5cm")
boxplot(d2$soil~factor(d2$yr),  ylim=range(ymin,ymax),ylab=label,  col=(c("grey100","grey70",
"grey51" ,"grey90")))
title("25cm")
boxplot(d3$soil~factor(d3$yr), ylim=range(ymin,ymax), ylab=label, col=(c("grey100","grey70",
"grey51" ,"grey90")))
title("50cm")
boxplot(d4$soil~factor(d4$yr), ylim=range(ymin,ymax), ylab=label, col=(c("grey100","grey70",
"grey51" ,"grey90")))
title("100cm")
title(str_c(datatitle, " by Depth and by Year ", sep=" "), outer=TRUE)
dev.off()
#By season by geo
pick your depth
d=d4 #or d2 or d3 or d4
dlabel="100 cm"
png(str_c(datalabel,"_" ,dlabel,"Boxplots by season by geo.png"), width=1500, height=900)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7, las=2)
dSu=d[d$seas=="Summer",]
dFa=d[d$seas=="Fall",]
dWi=d[d$seas=="Winter",]
dSp=d[d$seas=="Spring",]
boxplot(dSu$soil~factor(dSu$geo), ylim=range(ymin,ymax), ylab=label)
title("Summer")
boxplot(dFa$soil~factor(dFa$geo), ylim=range(ymin,ymax),ylab=label)
title("Fall")
```

```
boxplot(dWi$soil~factor(dWi$geo), ylim=range(ymin,ymax), ylab=label)
title("Winter")
boxplot(dSp$soil~factor(dSp$geo), ylim=range(ymin,ymax), ylab=label)
title("Spring")
title(str_c(datatitle, " by Depth Geomorphic Surface and Season at ", dlabel, sep=" "),
outer=TRUE)
dev.off()

png(str_c(datalabel,"_" ,dlabel, "Boxplots by geo by season.png"), width=1500, height=450)
par(mfrow=c(1,2), oma=c(0,0,2,0), cex=0.7, las=1)
dT=d[d$geo=="Terrace",]
dW=d[d$geo=="Wash",]
boxplot(dT$soil~factor(dT$seas), ylim=range(ymin,ymax), ylab=label)
title("Terrace")
boxplot(dW$soil~factor(dW$seas), ylim=range(ymin,ymax),ylab=label)
title("Wash")
#Barplots by Season by Factor
source("Func_2waytables.R")
ls()
names(seasyrsummary)
names(yrsummary)
names(seassummary)
#6=Median
#7=GMean
#8=Mean
#these two function creates the data sets listed below.  The first argument is
#one #of the three datasets listed above and second argument is the column of
#the statistic you want to run; make sure you that no other data is attached
#detach()
#run as many times until you get an error message
#if you are just interested in SEASON by geo, veg, location run this section
attach(twoway.seas(seassummary,6)) #6 refers to medians, change to 8 for means
        #makes these two way tables:
                #seas.g1, seas.g2, seas.g3, seas.g4,  Seas-Geo
                #seas.v1, seas.v2, seas.v3, seas.v4,  Seas-Veg
                #seas.l1, seas.l2, seas.l3, seas.l4,  Seas-Loc
                #seas.s1, seas.s2, seas.s3, seas.s4,  Seas-Stn
#if you are interested in YEAR by geo veg location or stn
attach(twoway.yr(yrsummary,6))
        #makes these two way tables:
                #yr.g1, yr.g2, yr.g3, yr.g4, Year-Geo
                #yr.v1, yr.v2, yr.v3, yr.v4, Year-Veg
                #yr.l1, yr.l2, yr.l3, yr.l4, Year-Loc
                #yr.s1, yr.s2, yr.s3, yr.s4, Year-Stn
#if you are interested in SEAS-YR by geo veg location or stn
attach(twoway.syr(seasyrsummary,6))
```

```
	#makes these two way tables:
		#syr.g1, syr.g2, syr.g3, syr.g4,		Seasyr-Geo
		#syr.v1, syr.v2, syr.v3, syr.v4,		Seasyr-Veg
		#syr.l1, syr.l2, syr.l3, syr.l4,	Seasyr-Loc
		#syr.s1, syr.s2, syr.s3, syr.s4,	Seasyr-Stn

#Choose data from above based on what you want to see.
Factorlabel="Year and by Geomorphic Surface"
statlabel="Median"
data1=yr.g1
data2=yr.g2
data3=yr.g3
data4=yr.g4
#for wcr
ymin=0
ymax=0.25
dev.new()
#for tc
ymin=0
ymax=60
png(str_c(statlabel, datalabel, "_Barplots", Factorlabel, ".png"), width=800, height=800)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=1)
barplot(data1, las=2,beside=T, ylim=range(ymin,ymax), ylab=label,
	main="2.5 cm",
	legend.text=rownames(data1), args.legend=list(horiz=T))
barplot(data2, las=2,beside=T, ylim=range(ymin,ymax), ylab=label,
	main="25 cm",
	legend.text=rownames(data2), args.legend=list(horiz=T))
barplot(data3, las=2, beside=T, ylim=range(ymin,ymax), ylab=label,
	main="50 cm",
	legend.text=rownames(data3), args.legend=list(horiz=T))
barplot(data4, las=2,beside=T, ylim=range(ymin,ymax), ylab=label,
	main="100 cm",
	legend.text=rownames(data4), args.legend=list(horiz=T))
title(str_c(statlabel,datatitle, "by", Factorlabel, sep= " "), outer=T)
dev.off()
#LINEPLOTS COMPARING FACTORS Through TIME
#To change between Medians, Means and Gmeans simply change all titles and
#change the stat number to reflect the appropriate statistic.
#6=median
#7=gmean
#8=mean
names(seasyrsummary) #lists the column names in the summary stats if you
#want to plot ANY of the statistics through time.
statlabel="Mean"
stat=8  #Is the column number for the statistic you want to run (see note above)
```

```
#for wcr
ymin=0.02 #min(data[,stat], na.rm=T) will make the min the min of the data
ymax=0.35 #min(data[,stat], na.rm=T) will make the max the max of the data
#for tc
ymin=0
ymax=60
png(str_c(datalabel,"_", statlabel,"_","locationthroughtime.png"), height=900,width=1200)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7, las=2)
seasbyloc(seasyrsummary, stat, 1, 15, ymin, ymax, label, "2.5cm")
seasbyloc(seasyrsummary, stat, 16, 30, ymin, ymax, label, "25cm")
seasbyloc(seasyrsummary, stat, 31, 45, ymin, ymax, label, "50cm")
seasbyloc(seasyrsummary, stat, 46, 60, ymin, ymax, label, "100cm")
title(str_c("Seasonal", statlabel,datatitle, "by Depth and by Location",
        sep=" "), outer=T)
dev.off()
png("str_c(datalabel,"_", statlabel,"_","vegthroughtime.png"), height=1000,width=1000)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7,las=2)
seasbyveg2.5(seasyrsummary, stat, 1, 15, ymin, ymax, label, "2.5cm")
seasbyveg(seasyrsummary, stat, 1, 15, 16, 30, ymin, ymax, label, "25cm")
seasbyveg(seasyrsummary, stat, 16, 30, 31, 45, ymin, ymax, label, "50cm")
seasbyveg(seasyrsummary, stat, 31, 45, 46, 60, ymin, ymax, label, "100cm")
title(str_c("Seasonal", statlabel,datatitle, "by Depth and by Cover",
        sep=" "), outer=T)
dev.off()
png("str_c(datalabel,"_", statlabel,"_","geothroughtime.png"), height=1000,width=1000)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7,las=2)
seasbygeo(seasyrsummary, stat, 1, 15, ymin, ymax, label, "2.5cm")
seasbygeo(seasyrsummary, stat, 16, 30, ymin, ymax, label, "25cm")
seasbygeo(seasyrsummary, stat, 31, 45, ymin, ymax, label, "50cm")
seasbygeo(seasyrsummary, stat, 46, 60, ymin, ymax, label, "100cm")
title(str_c("Seasonal", statlabel,datatitle, "by Depth and by Geomorphic
        Surface",sep=" "), outer=T)
dev.off()
png(str_c(datalabel,"_", statlabel,"_","stationthroughtime.png"), height=1000,width=1000)
par(mfrow=c(2,2), oma=c(0,0,2,0), cex=0.7,las=2)
seasbystn(seasyrsummary,stat, 1, 15,ymin, ymax, label, "2.5cm", "ECOV1","ECOV2", "MET1",
"MET2", "MET3", "MET4")
seasbystn(seasyrsummary,stat, 1, 15,ymin, ymax, label, "25cm", "SF1","SF2", "SF3", "SF4",
"SF5", "SF6")
seasbystn(seasyrsummary,stat, 16, 30,ymin, ymax, label, "50cm", "SF1","SF2", "SF3", "SF4",
"SF5", "SF6")
seasbystn(seasyrsummary,stat, 31, 45,ymin, ymax, label, "100cm", "SF1","SF2", "SF3", "SF4",
"SF5", "SF6")
title(str_c("Seasonal", statlabel,datatitle, "by Depth and by Station",
        sep=" "), outer=T)
dev.off()
```

Script_Triv_Summary_Tables.R

```
#This code makes the summary tables for Tri-Variate Pooling.  Bad probes
omitted in Data Read.

setwd("C:\\Users\\showe\\YumaWash\\soilmoisture\\CURRENT3")
load("wcrdepthloc.RData")
load("wcrdepthveg.RData")
load("wcrdepthgeo.RData")
#load("tcdepthgeo.RData")
#load("tcdepthveg.RData")
#load("tcdepthloc.RData")
source("Func_sumtables.R")
#Makes datasets holding depth and location constant
d1Lveg=yuma.f2summary(d1L$soil, d1L$veg, 2.5, "L")
d1Mveg=yuma.f2summary(d1M$soil, d1M$veg, 2.5, "M")
d1Uveg=yuma.f2summary(d1U$soil, d1U$veg, 2.5, "U")
d2Lveg=yuma.f2summary(d2L$soil, d2L$veg, 25, "L")
d2Mveg=yuma.f2summary(d2M$soil, d2M$veg, 25, "M")
d2Uveg=yuma.f2summary(d2U$soil, d2U$veg, 25, "U")
d3Lveg=yuma.f2summary(d3L$soil, d3L$veg, 50, "L")
d3Mveg=yuma.f2summary(d3M$soil, d3M$veg, 50, "M")
d3Uveg=yuma.f2summary(d3U$soil, d3U$veg, 50, "U")
d4Lveg=yuma.f2summary(d4L$soil, d4L$veg, 100, "L")
d4Mveg=yuma.f2summary(d4M$soil, d4M$veg, 100, "M")
d4Uveg=yuma.f2summary(d4U$soil, d4U$veg, 100, "U")
d1Lgeo=yuma.f2summary(d1L$soil, d1L$geo, 2.5, "L")
d1Mgeo=yuma.f2summary(d1M$soil, d1M$geo, 2.5, "M")
d1Ugeo=yuma.f2summary(d1U$soil, d1U$geo, 2.5, "U")
d2Lgeo=yuma.f2summary(d2L$soil, d2L$geo, 25, "L")
d2Mgeo=yuma.f2summary(d2M$soil, d2M$geo, 25, "M")
d2Ugeo=yuma.f2summary(d2U$soil, d2U$geo, 25, "U")
d3Lgeo=yuma.f2summary(d3L$soil, d3L$geo, 50, "L")
d3Mgeo=yuma.f2summary(d3M$soil, d3M$geo, 50, "M")
d3Ugeo=yuma.f2summary(d3U$soil, d3U$geo, 50, "U")
d4Lgeo=yuma.f2summary(d4L$soil, d4L$geo, 100, "L")
d4Mgeo=yuma.f2summary(d4M$soil, d4M$geo, 100, "M")
d4Ugeo=yuma.f2summary(d4U$soil, d4U$geo, 100, "U")
summary1=rbind(d1Lveg, d1Mveg, d1Uveg,d2Lveg, d2Mveg, d2Uveg, d3Lveg, d3Mveg,
d3Uveg, d4Lveg, d4Mveg, d4Uveg,
d1Lgeo, d1Mgeo, d1Ugeo,d2Lgeo, d2Mgeo, d2Ugeo, d3Lgeo, d3Mgeo, d3Ugeo, d4Lgeo,
d4Mgeo, d4Ugeo)
summary1$F3=c(rep("BG",3),rep(c("BG", "IW", "PV"), 9), rep(c("Terrace", "Wash"), 12))
#Makes datasets holding depth and veg constant
d1BGloc=yuma.f2summary(d1BG$soil, d1BG$loc, 2.5, "BG")
d2BGloc=yuma.f2summary(d2BG$soil, d2BG$loc, 25, "BG")
d2IWloc=yuma.f2summary(d2IW$soil, d2IW$loc, 25, "IW")
```

```
d2PVloc=yuma.f2summary(d2PV$soil, d2PV$loc, 25, "PV")
d3BGloc=yuma.f2summary(d3BG$soil, d3BG$loc, 50, "BG")
d3IWloc=yuma.f2summary(d3IW$soil, d3IW$loc, 50, "IW")
d3PVloc=yuma.f2summary(d3PV$soil, d3PV$loc, 50, "PV")
d4BGloc=yuma.f2summary(d4BG$soil, d4BG$loc, 100, "BG")
d4IWloc=yuma.f2summary(d4IW$soil, d4IW$loc, 100, "IW")
d4PVloc=yuma.f2summary(d4PV$soil, d4PV$loc, 100, "PV")
d1BGgeo=yuma.f2summary(d1BG$soil, d1BG$geo, 2.5, "BG")
d2BGgeo=yuma.f2summary(d2BG$soil, d2BG$geo, 25, "BG")
d2IWgeo=yuma.f2summary(d2IW$soil, d2IW$geo, 25, "IW")
d2PVgeo=yuma.f2summary(d2PV$soil, d2PV$geo, 25, "PV")
d3BGgeo=yuma.f2summary(d3BG$soil, d3BG$geo, 50, "BG")
d3IWgeo=yuma.f2summary(d3IW$soil, d3IW$geo, 50, "IW")
d3PVgeo=yuma.f2summary(d3PV$soil, d3PV$geo, 50, "PV")
d4BGgeo=yuma.f2summary(d4BG$soil, d4BG$geo, 100, "BG")
d4IWgeo=yuma.f2summary(d4IW$soil, d4IW$geo, 100, "IW")
d4PVgeo=yuma.f2summary(d4PV$soil, d4PV$geo, 100, "PV")
summary2=rbind(d1BGloc,d2BGloc, d2IWloc, d2PVloc, d3BGloc, d3IWloc, d3PVloc,
d4BGloc, d4IWloc, d4PVloc,
d1BGgeo,d2BGgeo, d2IWgeo, d2PVgeo, d3BGgeo, d3IWgeo, d3PVgeo, d4BGgeo, d4IWgeo,
d4PVgeo)
summary2$F3=c(rep(c("Lower", "Middle", "Upper"), 10), rep(c("Terrace", "Wash"), 10))
#Makes datasets holding depth and geo constant
d1Tveg=yuma.f2summary(d1T$soil, d1T$veg, 2.5, "T")
d1Wveg=yuma.f2summary(d1W$soil, d1W$veg, 2.5, "W")
d2Tveg=yuma.f2summary(d2T$soil, d2T$veg, 25, "T")
d2Wveg=yuma.f2summary(d2W$soil, d2W$veg, 25, "W")
d3Tveg=yuma.f2summary(d3T$soil, d3T$veg, 50, "T")
d3Wveg=yuma.f2summary(d3W$soil, d3W$veg, 50, "W")
d4Tveg=yuma.f2summary(d4T$soil, d4T$veg, 100, "T")
d4Wveg=yuma.f2summary(d4W$soil, d4W$veg, 100, "W")
d1Tloc=yuma.f2summary(d1T$soil, d1T$loc, 2.5, "T")
d1Wloc=yuma.f2summary(d1W$soil, d1W$loc, 2.5, "W")
d2Tloc=yuma.f2summary(d2T$soil, d2T$loc, 25, "T")
d2Wloc=yuma.f2summary(d2W$soil, d2W$loc, 25, "W")
d3Tloc=yuma.f2summary(d3T$soil, d3T$loc, 50, "T")
d3Wloc=yuma.f2summary(d3W$soil, d3W$loc, 50, "W")
d4Tloc=yuma.f2summary(d4T$soil, d4T$loc, 100, "T")
d4Wloc=yuma.f2summary(d4W$soil, d4W$loc, 100, "W")
summary3=rbind(d1Tveg, d1Wveg, d2Tveg, d2Wveg, d3Tveg, d3Wveg, d4Tveg, d4Wveg,
d1Tloc, d1Wloc, d2Tloc, d2Wloc, d3Tloc, d3Wloc, d4Tloc, d4Wloc)
summary3$F3=c("BG","BG",rep(c("BG", "IW", "PV"), 6), rep(c("Lower", "Middle", "Upper"),
8))
#Puts all the data into one table
summary=rbind(summary1,summary2,summary3)
write.csv(summary, "wcrTrivSummary.csv")
```

```
#write.csv(summary, "tcTrivSummary.csv")
#Tri Variate Summary Tables by Season
#depth-veg-location by season
dvl=rbind(
yuma.fS2summary(d1BG[factor(d1BG$location)=="Lower",]$soil,
d1BG[factor(d1BG$location)=="Lower",]$seasyr, 2.5, "BG", "L")
,yuma.fS2summary(d1BG[factor(d1BG$location)=="Middle",]$soil,
d1BG[factor(d1BG$location)=="Middle",]$seasyr, 2.5, "BG", "M")
,yuma.fS2summary(d1BG[factor(d1BG$location)=="Upper",]$soil,
d1BG[factor(d1BG$location)=="Upper",]$seasyr, 2.5, "BG", "U")
,yuma.fS2summary(d2BG[factor(d2BG$location)=="Lower",]$soil,
d2BG[factor(d2BG$location)=="Lower",]$seasyr, 25, "BG", "L")
,yuma.fS2summary(d2IW[factor(d2IW$location)=="Lower",]$soil,
d2IW[factor(d2IW$location)=="Lower",]$seasyr, 25, "IW", "L")
,yuma.fS2summary(d2PV[factor(d2PV$location)=="Lower",]$soil,
d2PV[factor(d2PV$location)=="Lower",]$seasyr, 25, "PV", "L")
,yuma.fS2summary(d2BG[factor(d2BG$location)=="Middle",]$soil,
d2BG[factor(d2BG$location)=="Middle",]$seasyr, 25, "BG", "M")
,yuma.fS2summary(d2IW[factor(d2IW$location)=="Middle",]$soil,
d2IW[factor(d2IW$location)=="Middle",]$seasyr, 25, "IW", "M")
,yuma.fS2summary(d2PV[factor(d2PV$location)=="Middle",]$soil,
d2PV[factor(d2PV$location)=="Middle",]$seasyr, 25, "PV", "M")
,yuma.fS2summary(d2BG[factor(d2BG$location)=="Upper",]$soil,
d2BG[factor(d2BG$location)=="Upper",]$seasyr, 25, "BG", "U")
,yuma.fS2summary(d2IW[factor(d2IW$location)=="Upper",]$soil,
d2IW[factor(d2IW$location)=="Upper",]$seasyr, 25, "IW", "U")
,yuma.fS2summary(d2PV[factor(d2PV$location)=="Upper",]$soil,
d2PV[factor(d2PV$location)=="Upper",]$seasyr, 25, "PV", "U")
,yuma.fS2summary(d3BG[factor(d3BG$location)=="Lower",]$soil,
d3BG[factor(d3BG$location)=="Lower",]$seasyr, 50, "BG", "L")
,yuma.fS2summary(d3IW[factor(d3IW$location)=="Lower",]$soil,
d3IW[factor(d3IW$location)=="Lower",]$seasyr, 50, "IW", "L")
,yuma.fS2summary(d3PV[factor(d3PV$location)=="Lower",]$soil,
d3PV[factor(d3PV$location)=="Lower",]$seasyr, 50, "PV", "L")
,yuma.fS2summary(d3BG[factor(d3BG$location)=="Middle",]$soil,
d3BG[factor(d3BG$location)=="Middle",]$seasyr, 50, "BG", "M")
,yuma.fS2summary(d3IW[factor(d3IW$location)=="Middle",]$soil,
d3IW[factor(d3IW$location)=="Middle",]$seasyr, 50, "IW", "M")
,yuma.fS2summary(d3PV[factor(d3PV$location)=="Middle",]$soil,
d3PV[factor(d3PV$location)=="Middle",]$seasyr, 50, "PV", "M")
,yuma.fS2summary(d3BG[factor(d3BG$location)=="Upper",]$soil,
d3BG[factor(d3BG$location)=="Upper",]$seasyr, 50, "BG", "U")
,yuma.fS2summary(d3IW[factor(d3IW$location)=="Upper",]$soil,
d3IW[factor(d3IW$location)=="Upper",]$seasyr, 50, "IW", "U")
,yuma.fS2summary(d3PV[factor(d3PV$location)=="Upper",]$soil,
d3PV[factor(d3PV$location)=="Upper",]$seasyr, 50, "PV", "U")
```

```
,yuma.fS2summary(d4BG[factor(d4BG$location)=="Lower",]$soil,
d4BG[factor(d4BG$location)=="Lower",]$seasyr, 100, "BG", "L")
,yuma.fS2summary(d4IW[factor(d4IW$location)=="Lower",]$soil,
d4IW[factor(d4IW$location)=="Lower",]$seasyr, 100, "IW", "L")
,yuma.fS2summary(d4PV[factor(d4PV$location)=="Lower",]$soil,
d4PV[factor(d4PV$location)=="Lower",]$seasyr, 100, "PV", "L")
,yuma.fS2summary(d4BG[factor(d4BG$location)=="Middle",]$soil,
d4BG[factor(d4BG$location)=="Middle",]$seasyr, 100, "BG", "M")
,yuma.fS2summary(d4IW[factor(d4IW$location)=="Middle",]$soil,
d4IW[factor(d4IW$location)=="Middle",]$seasyr, 100, "IW", "M")
,yuma.fS2summary(d4PV[factor(d4PV$location)=="Middle",]$soil,
d4PV[factor(d4PV$location)=="Middle",]$seasyr, 100, "PV", "M")
,yuma.fS2summary(d4BG[factor(d4BG$location)=="Upper",]$soil,
d4BG[factor(d4BG$location)=="Upper",]$seasyr, 100, "BG", "U")
,yuma.fS2summary(d4IW[factor(d4IW$location)=="Upper",]$soil,
d4IW[factor(d4IW$location)=="Upper",]$seasyr, 100, "IW", "U")
,yuma.fS2summary(d4PV[factor(d4PV$location)=="Upper",]$soil,
d4PV[factor(d4PV$location)=="Upper",]$seasyr, 100, "PV", "U")
)
#Depth-Location-Geo
dlg=rbind(
yuma.fS2summary(d1L[factor(d1L$geo)=="Terrace",]$soil,
d1L[factor(d1L$geo)=="Terrace",]$seasyr,2.5, "L", "T")
,yuma.fS2summary(d1M[factor(d1M$geo)=="Terrace",]$soil,
d1M[factor(d1M$geo)=="Terrace",]$seasyr,2.5, "M", "T")
,yuma.fS2summary(d1U[factor(d1U$geo)=="Terrace",]$soil,
d1U[factor(d1U$geo)=="Terrace",]$seasyr,2.5, "U", "T")
,yuma.fS2summary(d1L[factor(d1L$geo)=="Wash",]$soil,
d1L[factor(d1L$geo)=="Wash",]$seasyr,2.5, "L", "W")
,yuma.fS2summary(d1M[factor(d1M$geo)=="Wash",]$soil,
d1M[factor(d1M$geo)=="Wash",]$seasyr,2.5, "M", "W")
,yuma.fS2summary(d1U[factor(d1U$geo)=="Wash",]$soil,
d1U[factor(d1U$geo)=="Wash",]$seasyr,2.5, "U", "W")
,yuma.fS2summary(d2L[factor(d2L$geo)=="Terrace",]$soil,
d2L[factor(d2L$geo)=="Terrace",]$seasyr,25, "L", "T")
,yuma.fS2summary(d2M[factor(d2M$geo)=="Terrace",]$soil,
d2M[factor(d2M$geo)=="Terrace",]$seasyr,25, "M", "T")
,yuma.fS2summary(d2U[factor(d2U$geo)=="Terrace",]$soil,
d2U[factor(d2U$geo)=="Terrace",]$seasyr,25, "U", "T")
,yuma.fS2summary(d2L[factor(d2L$geo)=="Wash",]$soil,
d2L[factor(d2L$geo)=="Wash",]$seasyr,25, "L", "W")
,yuma.fS2summary(d2M[factor(d2M$geo)=="Wash",]$soil,
d2M[factor(d2M$geo)=="Wash",]$seasyr,25, "M", "W")
,yuma.fS2summary(d2U[factor(d2U$geo)=="Wash",]$soil,
d2U[factor(d2U$geo)=="Wash",]$seasyr,25, "U", "W")
```

```
,yuma.fS2summary(d3L[factor(d3L$geo)=="Terrace",]$soil,
d3L[factor(d3L$geo)=="Terrace",]$seasyr,50, "L", "T")
,yuma.fS2summary(d3M[factor(d3M$geo)=="Terrace",]$soil,
d3M[factor(d3M$geo)=="Terrace",]$seasyr,50, "M", "T")
,yuma.fS2summary(d3U[factor(d3U$geo)=="Terrace",]$soil,
d3U[factor(d3U$geo)=="Terrace",]$seasyr, 50, "U", "T")
,yuma.fS2summary(d3L[factor(d3L$geo)=="Wash",]$soil,
d3L[factor(d3L$geo)=="Wash",]$seasyr,50, "L", "W")
,yuma.fS2summary(d3M[factor(d3M$geo)=="Wash",]$soil,
d3M[factor(d3M$geo)=="Wash",]$seasyr,50, "M", "W")
,yuma.fS2summary(d3U[factor(d3U$geo)=="Wash",]$soil,
d3U[factor(d3U$geo)=="Wash",]$seasyr,50, "U", "W")
,yuma.fS2summary(d4L[factor(d4L$geo)=="Terrace",]$soil,
d4L[factor(d4L$geo)=="Terrace",]$seasyr,100, "L", "T")
,yuma.fS2summary(d4M[factor(d4M$geo)=="Terrace",]$soil,
d4M[factor(d4M$geo)=="Terrace",]$seasyr,100, "M", "T")
,yuma.fS2summary(d4U[factor(d4U$geo)=="Terrace",]$soil,
d4U[factor(d4U$geo)=="Terrace",]$seasyr,100, "U", "T")
,yuma.fS2summary(d4L[factor(d4L$geo)=="Wash",]$soil,
d4L[factor(d4L$geo)=="Wash",]$seasyr,100, "L", "W")
,yuma.fS2summary(d4M[factor(d4M$geo)=="Wash",]$soil,
d4M[factor(d4M$geo)=="Wash",]$seasyr,100, "M", "W")
,yuma.fS2summary(d4U[factor(d4U$geo)=="Wash",]$soil,
d4U[factor(d4U$geo)=="Wash",]$seasyr,100, "U", "W")
)
#Depth-Geo-Veg
dgv=rbind(
yuma.fS2summary(d1T[factor(d1T$veg)=="BG",]$soil,
d1T[factor(d1T$veg)=="BG",]$seasyr,2.5, "T", "BG")
,yuma.fS2summary(d1W[factor(d1W$veg)=="BG",]$soil,
d1W[factor(d1W$veg)=="BG",]$seasyr,2.5, "W", "BG")
,yuma.fS2summary(d2T[factor(d2T$veg)=="BG",]$soil,
d2T[factor(d2T$veg)=="BG",]$seasyr,25, "T", "BG")
,yuma.fS2summary(d2W[factor(d2W$veg)=="BG",]$soil,
d2W[factor(d2W$veg)=="BG",]$seasyr,25, "W", "BG")
,yuma.fS2summary(d2T[factor(d2T$veg)=="IW",]$soil,
d2T[factor(d2T$veg)=="IW",]$seasyr,25, "T", "IW")
,yuma.fS2summary(d2W[factor(d2W$veg)=="IW",]$soil,
d2W[factor(d2W$veg)=="IW",]$seasyr,25, "W", "IW")
,yuma.fS2summary(d2T[factor(d2T$veg)=="PV",]$soil,
d2T[factor(d2T$veg)=="PV",]$seasyr,25, "T", "PV")
,yuma.fS2summary(d2W[factor(d2W$veg)=="PV",]$soil,
d2W[factor(d2W$veg)=="PV",]$seasyr,25, "W", "PV")
,yuma.fS2summary(d3T[factor(d3T$veg)=="BG",]$soil,
d3T[factor(d3T$veg)=="BG",]$seasyr,50, "T", "BG")
```

```
,yuma.fS2summary(d3W[factor(d3W$veg)=="BG",]$soil,
d3W[factor(d3W$veg)=="BG",]$seasyr,50, "W", "BG")
,yuma.fS2summary(d3T[factor(d3T$veg)=="IW",]$soil,
d3T[factor(d3T$veg)=="IW",]$seasyr,50, "T", "IW")
,yuma.fS2summary(d3W[factor(d3W$veg)=="IW",]$soil,
d3W[factor(d3W$veg)=="IW",]$seasyr,50, "W", "IW")
,yuma.fS2summary(d3T[factor(d3T$veg)=="PV",]$soil,
d3T[factor(d3T$veg)=="PV",]$seasyr,50, "T", "PV")
,yuma.fS2summary(d3W[factor(d3W$veg)=="PV",]$soil,
d3W[factor(d3W$veg)=="PV",]$seasyr,50, "W", "PV")
,yuma.fS2summary(d4T[factor(d4T$veg)=="BG",]$soil,
d4T[factor(d4T$veg)=="BG",]$seasyr,100, "T", "BG")
,yuma.fS2summary(d4W[factor(d4W$veg)=="BG",]$soil,
d4W[factor(d4W$veg)=="BG",]$seasyr,100, "W", "BG")
,yuma.fS2summary(d4T[factor(d4T$veg)=="IW",]$soil,
d4T[factor(d4T$veg)=="IW",]$seasyr,100, "T", "IW")
,yuma.fS2summary(d4W[factor(d4W$veg)=="IW",]$soil,
d4W[factor(d4W$veg)=="IW",]$seasyr,100, "W", "IW")
,yuma.fS2summary(d4T[factor(d4T$veg)=="PV",]$soil,
d4T[factor(d4T$veg)=="PV",]$seasyr,100, "T", "PV")
,yuma.fS2summary(d4W[factor(d4W$veg)=="PV",]$soil,
d4W[factor(d4W$veg)=="PV",]$seasyr,100, "W", "PV")
)
write.csv(dvl, "wcrTrivSeasDVL.csv")
write.csv(dlg, "wcrTrivSeasDLG.csv")
write.csv(dgv, "wcrTrivSeasDGV.csv")
dlg=read.csv("wcrTrivSeasDLG.csv")[2:23]
dgl=dlg
names(dgl)=c("Obs", "NaN", "Min", "Q1", "Median", "GMean", "Mean", "Q3", "Max", "IQR",
"SD",
        "MAD", "CV", "CVR", "Skew", "Kurt", "GSD", "GCV", "f1","f3","f2","seasyr")
dgv=read.csv("wcrTrivSeasDGV.csv")[2:23]
dvg=dgv
names(dvg)=c("Obs", "NaN", "Min", "Q1", "Median", "GMean", "Mean", "Q3", "Max", "IQR",
"SD",
        "MAD", "CV", "CVR", "Skew", "Kurt", "GSD", "GCV", "f1","f3","f2","seasyr")
dvl=read.csv("wcrTrivSeasDVL.csv")[2:23]
dlv=dvl
names(dlv)=c("Obs", "NaN", "Min", "Q1", "Median", "GMean", "Mean", "Q3", "Max", "IQR",
"SD",
        "MAD", "CV", "CVR", "Skew", "Kurt", "GSD", "GCV", "f1","f3","f2","seasyr")
write.csv(
rbind(dlg,dgv,dvl), "wcrTrivSeasSummary1.csv")
write.csv(
rbind(dgl,dvg,dlv), "wcrTrivSeasSummary2.csv")
#DEPTH-LOC-VEG
```

```
png(str_c(statistic, datalabel, "pooled by Depth and Geo--Comparison of Cover and Location.png", sep=""), width=1000, height=1400)
par(mfrow=c(4,2), oma=c(0,0,2,0), cex=1.15)
barplot(lv1,  beside=T, ylim=range(ymin,ymax), ylab=label, xlab="2.5 cm",
                    legend.text=rownames(lv1), args.legend=list(horiz=T))
barplot(t(lv1),  beside=T, ylim=range(ymin,ymax), ylab=label,xlab="2.5 cm",
                        legend.text=colnames(lv1), args.legend=list(horiz=T))
barplot(lv2,  beside=T, ylim=range(ymin,ymax), ylab=label, xlab="25 cm")
barplot(t(lv2),  beside=T, ylim=range(ymin,ymax), ylab=label,xlab="25 cm",
                        legend.text=colnames(lv2), args.legend=list(horiz=T, y=ymax))
barplot(lv3,  beside=T, ylim=range(ymin,ymax), ylab=label,xlab="50 cm")
barplot(t(lv3),  beside=T, ylim=range(ymin,ymax), ylab=label,xlab="50 cm")
barplot(lv4,  beside=T, ylim=range(ymin,ymax), ylab=label,xlab="100 cm")
barplot(t(lv4),  beside=T, ylim=range(ymin,ymax), ylab=label,xlab="100 cm")
title(str_c(statistic," Volumetric Water Content Pooled by Depth and Geomorphic Surface--Comparison of Cover and Location", sep=" "), outer=T)
dev.off()
#DEPTH-VEG-GEO
png(str_c(statistic,datalabel, "pooled by Depth and Location--Comparison of Geomorphic Surface and Cover.png", sep=""), width=1000, height=1400)
par(mfrow=c(4,2), oma=c(0,0,2,0), cex=1.15)
barplot(vg1,  beside=T, ylim=range(ymin,ymax), ylab=label, xlab="2.5 cm",
                legend.text=rownames(vg1), args.legend=list(horiz=T))
barplot(t(vg1),  beside=T, ylim=range(ymin,ymax), ylab=label,xlab="2.5 cm",
                legend.text=colnames(vg1), args.legend=list(horiz=T))
barplot(vg2,  beside=T, ylim=range(ymin,ymax), ylab=label, xlab="25 cm",
                legend.text=rownames(vg2), args.legend=list(horiz=T, y=ymax))
barplot(t(vg2),  beside=T, ylim=range(ymin,ymax), ylab=label,xlab="25 cm")
barplot(vg3,  beside=T, ylim=range(ymin,ymax), ylab=label,xlab="50 cm")
barplot(t(vg3),  beside=T, ylim=range(ymin,ymax), ylab=label,xlab="50 cm")
barplot(vg4,  beside=T, ylim=range(ymin,ymax), ylab=label,xlab="100 cm")
barplot(t(vg4),  beside=T, ylim=range(ymin,ymax), ylab=label,xlab="100 cm")
title(str_c(statistic, " Volumetric Water Content Pooled by Depth and Location--Comparison of Geomorphic Surface and Cover", sep=" "), outer=T)
dev.off()
#LINE PLOTS BY SEASON
summary1=read.csv("wcrTrivSeasSummary1.csv") # contains lg gv and vl--location by geo, geo by veg, and veg by location
summary2=read.csv("wcrTrivSeasSummary2.csv")# contains gl vg and lv--geo by location, veg by geo, and location by veg
names(summary1) #lists the column names in the summary stats if you
#want to plot ANY of the statistics through time.
#To change between Medians, Means and Gmeans simply change all titles and
#change the stat number to reflect the appropriate statistic.
#6=median
#7=gmean
```

```
#8=mean
datalabel="Seasonal Volumetric Water Content at "
statistic="Median"
stat=6  #Is the column number for the statistic you want to run (see note above)
ymin=0 #min(data[,stat], na.rm=T) will make the min the min of the data
ymax=0.3 #min(data[,stat], na.rm=T) will make the max the max of the data
depth=25 # change for each depth you want to look at  (and also below for the veg labels (e.g. BG50 or BG25)
#Depth-Veg are pooled; allows for comparisons of probes at a given depth and veg type, by geo or by location
#for example, all PV probes at 25cm on terraces vs on washes; or all PV probes at 25cm in lower, vs middle, vs upper wash
png(str_c(statistic,datalabel,as.character(depth), "cm Pooled by Depth and Cover.png", sep=" "),width=800, height=900)
par(mfrow=c(3,2),  oma=c(0,0,2,0), las=2 ,cex=0.8)#if want to export without defining a cex, put a )# after the las=2
seas2byloc(summary1, statcol ,depth, "BG" , ymin, ymax, label,"Bare Ground (BG25) by location")
seas2bygeo(summary2, statcol ,depth, "BG" , ymin, ymax, label,"Bare Ground (BG25) by geo surface")
seas2byloc(summary1, statcol ,depth, "IW" , ymin, ymax, label,"O.tesota (IW25) by location")
seas2bygeo(summary2, statcol ,depth, "IW" , ymin, ymax, label,"O.tesota (IW25) by geo surface")
seas2byloc(summary1, statcol ,depth, "PV" , ymin, ymax, label,"P.microphylla (PV25) by location")
seas2bygeo(summary2, statcol ,depth, "PV" , ymin, ymax, label,"P.microphylla (PV25) by geo surface")
title(str_c(statistic, datalabel, as.character(depth), "cm Pooled by Depth and Cover--Comparison of Location and Geomorphic Surface", sep=" "), outer=T)
dev.off()
#Depth-Loc are pooled; allows for comparisons of probes at a given depth and location, by geo or by veg
#for example, all probes at 25cm on lower terraces vs 25cm on middle terraces vs 25cm on upper terraces; or,
#all probes at 25cm lower/PV vs 25cm middle/PV probes vs 25cm upper/PV probes; or,
 png(str_c(statistic, datalabel, as.character(depth), "cm Pooled by Depth and Location.png", sep=" "),width=800, height=900)
par(mfrow=c(3,2),  oma=c(0,0,2,0), las=2 ,cex=0.8)
seas2byveg(summary2, statcol ,depth, "L" , ymin, ymax, label,"Lower by cover")
seas2bygeo(summary1, statcol ,depth, "L" , ymin, ymax, label,"Lower by geo surface")
seas2byveg(summary2, statcol ,depth, "M" , ymin, ymax, label,"Middle by cover")
seas2bygeo(summary1, statcol ,depth, "M" , ymin, ymax, label,"Middle by geo surface")
seas2byveg(summary2, statcol ,depth, "U" , ymin, ymax, label,"Upper by cover")
seas2bygeo(summary1, statcol ,depth, "U" , ymin, ymax, label,"Upper by geo surface")
title(str_c(statistic, datalabel, as.character(depth), "cm Pooled by Location--Comparison of Cover and Geomorphic Surface", sep=" "), outer=T)
```

dev.off()
#Depth-Geo are pooled; allows for comparisons of probes at a given depth and geomorphic surface, by veg or by location
#for example, all 25cm terrace PV probes vs all 25cm terrace IW probes vs all 25cm terrace BG probes;
#or, all 25cm terrace lower probes vs 25cm terrace middle probes vs 25cm terrace upper probes
png(str_c(statistic, datalabel, as.character(depth), "cm Pooled by Depth and Geomorphic Surface.png", sep=" "),width=800, height=900)
par(mfrow=c(3,2), oma=c(0,0,2,0), las=2 ,cex=0.8)
seas2byveg(summary1, statcol ,depth, "T" , ymin, ymax, label,"Terrace by cover")
seas2byloc(summary2, statcol ,depth, "T" , ymin, ymax, label,"Terrace by location")
seas2byveg(summary1, statcol ,depth, "W" , ymin, ymax, label,"Wash by cover")
seas2byloc(summary2, statcol ,depth, "W" , ymin, ymax, label,"Wash by location")
title(str_c(datalabel, as.character(depth), "cm Pooled by Geo**morphic Surface--**Comparison of Cover Types and Location", sep=" "), outer=T)
dev.off()
****
Scripts equivalent in functionality to those developed above for analysis of 15-minute volumetric soil moisture data were also developed for analyzing ‘event mean’ and ‘event magnitude’ data estimated for each soil moisture event. These scripts are not included here to avoid redundancy and in order to reduce size of the Appendices.
****
Statistical Tests Code for Soil Moisture Data averaged as weekly means from 15-minute data for the entire period of record, or for analysis of Timing data, where ‘event means’ and ‘event magnitudes’ are derived from.

Script_wcrTests_11_7_12

#Script runs non-parametric stats (Kruskal Wallis and Wilcoxon tests) for both spatial and temporal comparisons.
setwd("C:\\Users\\showe\\YumaWash\\soilmoisture\\CURRENT3")
# FIRST RUN the Data Read file for wcrweekly to create the .RData file for weekly wcr – needed only to re-create the wcrdepth_weekly data file; otherwise just load it.
#Load 'timingall.RData' for delwcr and meanwcr stats
#Load 'wcrdepth_weekly.RData' for wcr weekly stats
#Load function script 'Func_testtables.R' for either stats
load("timingall.RData")
td1=subset(timing, depth=="2.5")
td2=subset(timing, depth=="25")
td3=subset(timing, depth=="50")
td4=subset(timing, depth=="100")
names(timing)
load("wcrdepth_weekly.RData")
source("Func_testtables.R")
#timingall data is for event-based analyses on meanwcr and delwcr
#weekly data is for analyses on 15-minute data averaged as weekly

```
##################################################################
#OVERALL Kruskal Tests for factors veg, geo , location and probe, seas and yr
#Weekly WCR
kruskaltable2.5(d1)
kruskaltable(d2)
kruskaltable(d3)
kruskaltable(d4)
#TIMING WCR (MEANWCR dc=27; DELWCR dc=10)
kruskaltable2.5(td1, dc=27)
kruskaltable(td2, dc=27)
kruskaltable(td3, dc=27)
kruskaltable(td4, dc=27)
kruskaltable2.5(td1, dc=10)
kruskaltable(td2, dc=10)
kruskaltable(td3, dc=10)
kruskaltable(td4, dc=10)
##################################################################
#KRUSKAL AND WILCOX TESTS FOR DIFFERENCES BETWEEN DEPTHS
wilcoxdepth(rbind(d1,d2,d3,d4))# for Weekly Wcr
wilcoxdepth(timing, dc=27) # for timing meanwcr
wilcoxdepth(timing, dc=10) # for timing delwcr
##################################################################
#TESTS FOR BIVARIATE Comparisons, Depth then by factor
#WILCOX TESTS  for Yr, loc, geo, veg (SEE SCRIPT LOWER DOWN FOR SECTION ON
SEASONAL TESTS)
#WCR WEEKLY
this pools over all the data and just compares yrs
wilcoxyr(d1)# for 2.5cm
wilcoxyr(d2)# for 25 cm
wilcoxyr(d3)# for 50 cm
wilcoxyr(d4)# for 100 cm
wilcoxloc(d1)
wilcoxloc(d2)
wilcoxloc(d3)
wilcoxloc(d4)
wilcoxveg(d2)
wilcoxveg(d3)
wilcoxveg(d4)
wilcoxgeo2.5(d1)
wilcoxgeo(d2)
wilcoxgeo(d3)
wilcoxgeo(d4)
#TIMING WCR(MEANWCR dc=27; DELWCR dc=10)
# for meanwcr (dc=27)
wilcoxyr(td1, dc=27)# for 2.5cm
wilcoxyr(td2, dc=27)# for 25 cm
```

```
wilcoxyr(td3, dc=27)# for 50 cm
wilcoxyr(td4, dc=27)# for 100 cm
wilcoxloc(td1, dc=27)
wilcoxloc(td2, dc=27)
wilcoxloc(td3, dc=27)
wilcoxloc(td4, dc=27)
wilcoxveg(td2, dc=27)
wilcoxveg(td3, dc=27)
wilcoxveg(td4, dc=27)
wilcoxgeo2.5(td1, dc=27)
wilcoxgeo(td2, dc=27)
wilcoxgeo50(td3, dc=27)# Couldn't do all comparisons because of n values
wilcoxgeo(td4, dc=27)
# for delwcr (dc=10)
wilcoxyr(td1, dc=10)# for 2.5cm
wilcoxyr(td2, dc=10)# for 25 cm
wilcoxyr(td3, dc=10)# for 50 cm
wilcoxyr(td4, dc=10)# for 100 cm
wilcoxloc(td1, dc=10)
wilcoxloc(td2, dc=10)
wilcoxloc(td3, dc=10)
wilcoxloc(td4, dc=10)
wilcoxveg(td2, dc=10)
wilcoxveg(td3, dc=10)
wilcoxveg(td4, dc=10)
wilcoxgeo2.5(td1, dc=10)
wilcoxgeo(td2, dc=10)
wilcoxgeo50(td3, dc=10)# Couldn't do all comparisons because of n values
wilcoxgeo(td4, dc=10)
#####################################################################
#SEASONAL TESTS- Breaks Datasets up by seasons
#####################################################################
#Kruskal -Wilcox tests by Season
#this pools over all the data and just compares seasons
#WEEKLY DATA
wilcoxseas(d1)# for 2.5cm
wilcoxseas(d2)# for 25 cm
wilcoxseas(d3)# for 50 cm
wilcoxseas(d4)# for 100 cm
#TIMING WCR(MEANWCR dc=27; DELWCR dc=10)
wilcoxseas(td1, dc=27)# for 2.5cm
wilcoxseas(td2, dc=27)# for 25 cm
wilcoxseas(td3, dc=27)# for 50 cm
wilcoxseas(td4, dc=27)# for 100 cm
wilcoxseas(td1, dc=10)# for 2.5cm
wilcoxseas(td2, dc=10)# for 25 cm
```

```
wilcoxseas(td3, dc=10)# for 50 cm
wilcoxseas(td4, dc=10)# for 100 cm
#Now only testing on PV and IW data
#subselects only PV and IW and tells you if there is a difference between any seasons
#WEEKLY WCR
wilcoxseas(d2[d2$veg!="BG",])
wilcoxseas(d3[d3$veg!="BG",])
wilcoxseas(d4[d4$veg!="BG",])
#TIMING WCR (MEANWCR dc=27; DELWCR dc=10)
wilcoxseas(td2[td2$veg!="BG",], dc=27)
wilcoxseas(td3[td3$veg!="BG",], dc=27)
wilcoxseas(td4[td4$veg!="BG",], dc=27)
wilcoxseas(td2[td2$veg!="BG",], dc=10)
wilcoxseas(td3[td3$veg!="BG",], dc=10)
wilcoxseas(td4[td4$veg!="BG",], dc=10)
#Now only testing on BG data
#WEEKLY WCR
wilcoxseas(d1)
wilcoxseas(d2[d2$veg=="BG",])
wilcoxseas(d3[d3$veg=="BG",])
wilcoxseas(d4[d4$veg=="BG",])
#TIMING MEAN WCR
wilcoxseas(td1, dc=27)
wilcoxseas(td2[td2$veg=="BG",], dc=27)
wilcoxseas(td3[td3$veg=="BG",], dc=27)
wilcoxseas(td4[td4$veg=="BG",], dc=27)
wilcoxseas(td1, dc=10)
wilcoxseas(td2[td2$veg=="BG",], dc=10)
wilcoxseas(td3[td3$veg=="BG",], dc=10)
wilcoxseas(td4[td4$veg=="BG",], dc=10)
#Now only testing on IW data
#WEEKLY WCR
wilcoxseas(d2[d2$veg=="IW",])
wilcoxseas(d3[d3$veg=="IW",])
wilcoxseas(d4[d4$veg=="IW",])
#TIMING WCR
wilcoxseas(td2[td2$veg=="IW",], dc=27)
wilcoxseas(td3[td3$veg=="IW",], dc=27)
wilcoxseas(td4[td4$veg=="IW",], dc=27)
wilcoxseas(td2[td2$veg=="IW",], dc=10)
wilcoxseas(td3[td3$veg=="IW",], dc=10)
wilcoxseas(td4[td4$veg=="IW",], dc=10)
#Now only testing on PV data
# WEEKLY WCR
wilcoxseas(d2[d2$veg=="PV",])
wilcoxseas(d3[d3$veg=="PV",])
```

```
wilcoxseas(d4[d4$veg=="PV",])
# TIMING WCR
wilcoxseas(td2[td2$veg=="PV",], dc=27)
wilcoxseas(td3[td3$veg=="PV",], dc=27)
wilcoxseas(td4[td4$veg=="PV",], dc=27)
wilcoxseas(td2[td2$veg=="PV",], dc=10)
wilcoxseas(td3[td3$veg=="PV",], dc=10)
wilcoxseas(td4[td4$veg=="PV",], dc=10)
################################################
#By Depth then By Season Then By Factor- OVERALL KRUSKAL
################################################
FOR WEEKLY WCR
#pre-subselects different datasets
d1Su=d1[d1$seas=="Summer",]
d2Su=d2[d2$seas=="Summer",]
d3Su=d3[d3$seas=="Summer",]
d4Su=d4[d4$seas=="Summer",]
d1Fa=d1[d1$seas=="Fall",]
d2Fa=d2[d2$seas=="Fall",]
d3Fa=d3[d3$seas=="Fall",]
d4Fa=d4[d4$seas=="Fall",]
d1Wi=d1[d1$seas=="Winter",]
d2Wi=d2[d2$seas=="Winter",]
d3Wi=d3[d3$seas=="Winter",]
d4Wi=d4[d4$seas=="Winter",]
d1Sp=d1[d1$seas=="Spring",]
d2Sp=d2[d2$seas=="Spring",]
d3Sp=d3[d3$seas=="Spring",]
d4Sp=d4[d4$seas=="Spring",]
#SUMMER--this tests whether there are spatial differences in summer wcr, by geo, by location,
or temporal diffs between summers in each year
kruskaltable2.5seas(d1Su)
kruskaltableseas(d2Su)
kruskaltableseas(d3Su)
kruskaltableseas(d4Su)
#FALL
kruskaltable2.5seas(d1Fa)
kruskaltableseas(d2Fa)
kruskaltableseas(d3Fa)
kruskaltableseas(d4Fa)
#WINTER
kruskaltable2.5seas(d1Wi)
kruskaltableseas(d2Wi)
kruskaltableseas(d3Wi)
kruskaltableseas(d4Wi)
#SPRING
```

```
kruskaltable2.5seas(d1Sp)
kruskaltableseas(d2Sp)
kruskaltableseas(d3Sp)
kruskaltableseas(d4Sp)
###########
#FOR TIMING WCR (MEANWCR dc=27; DELWCR dc=10)
FOR meanwcr
#pre-subselects different datasets
td1Su=td1[td1$seas=="Summer",]
td2Su=td2[td2$seas=="Summer",]
td3Su=td3[td3$seas=="Summer",]
td4Su=td4[td4$seas=="Summer",]
td1Fa=td1[td1$seas=="Fall",]
td2Fa=td2[td2$seas=="Fall",]
td3Fa=td3[td3$seas=="Fall",]
td4Fa=td4[td4$seas=="Fall",]

td1Wi=td1[td1$seas=="Winter",]
td2Wi=td2[td2$seas=="Winter",]
td3Wi=td3[td3$seas=="Winter",]
td4Wi=td4[td4$seas=="Winter",]
td1Sp=td1[td1$seas=="Spring",]
td2Sp=td2[td2$seas=="Spring",]
td3Sp=td3[td3$seas=="Spring",]
td4Sp=td4[td4$seas=="Spring",]
#SUMMER--this tests whether there are spatial differences in summer wcr, by geo, by location,
or temporal diffs between summers in each year
kruskaltable2.5seas(td1Su, dc=27)
kruskaltableseas(td2Su, dc=27)
kruskaltableseas(td3Su, dc=27)
kruskaltableseas(td4Su, dc=27)
#FALL
kruskaltable2.5seas(td1Fa, dc=27)
kruskaltableseas(td2Fa, dc=27)
kruskaltableseas(td3Fa, dc=27)
kruskaltableseas(td4Fa, dc=27)
#WINTER
kruskaltable2.5seas(td1Wi, dc=27)
kruskaltableseas(td2Wi, dc=27)
kruskaltableseas(td3Wi, dc=27)
kruskaltableseas(td4Wi, dc=27)
#SPRING
kruskaltable2.5seas(td1Sp, dc=27)
kruskaltableseas(td2Sp, dc=27)
kruskaltableseas(td3Sp, dc=27)
kruskaltableseas(td4Sp, dc=27)
```

```
#######
FOR delwcr
#SUMMER--this tests whether there are spatial differences in summer wcr, by geo, by location,
or temporal diffs between summers in each year
kruskaltable2.5seas(td1Su, dc=10)
kruskaltableseas(td2Su, dc=10)
kruskaltableseas(td3Su, dc=10)
kruskaltableseas(td4Su, dc=10)
#FALL
kruskaltable2.5seas(td1Fa, dc=10)
kruskaltableseas(td2Fa, dc=10)
kruskaltableseas(td3Fa, dc=10)
kruskaltableseas(td4Fa, dc=10)
#WINTER
kruskaltable2.5seas(td1Wi, dc=10)
kruskaltableseas(td2Wi, dc=10)
kruskaltableseas(td3Wi, dc=10)
kruskaltableseas(td4Wi, dc=10)
#SPRING
kruskaltable2.5seas(td1Sp, dc=10)
kruskaltableseas(td2Sp, dc=10)
kruskaltableseas(td3Sp, dc=10)
kruskaltableseas(td4Sp, dc=10)
##################################################
# #By Depth then By Season Then By Factor- Wilcoxan pairwise comparisons
##################################################
#PAIRWISE TESTS WITHIN SEASON-  WHERE ARE THE DIFFERENCES OCCURRING-
by subselections by depth and season
#WEEKLY WCR
#TESTS FOR GEO
#Factor Terrace v Wash
#Summer
wilcoxtable(d1Su, d2Su, d3Su, d4Su, 7, "Terrace","Wash")
#Fall
wilcoxtable(d1Fa, d2Fa, d3Fa, d4Fa, 7, "Terrace","Wash")
#Winter
wilcoxtable(d1Wi, d2Wi, d3Wi, d4Wi, 7, "Terrace","Wash")
#Spring
wilcoxtable(d1Sp, d2Sp, d3Sp, d4Sp, 7, "Terrace","Wash")
#TESTS FOR Veg
#BG-PV ----
#Summer
wilcoxtableveg(d2Su, d3Su, d4Su, 6, "BG","PV")
#Fall
wilcoxtableveg(d2Fa, d3Fa, d4Fa, 6, "BG","PV")
#Winter
```

```
wilcoxtableveg(d2Wi, d3Wi, d4Wi, 6, "BG","PV")
#Spring
wilcoxtableveg(d2Sp, d3Sp, d4Sp, 6, "BG","PV")
#BG-IW
#Summer
wilcoxtableveg(d2Su, d3Su, d4Su, 6, "BG","IW")
#Fall
wilcoxtableveg(d2Fa, d3Fa, d4Fa, 6, "BG","IW")
#Winter
wilcoxtableveg(d2Wi, d3Wi, d4Wi, 6, "BG","IW")
#Spring
wilcoxtableveg(d2Sp, d3Sp, d4Sp, 6, "BG","IW")
#PV-IW
#Summer
wilcoxtableveg(d2Su, d3Su, d4Su, 6, "PV","IW")
 #Fall
wilcoxtableveg(d2Fa, d3Fa, d4Fa, 6, "PV","IW")
#Winter
wilcoxtableveg(d2Wi, d3Wi, d4Wi, 6, "PV","IW")
#Spring
wilcoxtableveg(d2Sp, d3Sp, d4Sp, 6, "PV","IW")
#TESTS FOR LOCATION
#Upper-Lower
#Summer
wilcoxtable(d1Su, d2Su, d3Su, d4Su, 3, "Upper","Lower")
#Fall
wilcoxtable(d1Fa, d2Fa, d3Fa, d4Fa, 3, "Upper","Lower")
#Winter
wilcoxtable(d1Wi, d2Wi, d3Wi, d4Wi, 3, "Upper","Lower")
#Spring
wilcoxtable(d1Sp, d2Sp, d3Sp, d4Sp, 3, "Upper","Lower")
#Upper-Middle
#Summer
wilcoxtable(d1Su, d2Su, d3Su, d4Su, 3, "Upper","Middle")
#Fall
wilcoxtable(d1Fa, d2Fa, d3Fa, d4Fa, 3, "Upper","Middle")
#Winter
wilcoxtable(d1Wi, d2Wi, d3Wi, d4Wi, 3, "Upper","Middle")
#Spring
wilcoxtable(d1Sp, d2Sp, d3Sp, d4Sp, 3, "Upper","Middle")
#Lower-Middle
#Summer
wilcoxtable(d1Su, d2Su, d3Su, d4Su, 3, "Lower","Middle")
#Fall
wilcoxtable(d1Fa, d2Fa, d3Fa, d4Fa, 3, "Lower","Middle")
#Winter
```

```
wilcoxtable(d1Wi, d2Wi, d3Wi, d4Wi, 3, "Lower","Middle")
#Spring
wilcoxtable(d1Sp, d2Sp, d3Sp, d4Sp, 3, "Lower","Middle")
#############
#TIMING WCR  (MEANWCR dc=27; DELWCR dc=10)
# FOR meanwcr:
#TESTS FOR GEO
#Factor Terrace v Wash
#Summer
wilcoxtable(td1Su, td2Su, td3Su, td4Su, 17, "Terrace","Wash", dc=27)
#Fall
wilcoxtable(td1Fa, td2Fa, td3Fa, td4Fa, 17, "Terrace","Wash", dc=27)
#Winter
wilcoxtable(td1Wi, td2Wi, td3Wi, td4Wi, 17, "Terrace","Wash", dc=27)
#Spring
wilcoxtable(td1Sp, td2Sp, td3Sp, td4Sp, 17, "Terrace","Wash", dc=27)

#TESTS FOR Veg
#BG-PV ----
#Summer
wilcoxtableveg(td2Su, td3Su, td4Su, 18, "BG","PV", dc=27)
#Fall
wilcoxtableveg(td2Fa, td3Fa, td4Fa, 18, "BG","PV", dc=27) #couldn't do all comparisons due to low n
#Winter
wilcoxtableveg(td2Wi, td3Wi, td4Wi, 18, "BG","PV", dc=27)
#Spring
wilcoxtableveg(td2Sp, td3Sp, td4Sp, 18, "BG","PV", dc=27) #couldn't do all comparisons due to low n
#BG-IW
wilcoxtableveg(td2Su, td3Su, td4Su, 18, "BG","IW", dc=27)
wilcoxtableveg.noD4(td2Fa, td3Fa, td4Fa, 18, "BG","IW", dc=27) #couldn't do all comparisons due to low n
wilcoxtableveg(td2Wi, td3Wi, td4Wi, 18, "BG","IW", dc=27)
wilcoxtableveg.noD34(td2Sp, td3Sp, td4Sp, 18, "BG","IW", dc=27) #couldn't do all comparisons due to low n
#PV-IW
wilcoxtableveg(td2Su, td3Su, td4Su, 18, "PV","IW", dc=27)
wilcoxtableveg(td2Fa, td3Fa, td4Fa, 18, "PV","IW", dc=27)
wilcoxtableveg(td2Wi, td3Wi, td4Wi, 18, "PV","IW", dc=27)
wilcoxtableveg(td2Sp, td3Sp, td4Sp, 18, "PV","IW", dc=27)
#TESTS FOR LOCATION
#Upper-Lower
wilcoxtable(td1Su, td2Su, td3Su, td4Su, 16, "Upper","Lower", dc=27)
wilcoxtable(td1Fa, td2Fa, td3Fa, td4Fa, 16, "Upper","Lower", dc=27)
wilcoxtable(td1Wi, td2Wi, td3Wi, td4Wi, 16, "Upper","Lower", dc=27)
```

```
wilcoxtable.noD34(td1Sp, td2Sp, td3Sp, td4Sp, 16, "Upper","Lower", dc=27)  #couldn't do all comparisons due to low n
#Upper-Middle
#Summer
wilcoxtable(td1Su, td2Su, td3Su, td4Su, 16, "Upper","Middle", dc=27)
wilcoxtable(td1Fa, td2Fa, td3Fa, td4Fa, 16, "Upper","Middle", dc=27)
wilcoxtable(td1Wi, td2Wi, td3Wi, td4Wi, 16, "Upper","Middle", dc=27)
wilcoxtable.noD234(td1Sp, td2Sp, td3Sp, td4Sp, 16, "Upper","Middle", dc=27)  #couldn't do all comparisons due to low n
#Lower-Middle
#Summer
wilcoxtable(td1Su, td2Su, td3Su, td4Su, 16, "Lower","Middle", dc=27)
wilcoxtable(td1Fa, td2Fa, td3Fa, td4Fa, 16, "Lower","Middle", dc=27)
wilcoxtable(td1Wi, td2Wi, td3Wi, td4Wi, 16, "Lower","Middle", dc=27)
wilcoxtable(td1Sp, td2Sp, td3Sp, td4Sp, 16, "Lower","Middle", dc=27)

###############
#FOR delwcr:
#TESTS FOR GEO
#Factor Terrace v Wash
#Summer
wilcoxtable(td1Su, td2Su, td3Su, td4Su, 17, "Terrace","Wash", dc=10)
#Fall
wilcoxtable(td1Fa, td2Fa, td3Fa, td4Fa, 17, "Terrace","Wash", dc=10)
#Winter
wilcoxtable(td1Wi, td2Wi, td3Wi, td4Wi, 17, "Terrace","Wash", dc=10)
#Spring
wilcoxtable(td1Sp, td2Sp, td3Sp, td4Sp, 17, "Terrace","Wash", dc=10)
#TESTS FOR Veg
#BG-PV ---- #Summer
wilcoxtableveg(td2Su, td3Su, td4Su, 18, "BG","PV", dc=10)
#Fall
wilcoxtableveg(td2Fa, td3Fa, td4Fa, 18, "BG","PV", dc=10) #couldn't do all comparisons due to low n
#Winter
wilcoxtableveg(td2Wi, td3Wi, td4Wi, 18, "BG","PV", dc=10)
#Spring
wilcoxtableveg(td2Sp, td3Sp, td4Sp, 18, "BG","PV", dc=10) #couldn't do all comparisons due to low n
#BG-IW
wilcoxtableveg(td2Su, td3Su, td4Su, 18, "BG","IW", dc=10)
wilcoxtableveg.noD4(td2Fa, td3Fa, td4Fa, 18, "BG","IW", dc=10) #couldn't do all comparisons due to low n
wilcoxtableveg(td2Wi, td3Wi, td4Wi, 18, "BG","IW", dc=10)
wilcoxtableveg.noD34(td2Sp, td3Sp, td4Sp, 18, "BG","IW", dc=10) #couldn't do all comparisons due to low n
```

```
#PV-IW
wilcoxtableveg(td2Su, td3Su, td4Su, 18, "PV","IW", dc=10)
wilcoxtableveg(td2Fa, td3Fa, td4Fa, 18, "PV","IW", dc=10)
wilcoxtableveg(td2Wi, td3Wi, td4Wi, 18, "PV","IW", dc=10)
wilcoxtableveg(td2Sp, td3Sp, td4Sp, 18, "PV","IW", dc=10)
#TESTS FOR LOCATION
#Upper-Lower
wilcoxtable(td1Su, td2Su, td3Su, td4Su, 16, "Upper","Lower", dc=10)
wilcoxtable(td1Fa, td2Fa, td3Fa, td4Fa, 16, "Upper","Lower", dc=10)
wilcoxtable(td1Wi, td2Wi, td3Wi, td4Wi, 16, "Upper","Lower", dc=10)
wilcoxtable.noD34(td1Sp, td2Sp, td3Sp, td4Sp, 16, "Upper","Lower", dc=10)  #couldn't do all
comparisons due to low n
#Upper-Middle
#Summer
wilcoxtable(td1Su, td2Su, td3Su, td4Su, 16, "Upper","Middle", dc=10)
wilcoxtable(td1Fa, td2Fa, td3Fa, td4Fa, 16, "Upper","Middle", dc=10)
wilcoxtable(td1Wi, td2Wi, td3Wi, td4Wi, 16, "Upper","Middle", dc=10)
wilcoxtable.noD234(td1Sp, td2Sp, td3Sp, td4Sp, 16, "Upper","Middle", dc=10)  #couldn't do all
comparisons due to low n
#Lower-Middle
#Summer
wilcoxtable(td1Su, td2Su, td3Su, td4Su, 16, "Lower","Middle", dc=10)
wilcoxtable(td1Fa, td2Fa, td3Fa, td4Fa, 16, "Lower","Middle", dc=10)
wilcoxtable(td1Wi, td2Wi, td3Wi, td4Wi, 16, "Lower","Middle", dc=10)
wilcoxtable(td1Sp, td2Sp, td3Sp, td4Sp, 16, "Lower","Middle", dc=10)
####################################
#TESTS FOR TRIVARIATE Comparisons
#WCR WEEKLY
load("wcrdepthgeo_weekly.RData") #brings in data variables d1T, d1W,... d4W
geovegtest(6, "BG","PV")
geovegtest(6, "BG","IW")
geovegtest(6, "IW","PV")
geotrivtest(3,"Upper","Lower")
geotrivtest(3,"Upper","Middle")
geotrivtest(3,"Middle","Lower")
geotrivtest(8, "Summer", "Spring")
geotrivtest(8, "Summer", "Fall")
geotrivtest(8, "Summer", "Winter")
geotrivtest(8, "Spring", "Fall")
geotrivtest(8, "Winter", "Spring")
geotrivtest(8, "Fall", "Winter")
load("wcrdepthveg_weekly.RData")
vegtrivtest(7,"Terrace","Wash")
vegtrivtest(3, "Upper", "Middle")
vegtrivtest(3, "Upper", "Lower")
vegtrivtest(3, "Lower", "Middle")
```

```
vegtrivtest(8, "Summer", "Spring")
vegtrivtest(8, "Summer", "Fall")
vegtrivtest(8, "Summer", "Winter")
vegtrivtest(8, "Spring", "Fall")
vegtrivtest(8, "Winter", "Spring")
vegtrivtest(8, "Fall", "Winter")
###########
#TIMING WCR
dc=27 is meanwcr; dc=10 is delwcr
#FOR meanwcr:
d1T=td1[td1$geo=="Terrace",]
d1W=td1[td1$geo=="Wash",]
d2T=td2[td2$geo=="Terrace",]
d2W=td2[td2$geo=="Wash",]
d3T=td3[td3$geo=="Terrace",]
d3W=td3[td3$geo=="Wash",]
d4T=td4[td4$geo=="Terrace",]
d4W=td4[td4$geo=="Wash",]
geovegtest.noD3T(18, "BG","PV", dc=27)#couldn't do all comparisons due to low n
geovegtest.noD3T(18, "BG","IW", dc=27)#couldn't do all comparisons due to low n
geovegtest(18, "IW","PV", dc=27)
geotrivtest(16,"Upper","Lower",dc=27)
geotrivtest.noD4W(16,"Upper","Middle",dc=27)#couldn't do all comparisons low n
geotrivtest.noD4W(16,"Middle","Lower",dc=27)#couldn't do all comparisons low n
geotrivtest.noD34W(20, "Summer", "Spring",dc=27)#couldn't do all comparisons low n
geotrivtest.noD4W(20, "Summer", "Fall",dc=27)#couldn't do all comparisons low n
geotrivtest(20, "Summer", "Winter",dc=27)
geotrivtest.noD34W(20, "Spring", "Fall",dc=27)#couldn't do all comparisons low n
geotrivtest.noD34W(20, "Winter", "Spring",dc=27)#couldn't do all comparisons low n
geotrivtest.noD4W(20, "Fall", "Winter",dc=27)#couldn't do all comparisons low n
d1BG=td1[td1$veg=="BG",]
d2BG=td2[td2$veg=="BG",]
d2IW=td2[td2$veg=="IW",]
d2PV=td2[td2$veg=="PV",]
d3BG=td3[td3$veg=="BG",]
d3IW=td3[td3$veg=="IW",]
d3PV=td3[td3$veg=="PV",]
d4BG=td4[td4$veg=="BG",]
d4IW=td4[td4$veg=="IW",]
d4PV=td4[td4$veg=="PV",]
vegtrivtest.noD3BG(17,"Terrace","Wash",dc=27)#couldn't do all comparisons low n
vegtrivtest(16, "Upper", "Middle",dc=27)
vegtrivtest(16, "Upper", "Lower",dc=27)
vegtrivtest(16, "Lower", "Middle",dc=27)
vegtrivtest.noD34BG(20, "Summer", "Spring",dc=27)#couldn't do all comparisons low n
vegtrivtest.noD34BG(20, "Summer", "Fall",dc=27)#couldn't do all comparisons low n
```

```
vegtrivtest(20, "Summer", "Winter",dc=27)
vegtrivtest.noD34BG(20, "Spring", "Fall",dc=27)#couldn't do all comparisons  low n
vegtrivtest.noD34BG(20, "Winter", "Spring",dc=27)#couldn't do all comparisons low n
vegtrivtest.noD34BG(20, "Fall", "Winter",dc=27)#couldn't do all comparisons low n
##############
#FOR delwcr:
d1T=td1[td1$geo=="Terrace",]
d1W=td1[td1$geo=="Wash",]
d2T=td2[td2$geo=="Terrace",]
d2W=td2[td2$geo=="Wash",]
d3T=td3[td3$geo=="Terrace",]
d3W=td3[td3$geo=="Wash",]
d4T=td4[td4$geo=="Terrace",]
d4W=td4[td4$geo=="Wash",]
geovegtest.noD3T(18, "BG","PV", dc=10)#couldn't do all comparisons due to low n
geovegtest.noD3T(18, "BG","IW", dc=10)#couldn't do all comparisons due to low n
geovegtest(18, "IW","PV", dc=10)
geotrivtest(16,"Upper","Lower",dc=10)
geotrivtest.noD4W(16,"Upper","Middle",dc=10)#couldn't do all comparisons low n
geotrivtest.noD4W(16,"Middle","Lower",dc=10)#couldn't do all comparisons low n
geotrivtest.noD34W(20, "Summer", "Spring",dc=10)#couldn't do all comparisons  low n
geotrivtest.noD4W(20, "Summer", "Fall",dc=10)#couldn't do all comparisons low n
geotrivtest(20, "Summer", "Winter",dc=10)
geotrivtest.noD34W(20, "Spring", "Fall",dc=10)#couldn't do all comparisons low n
geotrivtest.noD34W(20, "Winter", "Spring",dc=10)#couldn't do all comparisons low n
geotrivtest.noD4W(20, "Fall", "Winter",dc=10)#couldn't do all comparisons due to low n
  d1BG=td1[td1$veg=="BG",]
d2BG=td2[td2$veg=="BG",]
d2IW=td2[td2$veg=="IW",]
d2PV=td2[td2$veg=="PV",]
d3BG=td3[td3$veg=="BG",]
d3IW=td3[td3$veg=="IW",]
d3PV=td3[td3$veg=="PV",]
d4BG=td4[td4$veg=="BG",]
d4IW=td4[td4$veg=="IW",]
d4PV=td4[td4$veg=="PV",]
vegtrivtest.noD3BG(17,"Terrace","Wash",dc=10)#couldn't do all comparisons low n
vegtrivtest(16, "Upper", "Middle",dc=10)
vegtrivtest(16, "Upper", "Lower",dc=10)
vegtrivtest(16, "Lower", "Middle",dc=10)
vegtrivtest.noD34BG(20, "Summer", "Spring",dc=10)#couldn't do all comparisons low n
vegtrivtest.noD34BG(20, "Summer", "Fall",dc=10)#couldn't do all comparisons low n
vegtrivtest(20, "Summer", "Winter",dc=10)
vegtrivtest.noD34BG(20, "Spring", "Fall",dc=10)#couldn't do all comparisons low n
vegtrivtest.noD34BG(20, "Winter", "Spring",dc=10)#couldn't do all comparisons low n
vegtrivtest.noD34BG(20, "Fall", "Winter",dc=10)#couldn't do all comparisons low n
```

APPENDIX D

STATISTICAL OUTPUT: PRECIPITATION AND SOIL MOISTURE

Table D1. Distribution of 70 precipitation events recorded at six stations in Yuma Wash from July 2006-February 2010, including missing data points, zero and non-zero values by station.

Number of actual precipitation events (non-zero datapoints) recorded at each station					
	Total	Summer	Fall	Winter	Spring
ECOV1	36	18	1	12	5
ECOV2	43	14	3	21	5
MET1	41	13	4	20	4
MET2	48	22	4	19	3
MET3	49	18	6	22	3
MET4	50	20	5	22	3
Number of missing values from each station					
	Total	Summer	Fall	Winter	Spring
ECOV1	16	2	3	11	0
ECOV2	11	10	1	0	0
MET1	10	10	0	0	0
MET2	2	0	0	1	1
MET3	1	1	0	0	0
MET4	0	0	0	0	0
Number of zero datapoints					
	Total	Summer	Fall	Winter	Spring
ECOV1	19	11	2	4	2
ECOV2	17	7	2	6	2
MET1	20	8	2	7	3
MET2	21	9	2	7	3
MET3	21	12	0	5	4
MET4	21	11	1	5	4
Number of recorded values at each station when precipitation occurred at at least one station in Yuma Wash (zero and non-zero values)					
	Total	Summer	Fall	Winter	Spring
ECOV1	55	29	3	16	7
ECOV2	60	21	5	27	7
MET1	61	21	6	27	7
MET2	69	31	6	26	6
MET3	70	30	6	27	7
MET4	71	31	6	27	7

Table D2. Percent distribution of the 70 precipitation events recorded in Yuma Wash from July 2006-February 2010 by season and station.

Percent Distribution of Precipitation Recorded in Yuma Wash by Station and Season				
	% Summer	**% Fall**	**% Winter**	**%Spring**
ECOV1	0.50	0.03	0.33	0.14
ECOV2	0.33	0.07	0.49	0.11
MET1	0.32	0.10	0.48	0.10
MET2	0.46	0.08	0.40	0.06
MET3	0.37	0.12	0.44	0.06
MET4	0.40	0.10	0.44	0.06
mean	0.46	0.10	0.35	0.09

Table D3. Temporal distribution of 70 precipitation events recorded at six stations in Yuma Wash from July 2006-February 2010 by season and by year.

Number of Precipitation Events by Year					
	All seasons	**Summer**	**Fall**	**Winter**	**Spring**
All years	70	32	7	25	6
2006	11	10	1	NA	NA
2007	12	4	2	3	3
2008	26	13	2	8	3
2009	11	5	2	4	0
2010	10	NA	NA	10	NA

Table D4. Distribution of 54 precipitation events included in statistical analysis of precipitation in Yuma Wash, including missing data points, and zero and non-zero values.

Number of events selected for precipitation analyses					
	Total	Summer	Fall	Winter	Spring
ECOV1	45	21	3	16	5
ECOV2	51	20	5	21	5
MET1	52	20	6	21	5
MET2	53	22	6	20	5
MET3	53	21	6	21	5
MET4	54	23	5	21	5
Number of missing values from each station					
	Total	Summer	Fall	Winter	Spring
ECOV1	9	1	3	5	0
ECOV2	3	2	1	0	0
MET1	2	2	0	0	0
MET2	1	0	0	1	0
MET3	1	1	0	0	0
MET4	0	0	0	0	0
Number of zero datapoints					
	Total	Summer	Fall	Winter	Spring
ECOV1	14	7	2	4	1
ECOV2	13	7	2	3	1
MET1	17	8	2	5	2
MET2	15	6	2	5	2
MET3	13	7	0	4	2
MET4	13	7	0	4	2
Number of non-zero datapoints					
	Total	Summer	Fall	Winter	Spring
ECOV1	31	14	1	12	4
ECOV2	38	13	3	18	4
MET1	35	12	4	16	3
MET2	38	16	4	15	3
MET3	40	14	6	17	3
MET4	41	16	5	17	3

Table D5. Event precipitation summary statistics by station, location, geomorphic surface, season and year for 54 events.

	Median	GMean	Mean	Max	SD	GSD	CV	GCV
ECOV1	3	3	9	73	15	5	169	3.0
ECOV2	3	4	9	73	14	4	156	2.3
MET1	4	4	10	69	14	4	143	2.5
MET2	6	4	9	69	13	4	134	2.4
MET3	6	6	11	62	13	3	114	1.8
MET4	6	5	10	62	12	3	116	1.9
Lower	3	3	9	73	14	4	160	2.6
Middle	5	4	9	69	13	4	138	2.5
Upper	6	6	11	62	12	3	114	1.9
Terrace	5	4	10	73	13	4	138	2.5
Wash	6	5	10	73	13	4	132	2.2
Summer	5	5	9	36	9	3	101	1.9
Fall	17	14	19	41	13	2	68	1.1
Winter	4	4	10	73	16	4	169	2.4
Spring	1	2	3	11	4	4	112	2.0
Su06	21	19	19	26	5	1	25	0.3
Fa06	13	12	13	17	5	1	36	0.3
Wi06-07	1	1	2	3	1	1	46	0.4
Sp07	1	1	1	1	0	1	26	0.3
Su07	7	10	14	35	11	2	78	0.9
Fa07	18	14	18	31	12	2	68	0.9
Wi07-08	10	7	9	15	4	2	52	0.8
Sp08	3	2	4	11	4	4	92	2.9
Su08	3	3	6	36	8	3	131	1.7
Fa08	25	19	24	41	14	2	58	1.0
Wi08-09	2	4	8	21	8	4	100	2.5
Su09	4	4	7	19	7	4	91	2.0
Fa09	2	2	2	2	NA	1	NA	0.0
Wi09-10	4	4	12	73	21	5	180	2.9
2006	17	17	18	26	5	1	31	0.4
2007	6	5	11	35	12	4	107	2.0
2008	4	4	8	41	9	4	115	2.1
2009	4	3	7	21	7	4	103	2.1
2010	5	4	13	73	23	5	170	3.3

Table D6. Shapiro-Wilk test for normality in the distribution of event precipitation (mm) recorded.

Station	W	p-value
ECOV1	0.58	3.37E-08
ECOV2	0.62	1.03E-08
MET1	0.66	8.69E-08
MET2	0.67	4.94E-08
MET3	0.77	1.75E-06
MET4	0.75	6.93E-07

Table D7. Pearson's R-square and Spearman's rank correlation (rho) precipitation (mm) recorded at six stations in Yuma Wash for period of record.

Spearmans Rho	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	0.9502	0.8248	0.8960	0.8887	0.9008
ECOV2	0.9502	1	0.8639	0.7990	0.8248	0.8318
MET1	0.8248	0.8639	1	0.9201	0.7221	0.7233
MET2	0.8960	0.7990	0.9201	1	0.8238	0.8120
MET3	0.8887	0.8248	0.7221	0.8238	1	0.9960
MET4	0.9008	0.8318	0.7233	0.8120	0.9960	1
Pearsons R sq	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	0.993006	0.9468	0.9316	0.8759	0.8834
ECOV2	0.9930	1	0.9471	0.9077	0.7971	0.8005
MET1	0.9468	0.9471	1	0.9363	0.6382	0.6581
MET2	0.9316	0.9077	0.9363	1	0.7294	0.7532
MET3	0.8759	0.7971	0.6382	0.7294	1	0.9964
MET4	0.8834	0.8005	0.6581	0.7532	0.9964	1

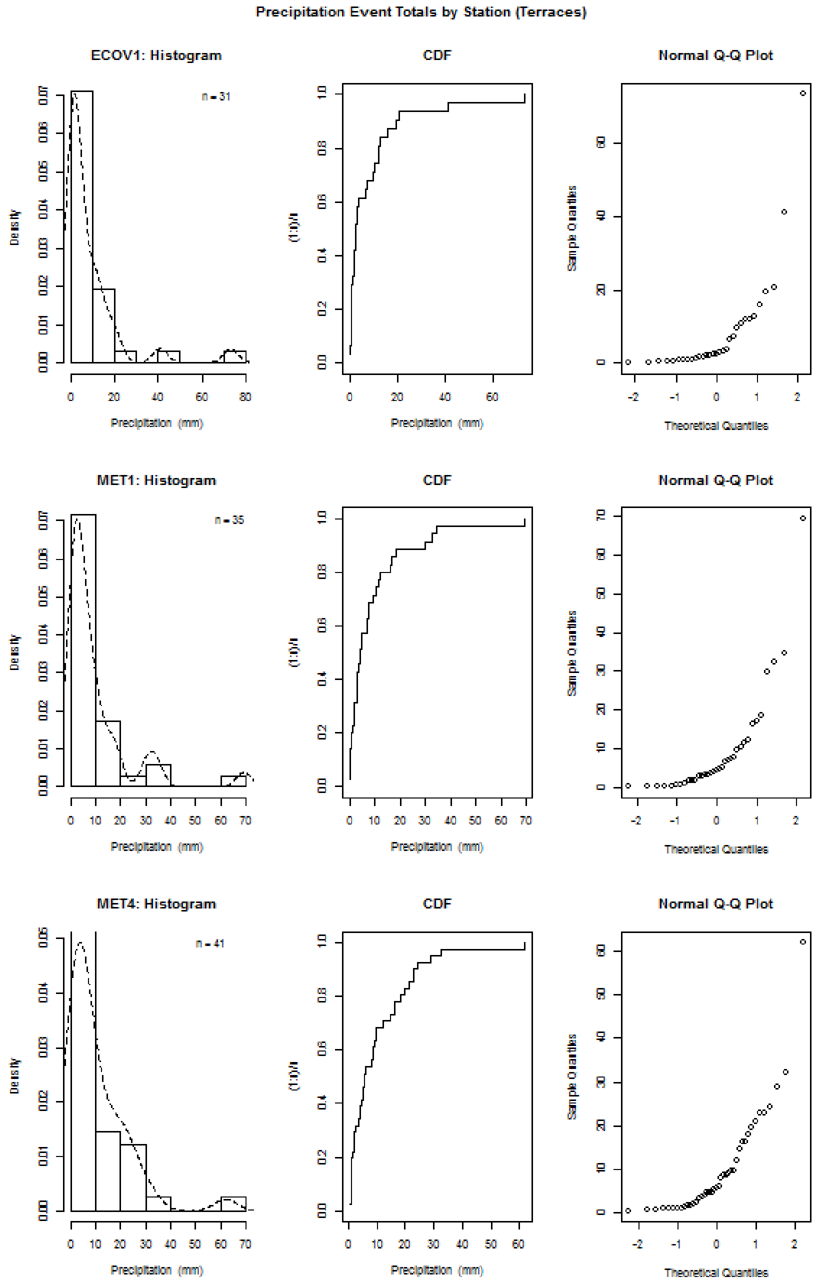

Figure D1. Histograms, cumulative distribution frequencies, and Q-Q plots of event precipitation (mm) recorded at terrace stations for the period of record from July 2006 to February 2010.

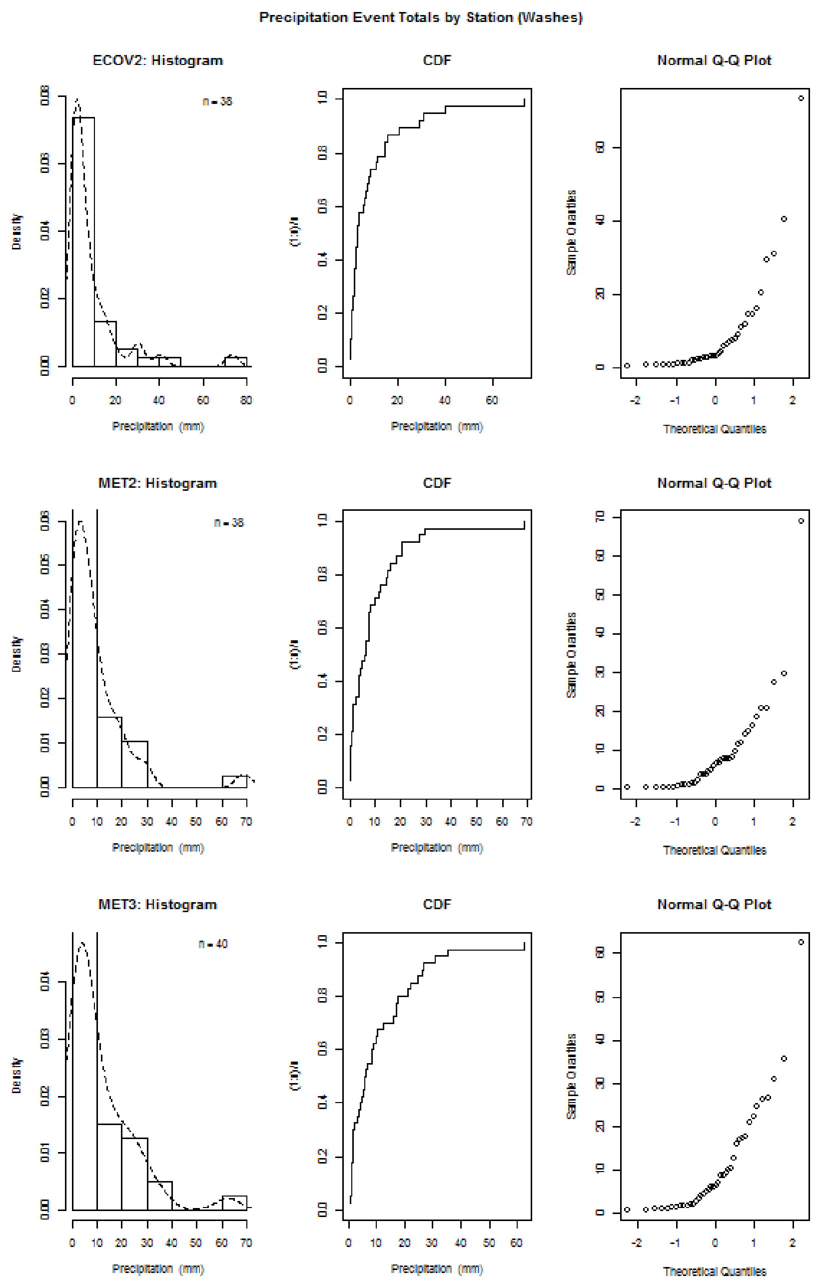

Figure D2. Histograms, cumulative distribution frequencies, and Q-Q plots of event precipitation (mm) recorded at wash stations for the period of record from July 2006 to February 2010.

Table D8. Kolmogorov-Smirnov tests between individual stations for differences in distribution of event precipitation (mm) for the period of record and for each season.

Kolmgorov Smirnov Distribution Test										
	All	**α = 0.05**	Sum	**α = 0.05**	Fall	**α = 0.05**	Win	**α = 0.05**	Spr	**α = 0.05**
	D	p	D	p	D	p	D	p	D	p
ECOV1-ECOV2	0.10	1.00	0.18	0.98	1.00	0.50	0.31	0.51	0.25	1.00
ECOV1-MET1	0.21	0.50	0.23	0.90	1.00	0.40	0.40	0.23	0.50	0.66
ECOV1-MET2	0.27	0.20	0.33	0.39	1.00	0.40	0.23	0.86	0.42	0.89
ECOV1-MET3	0.27	0.22	0.36	0.33	1.00	0.29	0.35	0.36	0.75	0.23
ECOV1-MET4	0.27	0.18	0.33	0.39	1.00	0.33	0.29	0.60	0.50	0.78
ECOV2-MET1	0.15	0.81	0.18	0.99	0.42	0.89	0.24	0.73	0.50	0.78
ECOV2-MET2	0.21	0.37	0.25	0.74	0.67	0.40	0.21	0.86	0.42	0.93
ECOV2-MET3	0.20	0.39	0.41	0.22	0.67	0.33	0.20	0.88	0.75	0.29
ECOV2-MET4	0.21	0.34	0.30	0.53	0.67	0.38	0.20	0.88	0.50	0.78
MET1-MET2	0.11	0.97	0.23	0.86	0.50	0.77	0.21	0.88	0.33	1.00
MET1-MET3	0.18	0.62	0.38	0.31	0.50	0.55	0.19	0.93	0.33	1.00
MET1-MET4	0.15	0.78	0.35	0.36	0.50	0.56	0.16	0.98	0.33	1.00
MET2-MET3	0.16	0.72	0.29	0.58	0.33	0.92	0.16	0.98	0.33	1.00
MET2-MET4	0.13	0.87	0.25	0.70	0.40	0.75	0.15	1.00	0.33	1.00
MET3-MET4	0.10	0.99	0.22	0.85	0.17	1.00	0.12	1.00	0.33	1.00

Table D9. F, Kruskal Wallis, and Tukey tests for differences in event precipitation (mm) by station, by location, and by geomorphic surface.

F and Kruskal Wallis Tests for Differences in Event Precipitation				
by station		**α = 0.05**		**α = 0.05**
	F	p.value	chi.sq	p.value
all	0.15	0.98	4.64	0.46
Su	1.24	0.30	4.70	0.45
Fa	1.09	0.40	5.60	0.35
Wi	0.02	1.00	1.07	0.96
Sp	0.05	1.00	2.80	0.73
by location				
	F	p.value	chi.sq	p.value
all	0.34	0.71	4.39	0.11
Su	2.98	0.06	4.16	0.13
Fa	2.34	0.12	4.41	0.11
Wi	0.01	0.99	0.74	0.69
Sp	0.14	0.87	2.50	0.29
by geomorphic surface				
	F	p.value	chi.sq	p.value
all	0.02	0.90	0.13	0.72
Su	0.24	0.62	0.33	0.56
Fa	0.12	0.73	0.16	0.69
Wi	0.02	0.89	0.02	0.88
Sp	0.01	0.91	0.02	0.88
Tukey Test for Multiple Comparisons				
by location_summer		p.adjusted		
Middle-Lower		0.76		
Upper-Lower		**0.05**		
Upper-Middle		0.23		

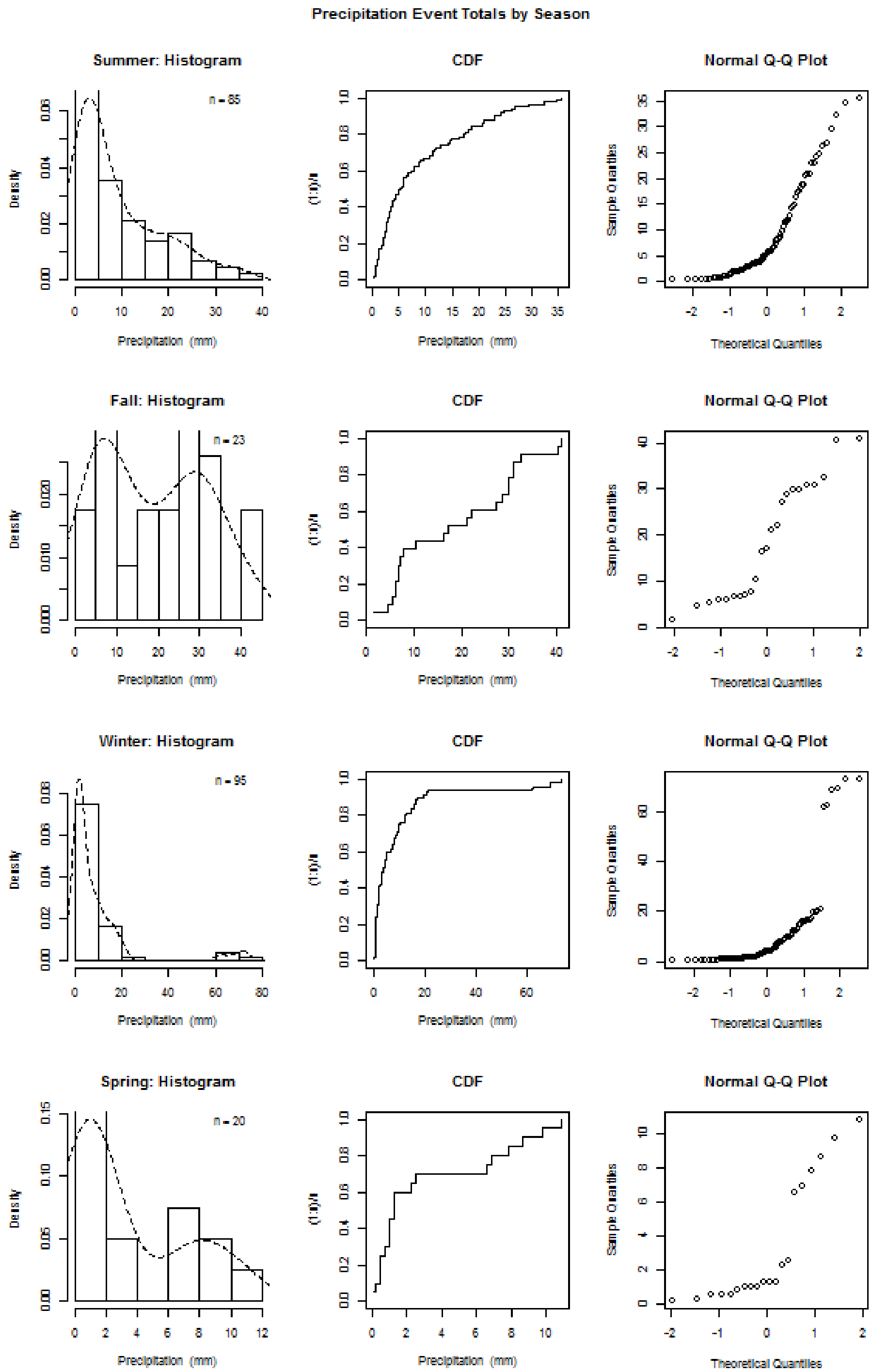

Figure D3. Histograms, cumulative distribution frequencies, and QQ plots for event precipitation (mm) for the period record, truncated by season in the Yuma Wash watershed.

Table D10. Shapiro-Wilks test for normality of seasonal event precipitation (mm) for the period of record when at least five stations were operative.

Station--Winter	**W**	**p-value**
ECOV1	0.5791	7.22E-05
ECOV2	0.5275	1.40E-06
MET1	0.5381	4.46E-06
MET2	0.5228	5.41E-06
MET3	0.5998	1.04E-05
MET4	0.5855	7.57E-06
Station--Spring	**W**	**p-value**
ECOV1	0.7022	0.0123
ECOV2	0.6648	0.0042
MET1	0.8118	0.1431
MET2	0.8665	0.2857
MET3	0.8748	0.3092
MET4	0.8847	0.3383
Station--Summer	**W**	**p-value**
ECOV1	0.7943	0.0042
ECOV2	0.7297	0.0011
MET1	0.7484	0.0026
MET2	0.8852	0.0467
MET3	0.8841	0.0665
MET4	0.8720	0.0292
Station--Fall	**W**	**p-value**
ECOV1*	--	--
ECOV2	0.9364	0.5132
MET1	0.8344	0.1796
MET2	0.7980	0.0987
MET3	0.9342	0.6128
MET4	0.9337	0.6218

* not enough datapoints from station ECOV1 to conduct a Shapiro Wilks test for normality in Fall precipitation.

Table D11. Pearson's R-square and Spearman's rank correlation (rho) for seasonal event precipitation (mm) recorded at six stations in Yuma Wash for period of record.

Winter (rho)	ECOV1	ECOV2	MET1	MET2	MET3	MET4
ECOV1	1	0.9453	0.9787	0.9664	0.7903	0.8445
ECOV2	0.9453	1	0.9686	0.9360	0.8801	0.8916
MET1	0.9787	0.9686	1	0.9371	0.8551	0.8638
MET2	0.9664	0.9360	0.9371	1	0.9361	0.9547
MET3	0.7903	0.8801	0.8551	0.9361	1	0.9926
MET4	0.8445	0.8916	0.8638	0.9547	0.9926	1
Winter (R-sq)	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	0.9982	0.9967	0.9983	0.9836	0.9855
ECOV2	0.9982	1	0.9918	0.9829	0.9617	0.9626
MET1	0.9967	0.9918	1	0.9922	0.9773	0.9799
MET2	0.9983	0.9829	0.9922	1	0.9972	0.9972
MET3	0.9836	0.9617	0.9773	0.9972	1	0.9990
MET4	0.9855	0.9626	0.9799	0.9972	0.9990	1
Spring (rho)	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	1	1	1	0.5	0.5
ECOV2	1	1	1	1	1	1
MET1	1	1	1	1	0.5	0.5
MET2	1	1	1	1	0.5	0.5
MET3	0.5	1	0.5	0.5	1	1
MET4	0.5	1	0.5	0.5	1	1
Spring (R-sq)	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	1.0000	0.9999	0.9956	0.9410	0.9336
ECOV2	1.0000	1	1	1	1	1
MET1	0.9999	1	1	0.9944	0.9450	0.9378
MET2	0.9956	1	0.9944	1	0.9061	0.8970
MET3	0.9410	1	0.9450	0.9061	1	0.9998
MET4	0.9336	1	0.9378	0.8970	0.9998	1
Summer (rho)	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	0.7754	0.4519	0.8693	0.8214	0.8500
ECOV2	0.7754	1	0.5356	0.5701	0.1818	0.4519
MET1	0.4519	0.5356	1	0.8818	0.1796	0.2727
MET2	0.8693	0.5701	0.8818	1	0.5205	0.5138
MET3	0.8214	0.1818	0.1796	0.5205	1	0.9868
MET4	0.8500	0.4519	0.2727	0.5138	0.9868	1
Summer (R-sq)	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	0.8512	0.3041	0.7210	0.5563	0.6022
ECOV2	0.8512	1	0.8348	0.5360	0.0594	0.0990
MET1	0.3041	0.8348	1	0.7001	0.0089	0.0000
MET2	0.7210	0.5360	0.7001	1	0.0705	0.1101
MET3	0.5563	0.0594	0.0089	0.0705	1	0.9951
MET4	0.6022	0.0990	0.0000	0.1101	0.9951	1
Fall (rho)	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	NA	NA	NA	NA	NA	NA
ECOV2	NA	1	1	0.5	0.5	0.5
MET1	NA	1	1	0.8	0.8	0.8
MET2	NA	0.5	0.8	1	1	1
MET3	NA	0.5	0.8	1	1	1
MET4	NA	0.5	0.8	1	1	1
Fall (R-sq)	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	NA	NA	NA	NA	NA	NA
ECOV2	NA	1	0.9687	0.8699	0.6492	0.6751
MET1	NA	0.9687	1	0.9689	0.7153	0.7201
MET2	NA	0.8699	0.9689	1	0.7711	0.7663
MET3	NA	0.6492	0.7153	0.7711	1	0.9991
MET4	NA	0.6751	0.7201	0.7663	0.9991	1

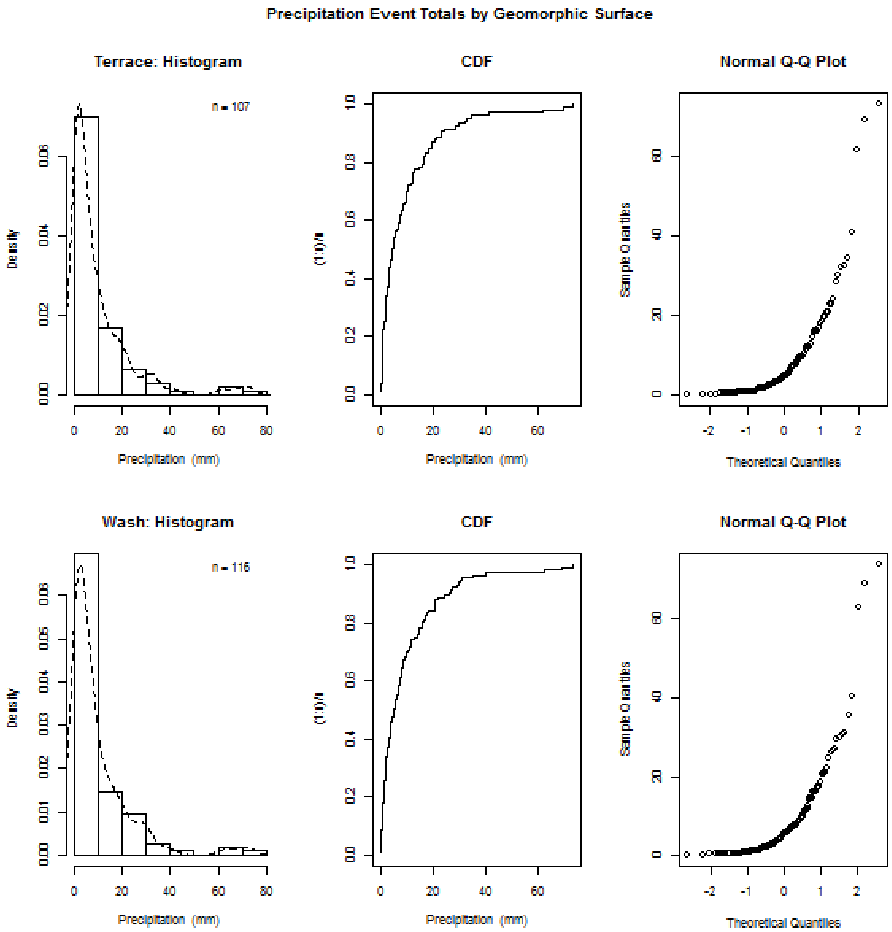

Figure D4.Histograms, cumulative distribution frequencies, and QQ plots for event precipitation (mm) for the period of record pooled by geomorphic surface in the Yuma Wash watershed.

Table D12. F and Kruskal Wallis tests for interannual differences in event precipitation by season.

F and Kruskal Wallis tests for Interannual Differences in Event Precipitation				
		α = 0.05		**α = 0.05**
	F	p.value	chi.sq	p.value
All	2.58	0.04	14.16	0.0068
Summers	7.26	0.000227	20.50	0.0001
Falls	1.53	0.24	3.61	0.31
Winters	1.72	0.17	8.74	0.03
Springs	4.70	0.04	0.99	0.32

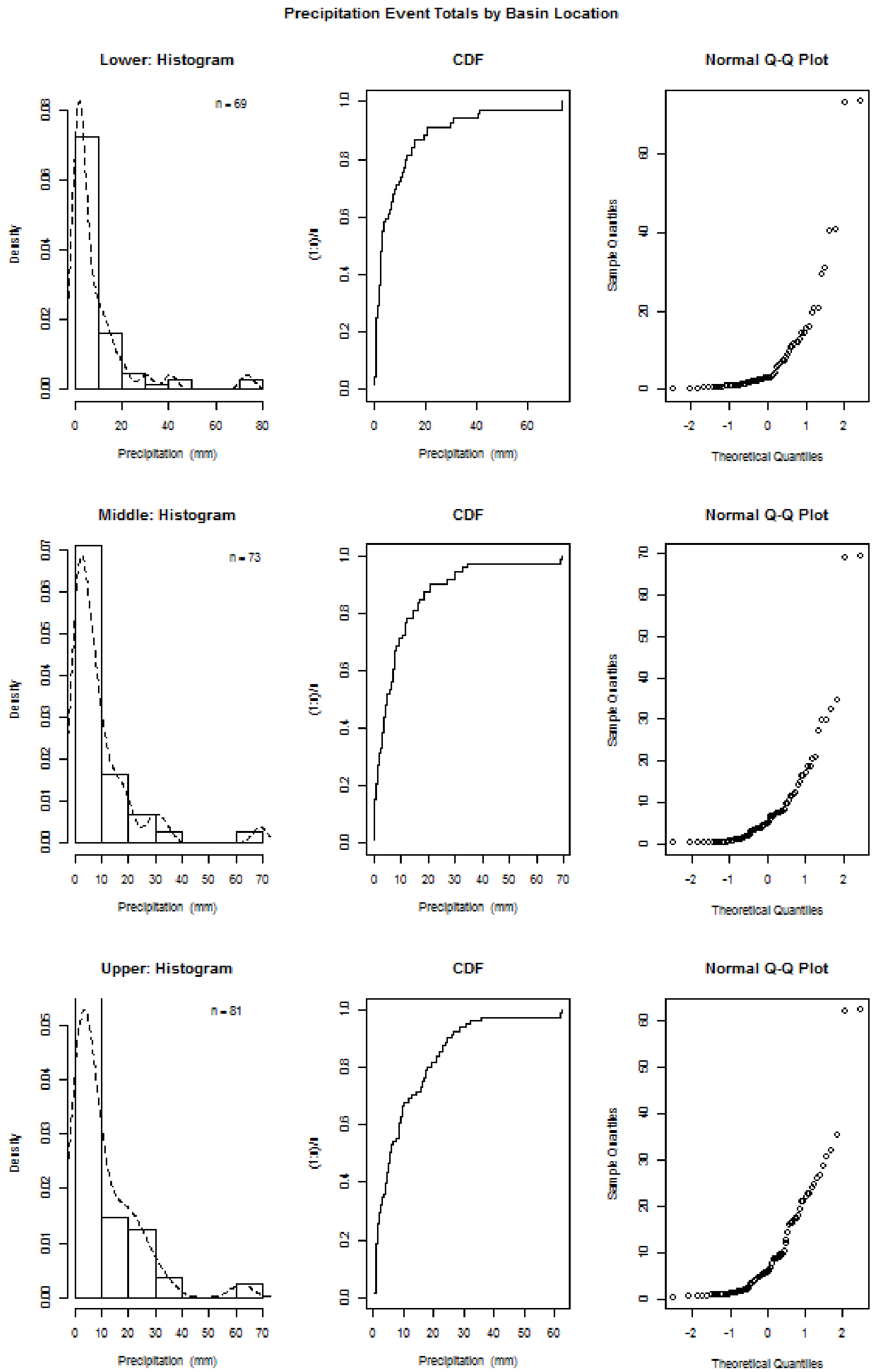

Figure D5. Histograms, cumulative distribution frequencies, and QQ plots for event precipitation (mm) for the period of record pooled by basin location in the Yuma Wash watershed.

Table D13. Tukey HSD and Mann Whitney Wilcoxon tests for interannual and interseasonal differences in event precipitation (mm) for the period of record.

Tukey HSD and Mann Whitney Wilcox test for Differences in Event Precipitation By season between years			
All Seasons	**Tukey HSD p.adj**	**W**	**p.test**
2006* vs 2007	0.6160	253	0.0342
2006 *vs 2008	0.1983	749	0.0004
2006* vs 2009	0.1365	346	0.0004
2006* vs 2010*	0.8773	360	0.0011
2007 vs 2008	0.8249	1705	0.4160
2007 vs 2009	0.6440	870	0.0716
2007 vs 2010*	0.9384	800	0.6402
2008 vs 2009	0.9809	1954	0.3782
2008 vs 2010*	0.2286	1974	0.7726
2009 vs 2010*	0.1659	832	0.8019
Fall		**W**	p.test
2006 vs 2007	0.8724	20	1
2006 vs 2008	0.4382	8	0.2141
2006 vs 2009	0.8398	4	0.4
2007 vs 2008	0.7314	35	0.6891
2007 vs 2009	0.5670	10	0.1538
2008 vs 2009	0.3222	8	0.2222
Winter		**W**	p.test
2006-07 vs 2007-08	0.7177	28	0.0020
2006-07 vs 2008-09	0.8927	56	0.3857
2006-07 vs 2009-10	0.2355	89	0.0313
2007-08 vs 2008-09	0.9772	295	0.1484
2007-08 vs 2009-10	0.6113	665	0.1934
2008-09 vs 2009-10	0.4241	340	0.4568
Spring		**W**	p.test
2007 vs 2008	0.0438	33	0.3395
Summer		W	p.test
2006 vs 2007	0.4259	73	0.1584
2006 vs 2008	0.0010	268	0.0006
2006 vs 2009	0.0068	133	0.0017
2007 vs 2008	0.0171	501	0.0008
2007 vs 2009	0.1195	220	0.0466
2008 vs 2009	0.9422	391	0.4703

*partial year totals for 2006 and 2010 render interannual comparisons for significant differences between these years invalid. For 2006, summer and fall seasonal comparisons between years are valid, and for 2009-10, winter seasonal comparisons between years are valid.

Table D14. F, Kruskal-Wallis, Tukey and Mann Whitney Wilcoxon tests for interseasonal differences in event precipitation (mm). Data pooled for each season for the period of record.

F Kruskal-Wallis test for Intrannual Differences in Event Precipitation				
		$\alpha = 0.05$		**$\alpha = 0.05$**
	F	p.value	chi.sq	p.value
Seasons	5.49	0.0012	26.97	5.98E-06
	Tukey		**Mann-Whitney**	
	p adj		W	p.test
Fall-Summer		0.0073	435	0.0002
Winter-Summer		0.9825	4301	0.1911
Spring-Summer		0.2757	1131	0.0033
Winter-Fall		0.0138	1586	6.40E-05
Spring-Fall		0.0006	368	3.39E-05
Spring-Winter		0.1751	1193	0.0167

Table D15. Event precipitation mean intensity descriptive statistics by station, location, geomorphic surface, season and year for the period of record.

	Median	GMean	Mean	SD	GSD	CV	GCV
ECOV1	3	4	5	4	2	67	0.7
ECOV2	4	5	7	8	2	112	1.0
MET1	3	4	5	7	2	133	0.9
MET2	4	4	6	5	2	87	0.9
MET3	5	5	8	9	2	115	1.0
MET4	4	5	7	9	3	116	1.2
Lower	4	4	6	6	2	99	0.9
Middle	3	4	5	6	2	109	0.9
Upper	4	5	8	9	2	115	1.1
Terrace	3	4	6	7	2	113	1.0
Wash	4	5	7	7	2	108	1.0
Summer	8	7	10	10	2	93	1.0
Fall	5	6	7	5	2	71	0.7
Winter	3	3	3	2	2	67	0.6
Spring	3	4	5	4	2	71	0.8
Su06	14	19	23	16	2	69	0.6
Fa06	11	10	11	5	1	44	0.4
Wi06-07	5	5	6	3	2	51	0.4
Sp07	2	2	3	2	2	60	0.5
Su07	10	9	14	13	3	98	1.3
Fa07	4	4	4	1	1	34	0.4
Wi07-08	2	2	3	4	2	139	0.8
Sp08	6	5	6	4	2	58	0.7
Su08	7	7	9	6	2	76	0.8
Fa08	8	8	10	6	2	66	0.6
Wi08-09	3	3	3	1	1	29	0.3
Su09	8	6	7	4	2	62	1.0
Fa09	5	5	5	NA	1	NA	0.0
Wi09-10	2	2	3	1	2	46	0.5
2006	14	16	19	14	2	71	0.6
2007	5	5	8	10	2	123	1.0
2008	5	5	7	6	2	86	0.9
2009	4	4	5	4	2	71	0.9
2010	2	2	3	1	1	43	0.4

Table D16. Event precipitation maximum intensity descriptive statistics by station, location, geomorphic surface, season and year.

	Median	GMean	Mean	Max	SD	GSD	CV	GCV
ECOV1	8	10	18	76	20	3	109	1.4
ECOV2	9	11	18	101	21	3	119	1.2
MET1	9	11	18	88	21	3	116	1.3
MET2	14	12	22	107	25	3	116	1.6
MET3	14	15	26	140	30	3	118	1.4
MET4	12	14	24	122	27	3	112	1.6
Lower	9	11	18	101	20	3	114	1.3
Middle	12	11	20	107	23	3	116	1.5
Upper	12	14	25	140	29	3	114	1.5
Terrace	9	12	20	122	23	3	114	1.5
Wash	12	12	22	140	26	3	118	1.4
Summer	21	20	32	140	29	3	91	1.4
Fall	24	23	25	49	10	1	41	0.4
Winter	6	7	12	107	19	2	159	1.0
Spring	6	8	14	49	16	3	116	1.3
Su06	76	61	64	88	22	1	34	0.4
Fa06	27	30	31	49	12	1	39	0.3
Wi06-07	6	7	8	15	4	2	50	0.5
Sp07	3	4	4	6	2	1	37	0.4
Su07	30	35	44	101	27	2	62	0.8
Fa07	20	21	22	37	9	1	39	0.4
Wi07-08	6	5	6	15	3	2	56	0.5
Sp08	9	11	19	49	18	3	96	1.4
Su08	16	16	26	140	31	3	120	1.3
Fa08	24	24	26	41	10	1	38	0.4
Wi08-09	8	6	8	21	5	2	64	0.7
Su09	21	15	26	61	21	3	81	1.8
Fa09	12	12	12	12	NA	1	NA	0.0
Wi09-10	6	8	16	107	25	3	157	1.4
2006	46	47	53	88	26	2	49	0.5
2007	15	17	25	101	24	3	96	1.2
2008	12	11	19	140	24	3	126	1.3
2009	8	10	18	61	18	3	103	1.4
2010	6	8	18	107	27	3	151	1.5

Table D17. Shapiro-Wilks test for normality of mean and maximum precipitation intensity (mm/hr) for the period of record at least five of six stations were operative.

Station	$W_{mean\ int}$	p-value$_{mean\ int}$	$W_{max\ int}$	p-value$_{max\ int}$
ECOV1	0.86	0.0009	0.77	1.64E-05
ECOV2	0.64	1.87E-08	0.69	9.78E-08
MET1	0.50	9.41E-10	0.72	7.03E-07
MET2	0.80	9.51E-06	0.75	1.08E-06
MET3	0.67	3.08E-08	0.73	3.00E-07
MET4	0.69	5.18E-08	0.77	1.66E-06

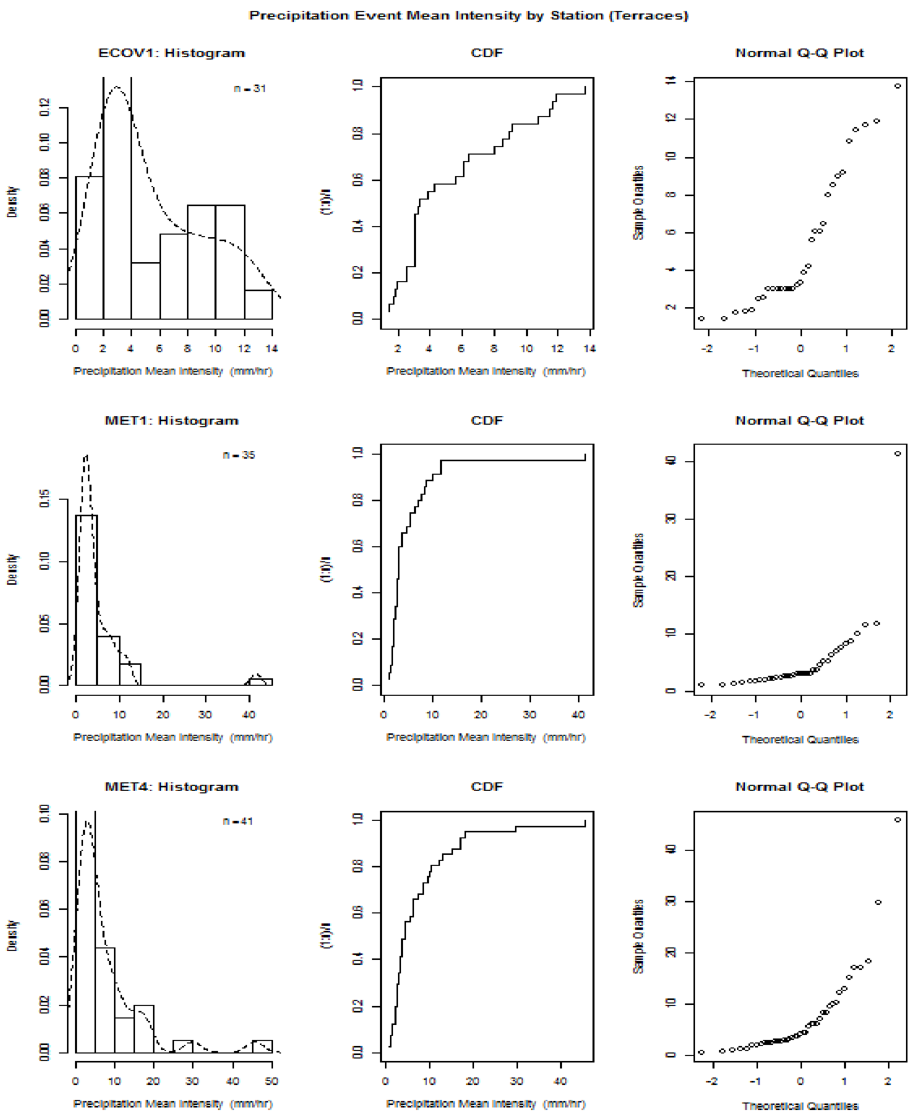

Figure D6. Histograms, cumulative distribution frequencies, and Q-Q plots of precipitation event mean intensities (mm) recorded at terrace stations for the period of record from July 2006 to February 2010 when at least 5 stations in Yuma Wash were operative.

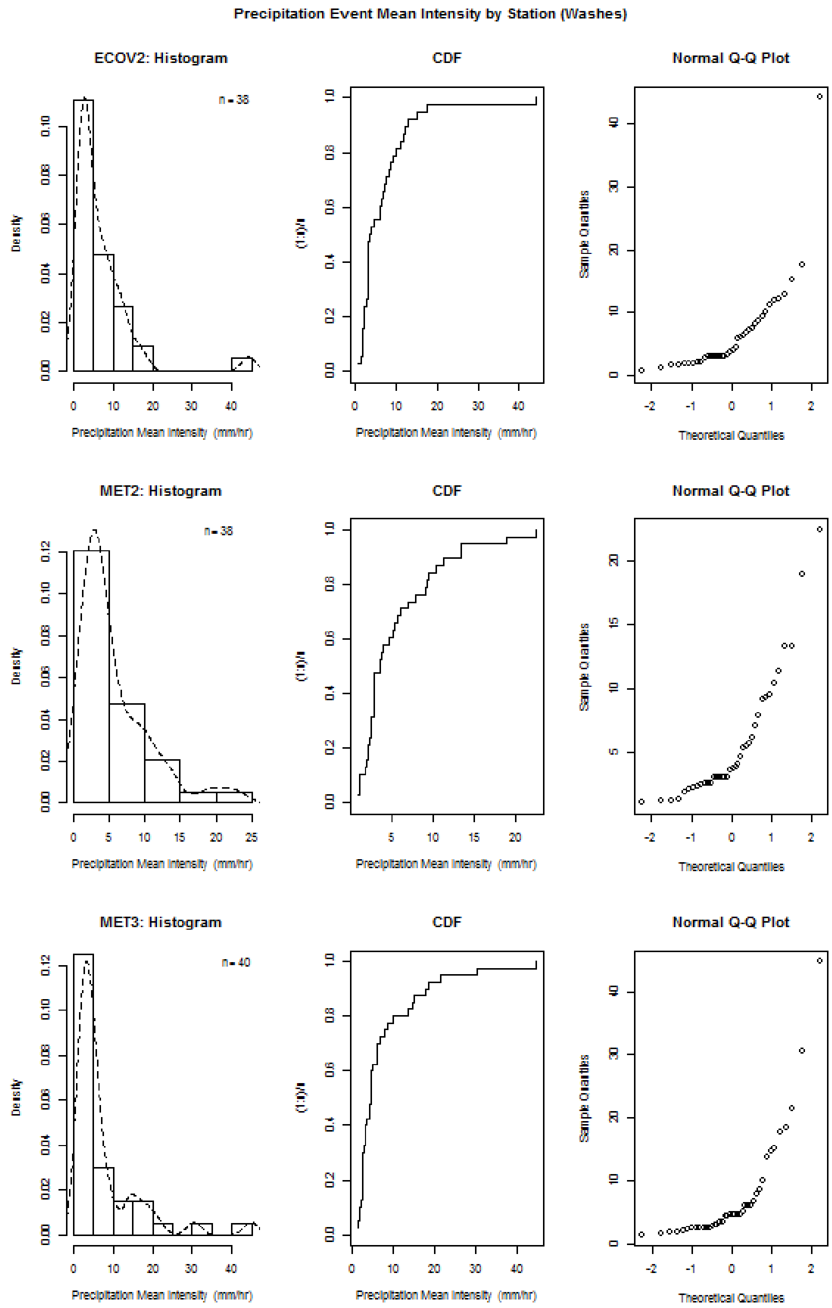

Figure D7. Histograms, cumulative distribution frequencies, and Q-Q plots of precipitation event mean intensities (mm) recorded at wash stations for the period of record from July 2006 to February 2010 when at least 5 stations in Yuma Wash were operative.

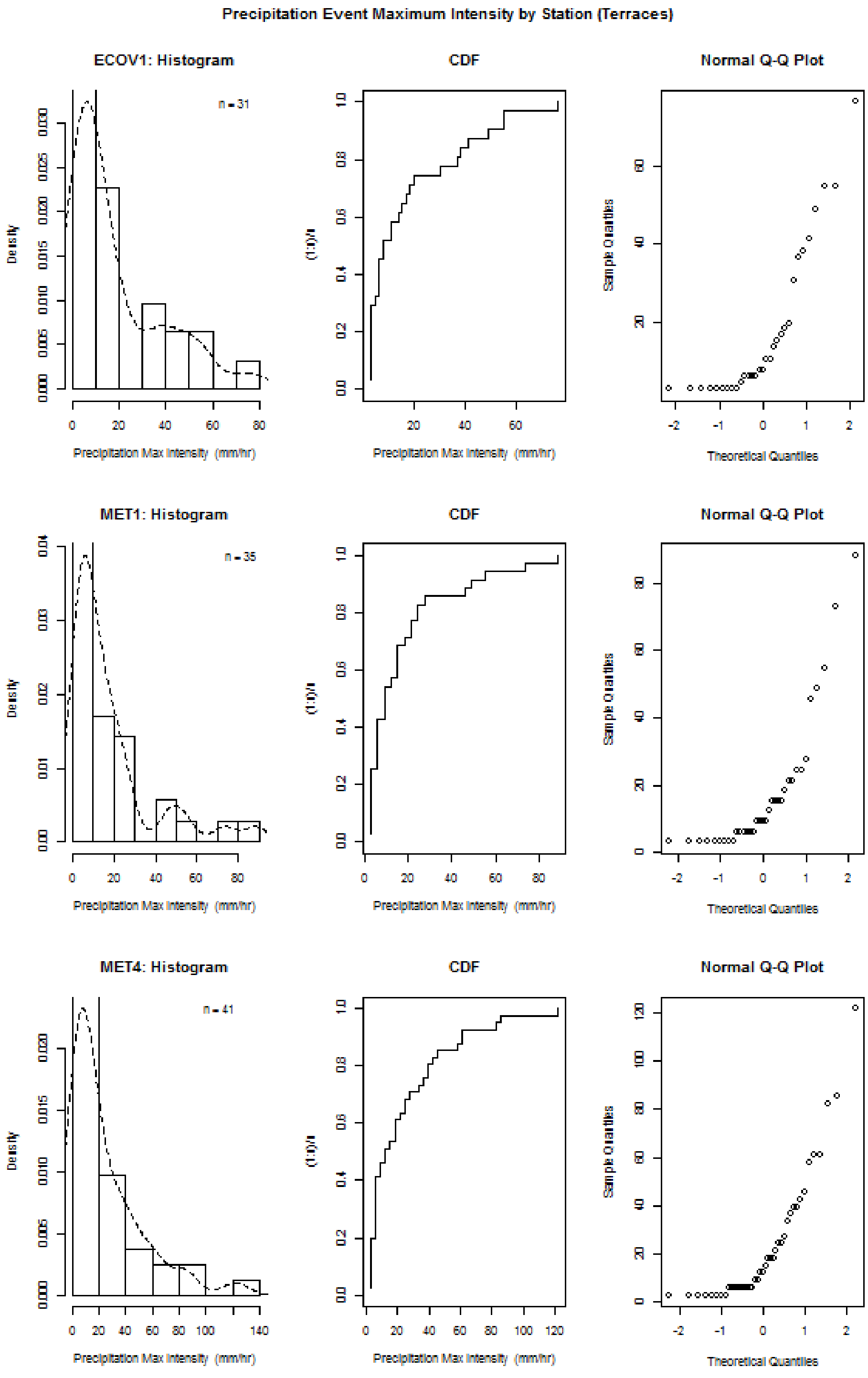

Figure D8. Histograms, cumulative distribution frequencies, and Q-Q plots of precipitation event maximum intensities (mm) recorded at terrace stations for the period of record from July 2006 to February 2010 when at least 5 stations in Yuma Wash were operative.

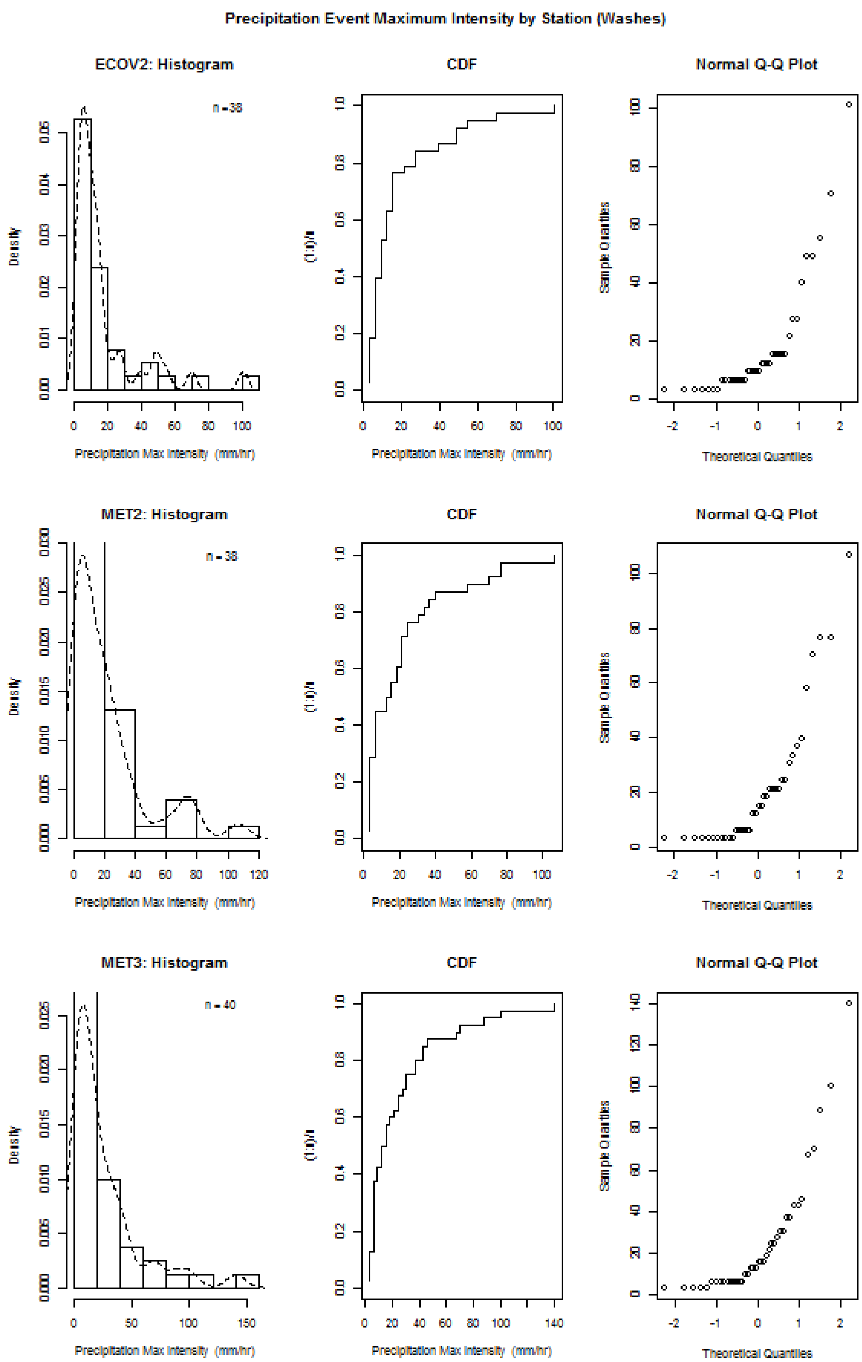

Figure D9. Histograms, cumulative distribution frequencies, and Q-Q plots of precipitation event maximum intensities (mm) recorded at wash stations for the period of record from July 2006 to February 2010 when at least 5 stations in Yuma Wash were operative.

Table D18. R-square and Spearman's rank correlation (rho) of station pairs for mean precipitation intensity (mm/hr) recorded for period of record station pairs were operative.

Spearmans Rho	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	0.8300	0.6531	0.7281	0.8486	0.8114
ECOV2	0.8300	1	0.7851	0.7567	0.6841	0.7183
MET1	0.6531	0.7851	1	0.8970	0.5067	0.5199
MET2	0.7281	0.7567	0.8970	1	0.7191	0.7200
MET3	0.8486	0.6841	0.5067	0.7191	1	0.9163
MET4	0.8114	0.7183	0.5199	0.7200	0.9163	1
Pearsons R sq	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	0.6099	0.5168	0.6284	0.6348	0.6368
ECOV2	0.6099	1	0.9088	0.6111	0.2742	0.2090
MET1	0.5168	0.9088	1	0.7044	0.0587	0.0434
MET2	0.6284	0.6111	0.7044	1	0.2416	0.1889
MET3	0.6348	0.2742	0.0587	0.2416	1	0.9743
MET4	0.6368	0.2090	0.0434	0.1889	0.9743	1

Table D19. R-square and Spearman's rank correlation (rho) of station pairs for maximum precipitation intensity (mm/hr) recorded for period of record station pairs were operative.

Spearmans Rho	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	0.7872	0.7523	0.8335	0.8796	0.8809
ECOV2	0.7872	1	0.7336	0.6041	0.8146	0.6774
MET1	0.7523	0.7336	1	0.8903	0.5646	0.6806
MET2	0.8335	0.6041	0.8903	1	0.6464	0.8138
MET3	0.8796	0.8146	0.5646	0.6464	1	0.8826
MET4	0.8809	0.6774	0.6806	0.8138	0.8826	1
Pearsons R sq	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	0.8693	0.6629	0.7358	0.6994	0.7536
ECOV2	0.8693	1	0.7048	0.5532	0.5015	0.3844
MET1	0.6629	0.7048	1	0.7489	0.1462	0.1738
MET2	0.7358	0.5532	0.7489	1	0.3273	0.3839
MET3	0.6994	0.5015	0.1462	0.3273	1	0.9145
MET4	0.7536	0.3844	0.1738	0.3839	0.9145	1

Table D20. Kolmogorov-Smirnov tests between individual stations for differences in distribution of event precipitation mean intensities (mm) for the entire period of record and for each season.

Kolmgorov Smirnov Distribution Test										
	All	**α = 0.05**	Sum	**α = 0.05**	Fall	**α = 0.05**	Win	**α = 0.05**	Spr	**α = 0.05**
	D	p	D	p	D	p	D	p	D	p
ECOV1-ECOV2	0.10	1.00	0.20	0.95	1.00	0.50	0.19	0.95	0.25	1.00
ECOV1-MET1	0.23	0.34	0.18	0.99	1.00	0.40	0.35	0.36	0.33	0.99
ECOV1-MET2	0.11	0.99	0.21	0.88	1.00	0.40	0.28	0.66	0.25	1.00
ECOV1-MET3	0.18	0.66	0.36	0.33	0.67	0.86	0.21	0.91	0.42	0.89
ECOV1-MET4	0.16	0.74	0.30	0.50	0.60	1.00	0.24	0.83	0.42	0.89
ECOV2-MET1	0.22	0.34	0.27	0.76	0.33	0.97	0.35	0.24	0.25	1.00
ECOV2-MET2	0.13	0.90	0.21	0.92	0.42	0.89	0.27	0.61	0.25	1.00
ECOV2-MET3	0.12	0.94	0.27	0.69	0.33	0.99	0.20	0.89	0.42	0.89
ECOV2-MET4	0.10	0.98	0.16	0.99	0.40	0.86	0.20	0.89	0.42	0.93
MET1-MET2	0.14	0.86	0.31	0.51	0.25	1.00	0.14	1.00	0.33	1.00
MET1-MET3	0.23	0.27	0.35	0.42	0.33	0.92	0.26	0.61	0.33	1.00
MET1-MET4	0.21	0.38	0.29	0.60	0.40	0.75	0.22	0.83	0.67	0.60
MET2-MET3	0.15	0.74	0.30	0.50	0.42	0.70	0.30	0.48	0.33	1.00
MET2-MET4	0.10	0.99	0.13	1.00	0.40	0.75	0.19	0.94	0.67	0.60
MET3-MET4	0.12	0.92	0.18	0.97	0.27	0.97	0.24	0.73	0.33	1.00

Table D21. Kolmogorov-Smirnov tests between individual stations for differences in distribution of event precipitation maximum intensities (mm) for the entire period of record and for each season.

Kolmgorov Smirnov Distribution Test										
	All	α = 0.05	Sum	α = 0.05	Fall	α = 0.05	Win	α = 0.05	Spr	α = 0.05
	D	p	D	p	D	p	D	p	D	p
ECOV1-ECOV2	0.14	0.90	0.19	0.97	1.00	0.50	0.22	0.87	0.25	1.00
ECOV1-MET1	0.12	0.98	0.14	1.00	0.75	0.80	0.21	0.93	0.25	1.00
ECOV1-MET2	0.14	0.91	0.27	0.66	1.00	0.40	0.18	0.98	0.25	1.00
ECOV1-MET3	0.20	0.50	0.36	0.33	1.00	0.36	0.18	0.97	0.50	0.78
ECOV1-MET4	0.14	0.88	0.31	0.46	1.00	0.33	0.13	1.00	0.50	0.78
ECOV2-MET1	0.08	1.00	0.20	0.97	0.25	1.00	0.09	1.00	0.25	1.00
ECOV2-MET2	0.21	0.37	0.30	0.53	0.67	0.43	0.18	0.96	0.25	1.00
ECOV2-MET3	0.19	0.50	0.41	0.20	0.33	0.98	0.09	1.00	0.50	0.78
ECOV2-MET4	0.23	0.26	0.37	0.29	0.33	0.99	0.13	1.00	0.50	0.78
MET1-MET2	0.13	0.90	0.19	0.97	0.50	0.70	0.11	1.00	0.33	1.00
MET1-MET3	0.16	0.75	0.39	0.27	0.25	1.00	0.08	1.00	0.33	1.00
MET1-MET4	0.15	0.79	0.25	0.78	0.25	1.00	0.11	1.00	0.33	1.00
MET2-MET3	0.16	0.67	0.21	0.88	0.33	0.95	0.16	0.98	0.67	0.52
MET2-MET4	0.09	0.99	0.19	0.94	0.40	0.87	0.09	1.00	0.67	0.52
MET3-MET4	0.07	1.00	0.15	1.00	0.17	1.00	0.12	1.00	0.33	1.00

Table D22. F, Kruskal Wallis, and Tukey tests for differences in event precipitation mean and maximum intensities (mm/hr) by station, by location, and by geomorphic surface.

F and Kruskal Wallis Tests for Differences in Event Intensity								
	Mean Precipitation Intensity				**Maximum Precipitation Intensity**			
by station		**α = 0.05**		**α = 0.05**		**α = 0.05**		**α = 0.05**
	F	p.value	chi.sq	p.value	F	p.value	chi.sq	p.value
all	0.82	0.54	3.92	0.56	0.77	0.57	3.04	0.69
Su	0.85	0.52	4.42	0.49	1.42	0.23	5.84	0.32
Fa	0.46	0.80	1.45	0.92	1.02	0.44	4.31	0.51
Wi	1.54	0.19	4.40	0.49	0.09	0.99	1.18	0.95
Sp	0.08	0.99	1.20	0.95	0.25	0.93	3.08	0.69
by location								
	F	p.value	chi.sq	p.value	F	p.value	chi.sq	p.value
all	1.71	0.18	2.74	0.25	1.69	0.19	2.70	0.26
Su	1.59	0.21	2.68	0.26	3.21	0.05	5.01	0.08
Fa	1.20	0.32	0.56	0.76	1.13	0.34	2.11	0.35
Wi	2.83	0.06	4.03	0.13	0.14	0.87	0.11	0.95
Sp	0.15	0.86	1.07	0.58	0.71	0.51	2.79	0.25
by geomorphic surface								
	F	p.value	chi.sq	p.value	F	p.value	chi.sq	p.value
all	0.37	0.54	0.69	0.40	0.19	0.66	0.26	0.61
Su	0.52	0.47	1.20	0.27	0.55	0.46	0.43	0.51
Fa	0.06	0.81	0.06	0.80	1.02	0.32	0.83	0.36
Wi	1.16	0.28	0.29	0.59	0.01	0.94	0.21	0.65
Sp	0.05	0.83	0.00	0.97	0.05	0.82	0.01	0.94

Tukey Test for Multiple Comparisons			**Mann Whitney Wilcoxon**	
by location	Mean Int Location_win	Max Int Location_summer	Max Int Location_summer	
	p.adj α = 0.05	p.adj α = 0.05	W	p.test α = 0.05
Middle-Lower	0.05	0.91	415	0.5372
Upper-Lower	0.39	0.05	274	0.0367
Upper-Middle	0.50	0.13	523.5	0.1080

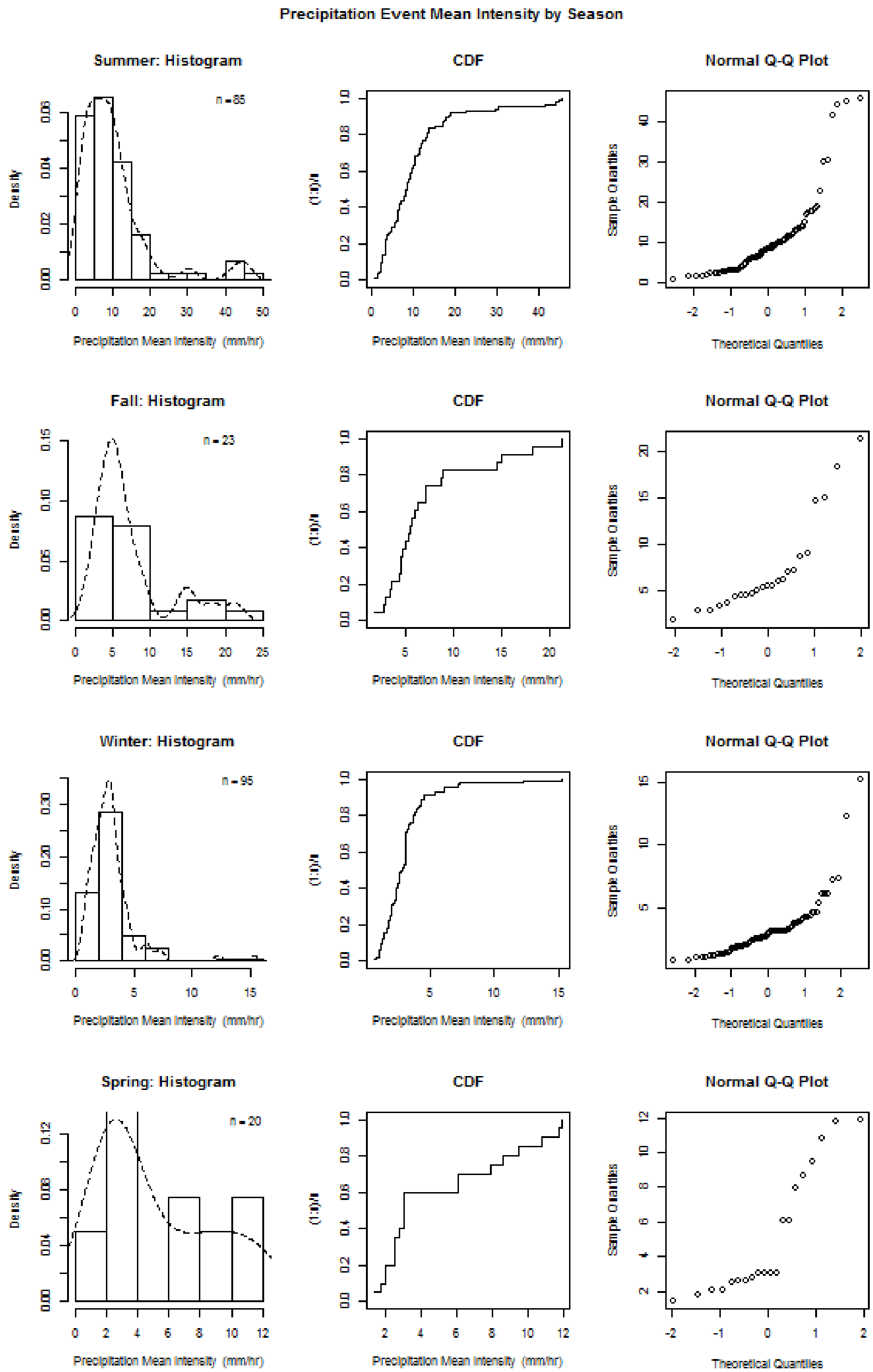

Figure D10. Histograms, cumulative distribution frequencies, and QQ plots for mean precipitation intensities truncated by season in the Yuma Wash watershed.

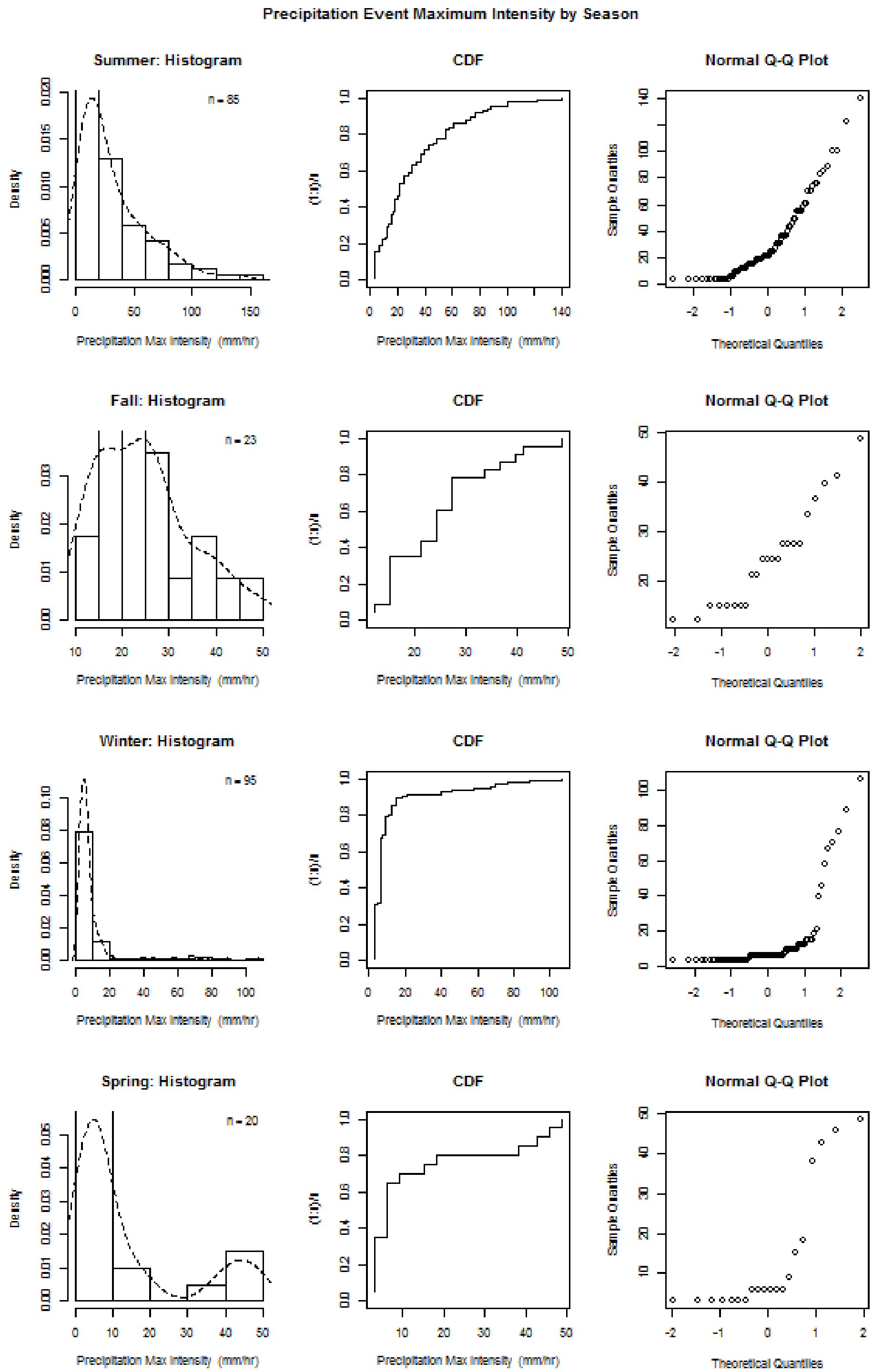

Figure D11. Histograms, cumulative distribution frequencies, and QQ plots for maximum precipitation intensities truncated by season in the Yuma Wash watershed.

Table D23. Shapiro-Wilks test for normality of seasonal mean and maximum precipitation intensity (mm/hr).

Station--Winter	$W_{mean\ int}$	p-value$_{mean\ int}$	$W_{max\ int}$	p-value$_{max\ int}$
ECOV1	0.88	0.0821	0.43	5.40E-06
ECOV2	0.71	9.51E-05	0.46	3.83E-07
MET1	0.94	0.3231	0.43	5.74E-07
MET2	0.94	0.3312	0.48	2.38E-06
MET3	0.91	0.1190	0.49	9.81E-07
MET4	0.91	0.0874	0.57	5.18E-06
Station--Spring	$W_{mean\ int}$	p-value$_{mean\ int}$	$W_{max\ int}$	p-value$_{max\ int}$
ECOV1	0.93	0.6141	0.69	0.0092
ECOV2	0.90	0.4273	0.68	0.0061
MET1	0.79	0.0937	0.92	0.4633
MET2	0.82	0.1634	0.75	0.0000
MET3	0.89	0.3456	0.81	0.1321
MET4	0.80	0.1062	0.75	0
Station--Summer	$W_{mean\ int}$	p-value$_{mean\ int}$	$W_{max\ int}$	p-value$_{max\ int}$
ECOV1	0.94	0.3604	0.88	0.0513
ECOV2	0.69	0.0005	0.74	0.0014
MET1	0.62	0.0002	0.86	0.0425
MET2	0.91	0.1374	0.87	0.0277
MET3	0.81	0.0067	0.88	0.0551
MET4	0.79	0.0022	0.89	0.0621
Station--Fall	$W_{mean\ int}$	p-value$_{mean\ int}$	$W_{max\ int}$	p-value$_{max\ int}$
ECOV1*				
ECOV2	1.00	0.9830	1.00	1
MET1	0.96	0.7688	0.92	0.5279
MET2	0.96	0.7942	0.89	0.4064
MET3	0.82	0.0891	0.91	0.4421
MET4	0.85	0.2070	0.95	0.7417

***** not enough datapoints at station ECOV1 to conduct a Shapiro Wilks test for normality in Fall precipitation intensities.

Table D24. Spearman's Rho values of the seasonal mean and maximum intensity (mm/hr) for all stations during the period of record when at least five stations were operative.

Rho winter mean	ECOV1	ECOV2	MET1	MET2	MET3	MET4
ECOV1	1	0.7660	0.5957	0.8476	0.8303	0.6970
ECOV2	0.7660	1	0.7785	0.8315	0.4251	0.5269
MET1	0.5957	0.7785	1	0.7864	0.3381	0.4558
MET2	0.8476	0.8315	0.7864	1	0.6077	0.7925
MET3	0.8303	0.4251	0.3381	0.6077	1	0.6474
MET4	0.6970	0.5269	0.4558	0.7925	0.6474	1
Rho winter max	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	0.5328	0.5002	0.7310	0.8522	0.7492
ECOV2	0.5328	1	0.4194	0.3033	0.5487	0.1683
MET1	0.5002	0.4194	1	0.7398	0.1504	0.5592
MET2	0.7310	0.3033	0.7398	1	0.3454	0.7558
MET3	0.8522	0.5487	0.1504	0.3454	1	0.6174
MET4	0.7492	0.1683	0.5592	0.7558	0.6174	1
Rho spring mean	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	1	1	1	1	1
ECOV2	1	1	1	1	1	1
MET1	1	1	1	1	1	1
MET2	1	1	1	1	1	1
MET3	1	1	1	1	1	1
MET4	1	1	1	1	1	1
Rho spring max	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	0.8660	0.8660	1	0.8660	1
ECOV2	0.8660	1	1	1	1	1
MET1	0.8660	1	1	0.8660	1	0.8660
MET2	1	1	0.8660	1	0.8660	1
MET3	0.8660	1	1	0.8660	1	0.8660
MET4	1	1	0.8660	1	0.8660	1
Rho summer mean	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	0.7133	0.4854	0.7356	0.8214	0.7167
ECOV2	0.7133	1	0.5167	0.5532	0.7500	0.6167
MET1	0.4854	0.5167	1	0.8091	0.0952	0.3091
MET2	0.7356	0.5532	0.8091	1	0.3973	0.4242
MET3	0.8214	0.7500	0.0952	0.3973	1	0.9780
MET4	0.7167	0.6167	0.3091	0.4242	0.9780	1
Rho summer max	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	0.7593	0.4596	0.6173	0.4636	0.7215
ECOV2	0.7593	1	0.5385	0.4798	0.3333	0.6483
MET1	0.4596	0.5385	1	0.8463	0.2169	0.4202
MET2	0.6173	0.4798	0.8463	1	0.5446	0.6340
MET3	0.4636	0.3333	0.2169	0.5446	1	0.9945
MET4	0.7215	0.6483	0.4202	0.6340	0.9945	1
Rho fall mean	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	NA	NA	NA	NA	NA	NA
ECOV2	NA	1	1	0.5	0.5	0.5
MET1	NA	1	1	0.4	0.4	0.4
MET2	NA	0.5	0.4	1	1	1
MET3	NA	0.5	0.4	1	1	1
MET4	NA	0.5	0.4	1	1	1
Rho fall max	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	NA	NA	NA	NA	NA	NA
ECOV2	NA	1	0.5000	0.5000	0.0000	0.5000
MET1	NA	0.5000	1	0.6325	0.7379	0.8000
MET2	NA	0.5000	0.6325	1	0.8333	0.9487
MET3	NA	0.0000	0.7379	0.8333	1	0.9747
MET4	NA	0.5000	0.8000	0.9487	0.9747	1

Table D25. Pearson's R-square values of the seasonal mean and maximum intensity (mm/hr) for all stations during the period of record when at least five stations were operative.

R^2 winter mean	ECOV1	ECOV2	MET1	MET2	MET3	MET4
ECOV1	1	0.7192	0.6838	0.6790	0.2918	0.1962
ECOV2	0.7192	1	0.6854	0.4431	0.1573	0.0752
MET1	0.6838	0.6854	1	0.5986	0.0654	0.0685
MET2	0.6790	0.4431	0.5986	1	0.1963	0.4614
MET3	0.2918	0.1573	0.0654	0.1963	1	0.2618
MET4	0.1962	0.0752	0.0685	0.4614	0.2618	1
R^2 winter max	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	0.9589	0.9733	0.9962	0.9445	0.9431
ECOV2	0.9589	1	0.9483	0.8412	0.9256	0.5221
MET1	0.9733	0.9483	1	0.9277	0.8774	0.6663
MET2	0.9962	0.8412	0.9277	1	0.8352	0.8720
MET3	0.9445	0.9256	0.8774	0.8352	1	0.5556
MET4	0.9431	0.5221	0.6663	0.8720	0.5556	1
R^2 spring mean	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	0.8431	0.9929	0.9977	0.9978	0.9939
ECOV2	0.8431	1	1	1	1	1
MET1	0.9929	1	1	0.9987	0.9827	1.0000
MET2	0.9977	1	0.9987	1	0.9909	0.9991
MET3	0.9978	1	0.9827	0.9909	1	0.9844
MET4	0.9939	1	1.0000	0.9991	0.9844	1
R^2 spring max	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	0.8660	0.8660	1	0.8660	1
ECOV2	0.8660	1	1	1	1	1
MET1	0.8660	1	1	0.8660	1	0.8660
MET2	1	1	0.8660	1	0.8660	1
MET3	0.8660	1	1	0.8660	1	0.8660
MET4	1	1	0.8660	1	0.8660	1
R^2 summer mean	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	0.4652	0.2138	0.5512	0.5736	0.5469
ECOV2	0.4652	1	0.9201	0.5480	0.0782	0.0574
MET1	0.2138	0.9201	1	0.6522	0.0021	0.0010
MET2	0.5512	0.5480	0.6522	1	0.0404	0.0320
MET3	0.5736	0.0782	0.0021	0.0404	1	0.9849
MET4	0.5469	0.0574	0.0010	0.0320	0.9849	1
R^2 summer max	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	1	0.7374	0.3214	0.5472	0.3112	0.6325
ECOV2	0.7374	1	0.6897	0.5245	0.0943	0.1598
MET1	0.3214	0.6897	1	0.5856	0.0272	0.0019
MET2	0.5472	0.5245	0.5856	1	0.1041	0.1612
MET3	0.3112	0.0943	0.0272	0.1041	1	0.9613
MET4	0.6325	0.1598	0.0019	0.1612	0.9613	1
R^2 fall mean	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	NA	NA	NA	NA	NA	NA
ECOV2	NA	1	0.9889	0.6762	0.6549	0.3007
MET1	NA	0.9889	1	0.5215	0.3023	0.2170
MET2	NA	0.6762	0.5215	1	0.8733	0.8213
MET3	NA	0.6549	0.3023	0.8733	1	0.9809
MET4	NA	0.3007	0.2170	0.8213	0.9809	1
R^2 fall max	**ECOV1**	**ECOV2**	**MET1**	**MET2**	**MET3**	**MET4**
ECOV1	NA	NA	NA	NA	NA	NA
ECOV2	NA	1.0000	0.5192	0.4286	0.0000	0.0174
MET1	NA	0.5192	1	0.2340	0.2241	0.3553
MET2	NA	0.4286	0.2340	1	0.5759	0.6754
MET3	NA	0.0000	0.2241	0.5759	1.0000	0.9656
MET4	NA	0.0174	0.3553	0.6754	0.9656	1

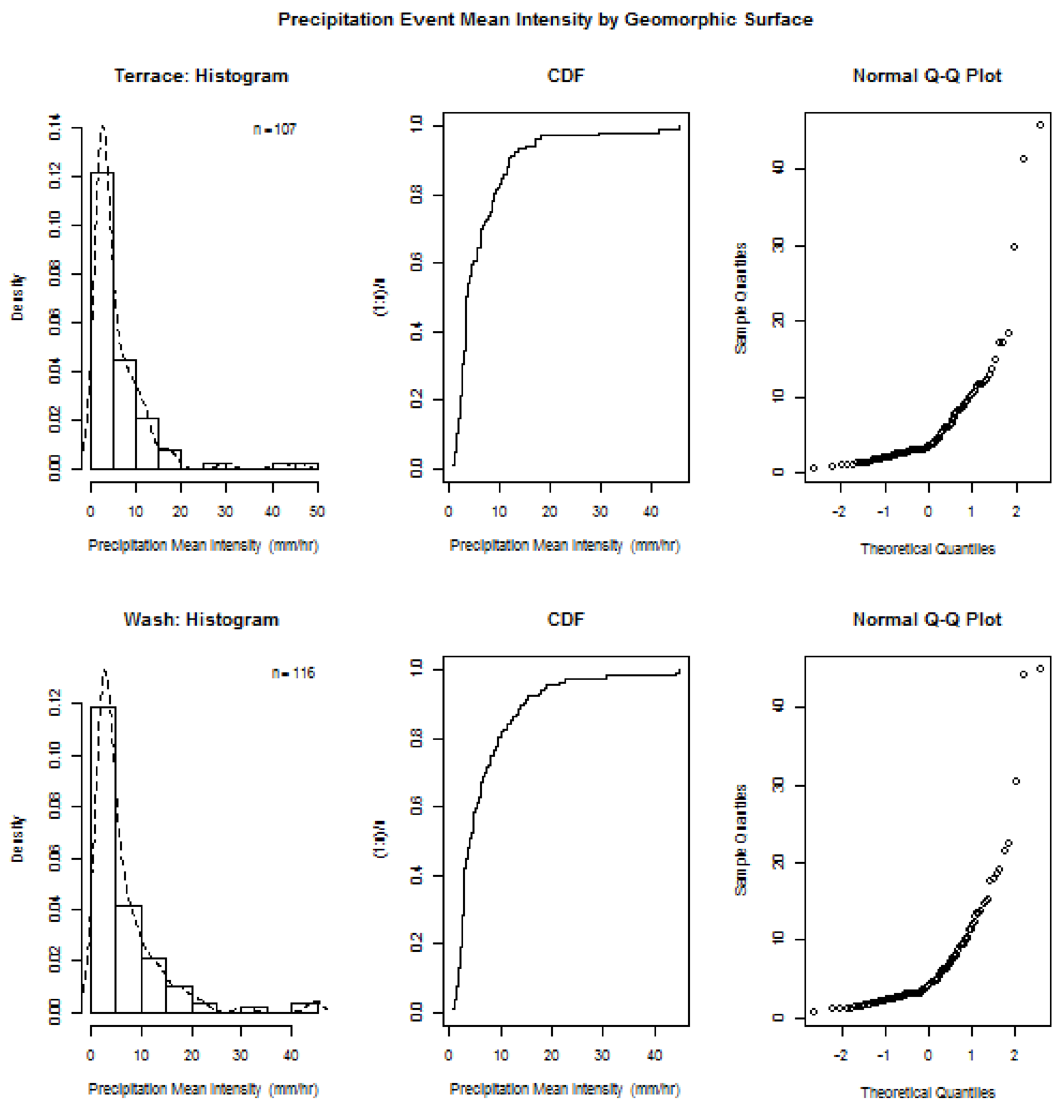

Figure D12. Histograms, cumulative distribution frequencies, and QQ plots for mean precipitation intensities pooled by geomorphic surface in the Yuma Wash watershed.

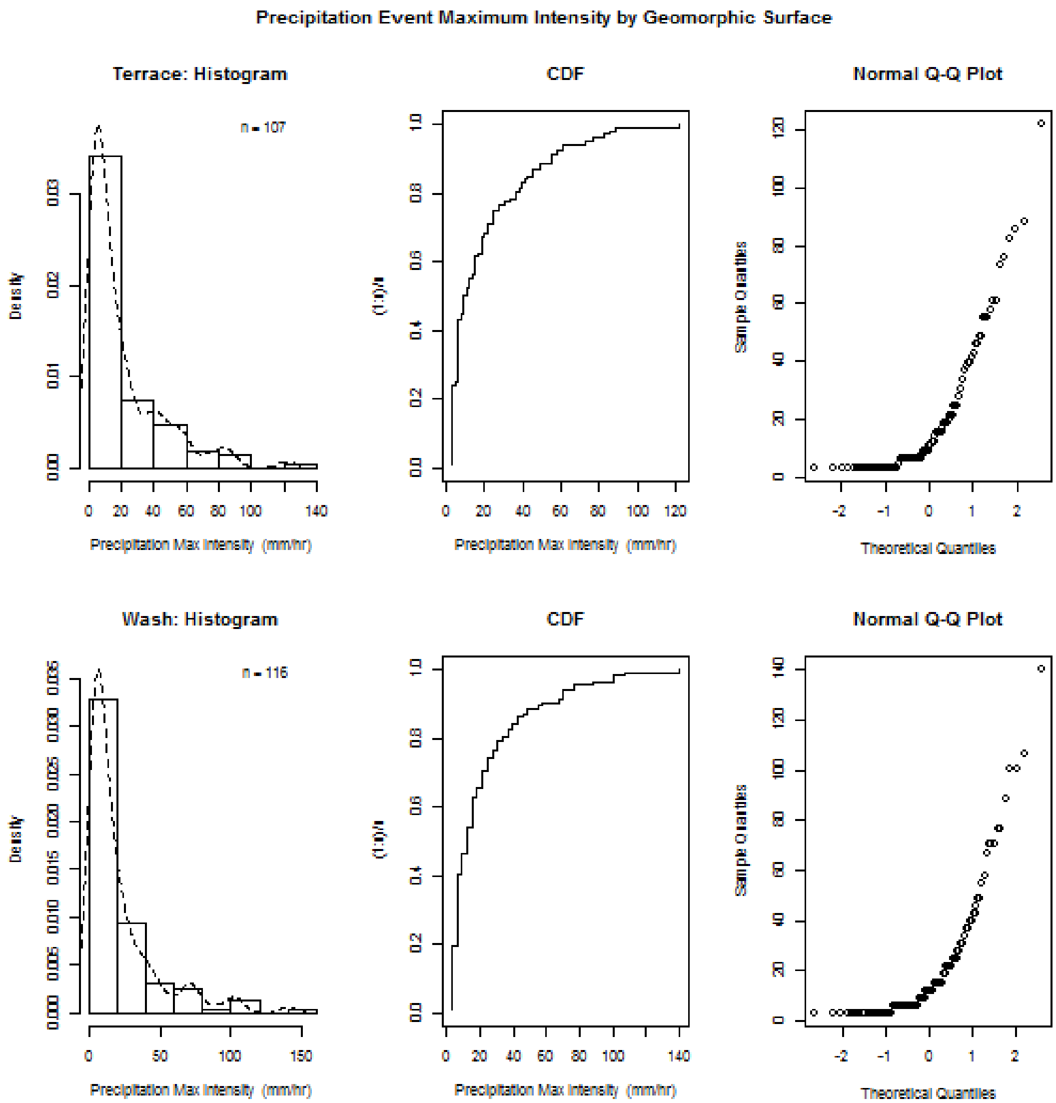

Figure D13. Histograms, cumulative distribution frequencies, and QQ plots for maximum precipitation intensities pooled by geomorphic surface in the Yuma Wash watershed.

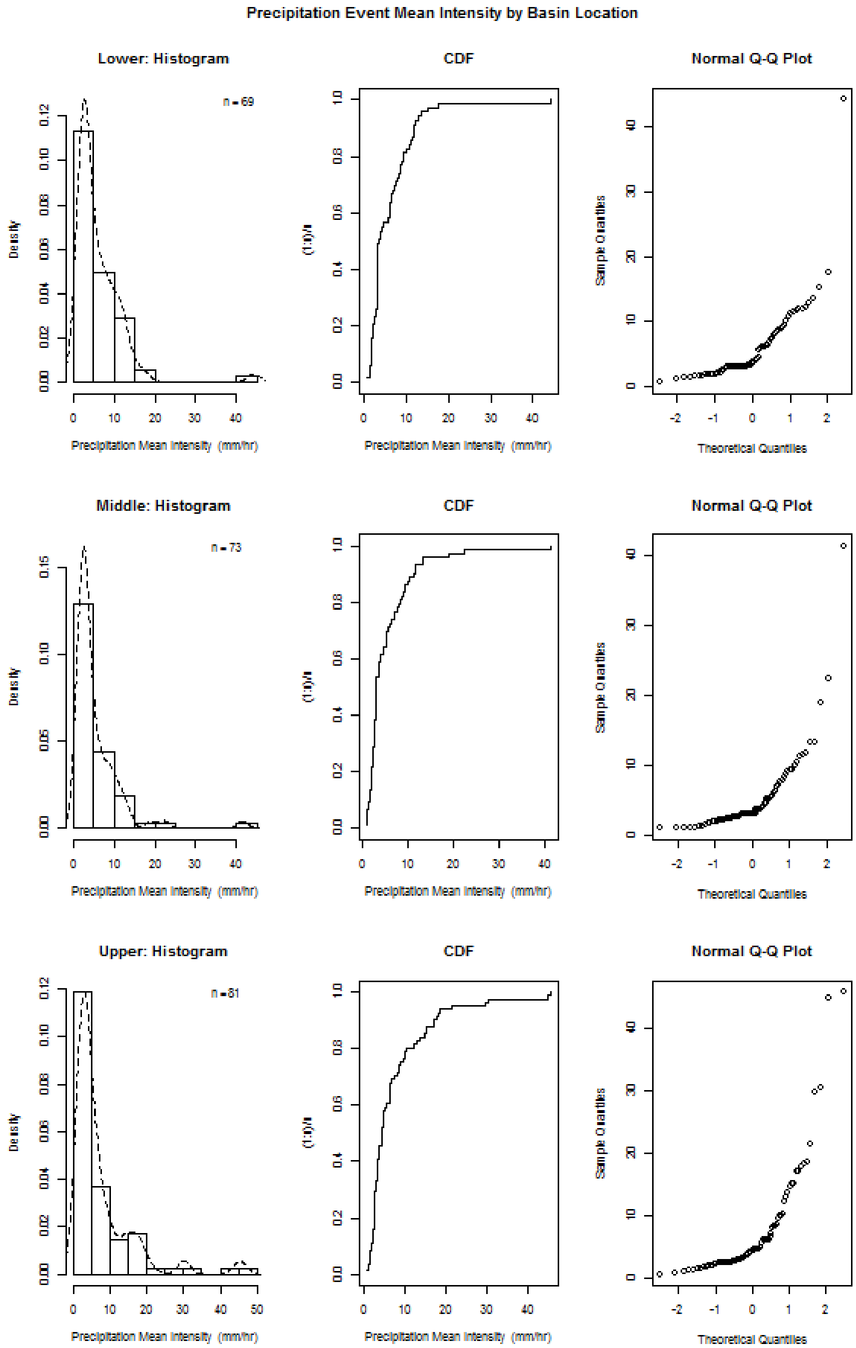

Figure D14. Histograms, cumulative distribution frequencies, and QQ plots for mean precipitation intensities pooled by basin location in the Yuma Wash watershed.

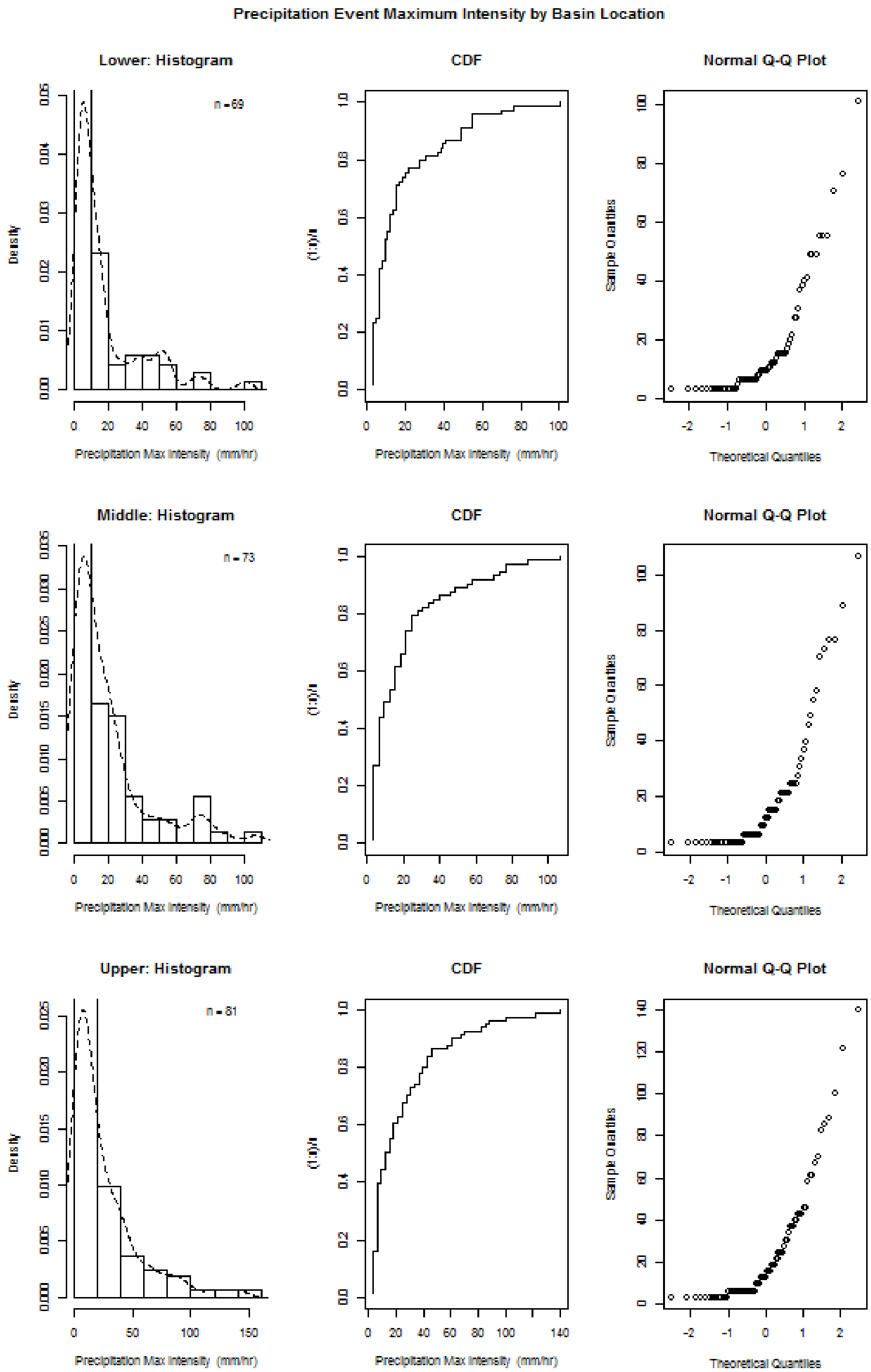

Figure D15. Histograms, cumulative distribution frequencies, and QQ plots for maximum precipitation intensities pooled by basin location in the Yuma Wash watershed.

Table D26. F and Kruskal Wallis tests for interannual differences in precipitation intensity.

F and Kruskal Wallis tests for Interannual Differences in Precipitation Intensity (mm/hr)								
	Mean Intensity				**Maximum Intensity**			
		α = 0.05		α = 0.05		α = 0.05		α = 0.05
	F	p.value	chi.sq	p.value	F	p.value	chi.sq	p.value
All	15.28	0	52.00	1.38E-10	5.35	0.0004	26.14	2.97E-05
Summers	6.94	0.0003	13.32	0.0040	5.18	0.0025	17.66	0.0005
Falls	3.52	0.0349	11.09	0.0112	1.39	0.2754	4.57	0.2061
Winters	6.75	0.0004	20.41	0.0001	2.66	0.0526	1.99	0.5752
Springs	6.58	0.0195	8.68	0.0032	4.41	0.0501	4.56	0.0328

Table D27. Tukey HSD and Mann Whitney Wilcoxon tests for interannual and interseasonal differences in precipitation mean intensity (mm/hr).

Tukey HSD and Mann Whitney Wilcox test for Differences in Precipitation Mean Intensity (α = 0.05)			
All Seasons	**Tukey HSD p.adj**	**W**	**p.test**
2006* vs 2007	1.46E-05	303.5	0.0005
2006 *vs 2008	1E-07	798.5	3.93E-05
2006* vs 2009	0.0000	381	1.19E-05
2006* vs 2010*	0.0000	429	1.19E-06
2007 vs 2008	0.8024	1539.5	0.9225
2007 vs 2009	0.3693	743	0.6517
2007 vs 2010*	0.0016	1208	4.82E-06
2008 vs 2009	0.8352	1927.5	0.4532
2008 vs 2010*	0.0050	3007	1.02E-07
2009 vs 2010*	0.2410	1318.5	2.96E-05
Fall		W	p.test
2006 vs 2007	0.0873	40	0.0020
2006 vs 2008	0.9865	19	0.6828
2006 vs 2009	0.6095	4	0.4000
2007 vs 2008	0.0602	12	0.0117
2007 vs 2009	0.9996	4	0.9091
2008 vs 2009	0.6856	7	0.4444
Winter		W	p.test
2006-07 vs 2007-08	0.0017	194	0.0002
2006-07 vs 2008-09	0.0254	107.5	0.0515
2006-07 vs 2009-10	0.0002	322	0.0001
2007-08 vs 2008-09	0.7733	141	0.0266
2007-08 vs 2009-10	0.8925	569	0.9060
2008-09 vs 2009-10	0.3424	541.5	0.0148
Spring		W	p.test
2007 vs 2008	0.0195	8.5	0.0037
Summer			
2006 vs 2007	0.1195	79	0.0668
2006 vs 2008	0.0009	264.5	0.0008
2006 vs 2009	0.0006	142	0.0003
2007 vs 2008	0.2069	368.5	0.3364
2007 vs 2009	0.1262	196	0.2226
2008 vs 2009	0.9349	471	0.6668

*partial year totals for 2006 and 2010 render interannual comparisons for significant differences between these years invalid. For 2006, summer and fall seasonal comparisons between years are valid, and for 2009-10, winter seasonal comparisons between years are valid.

Table D28. Tukey HSD and Mann Whitney Wilcoxon tests for interannual and interseasonal differences in precipitation max intensity (mm/hr)

Tukey HSD and Mann Whitney Wilcox test for Differences in Precipitation Maximum Intensity (α = 0.05)			
All Seasons	**Tukey HSD p.adj**	**W**	**p.test**
2006* vs 2007	0.0117	366.5	0.0008
2006 *vs 2008	0.0003	874.5	2.04E-05
2006* vs 2009	0.0004	388	0.0001
2006* vs 2010*	0.0003	412.5	0.0001
2007 vs 2008	0.6954	2092.5	0.1008
2007 vs 2009	0.6318	972	0.0964
2007 vs 2010*	0.6274	1171.5	0.0040
2008 vs 2009	0.9971	1866	0.6603
2008 vs 2010*	0.9975	2346.5	0.0332
2009 vs 2010*	1.0000	981	0.2609
Fall		W	p.test
2006 vs 2007	0.4224	29	0.2189
2006 vs 2008	0.7907	22.5	0.3022
2006 vs 2009	0.3262	4	0.2765
2007 vs 2008	0.8750	32.5	0.5239
2007 vs 2009	0.7591	9.5	0.1933
2008 vs 2009	0.5676	8	0.1661
Winter		W	p.test
2006-07 vs 2007-08	0.9955	133	0.2274
2006-07 vs 2008-09	1.0000	78.5	0.7274
2006-07 vs 2009-10	0.5252	191	0.6172
2007-08 vs 2008-09	0.9951	196.5	0.3583
2007-08 vs 2009-10	0.0676	476.5	0.2899
2008-09 vs 2009-10	0.2170	401.5	0.8179
Spring		W	p.test
2007 vs 2008	0.0501	19.5	0.0363
Summer			
2006 vs 2007	0.3572	81.5	0.0442
2006 vs 2008	0.0049	260	0.0013
2006 vs 2009	0.0110	129	0.0032
2007 vs 2008	0.1410	475.5	0.0037
2007 vs 2009	0.2473	219	0.0491
2008 vs 2009	0.9999	397.5	0.5285

*partial year totals for 2006 and 2010 render interannual comparisons for significant differences between these years invalid. For 2006, summer and fall seasonal comparisons between years are valid, and for 2009-10, winter seasonal comparisons between years are valid.

Table D29. F, Kruskal-Wallis, Tukey and Mann Whitney Wilcoxon tests for interseasonal differences in precipitation mean and maximum intensities. Data pooled for each season for the period of record.

F and Kruskal-Wallis tests for Intrannual Differences in Precipitation								
	Mean Intensity				**Max Intensity**			
		α = 0.05		**α = 0.05**		**α = 0.05**		**α = 0.05**
	F	p.value	Chi sq	p.value	F	p.value	Chi sq	p.value
Seasons	19.25	4.38E-11	70.85	2.81E-15	11.9	3.26E-07	54.9	6.93E-12

Tukey HSD and Mann Whitney for Pairwise Differences						
	Mean Intensity			**Max Intensity**		
	Tukey	**Mann-Whitney**		**Tukey**	**Mann-Whitney**	
	p adj	W	p.test	p adj	W	p.test
Fall-Summer	0.1818	1093	0.1575	0.4806	971.5	0.9670
Winter-Summer	0.0000	6494	5.53E-15	0.0000	6286.5	7.26E-11
Spring-Summer	0.0068	1092	0.0091	0.0069	1237	0.0015
Winter-Fall	0.0257	1752.5	2.11E-07	0.0767	1962.5	1.65E-09
Spring-Fall	0.6893	268	0.1259	0.4082	360.5	0.0014
Spring-Winter	0.5587	580	0.0185	0.9846	925	0.8510

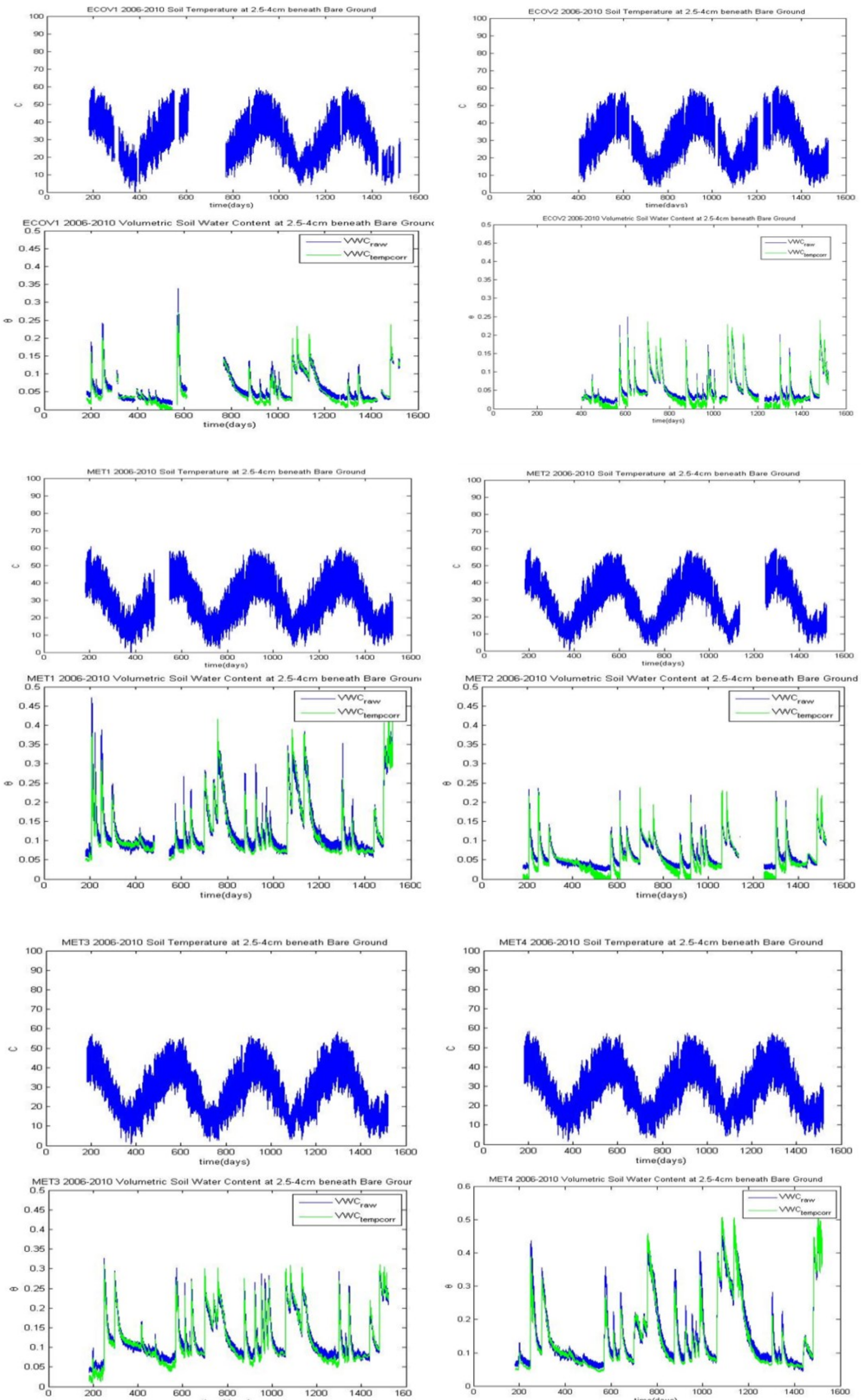

Figure D16. Fifteen minute soil temperature and volumetric water content (uncorrected in blue and temperature corrected in green) recorded at six stations at 2.5cm in Yuma Wash.

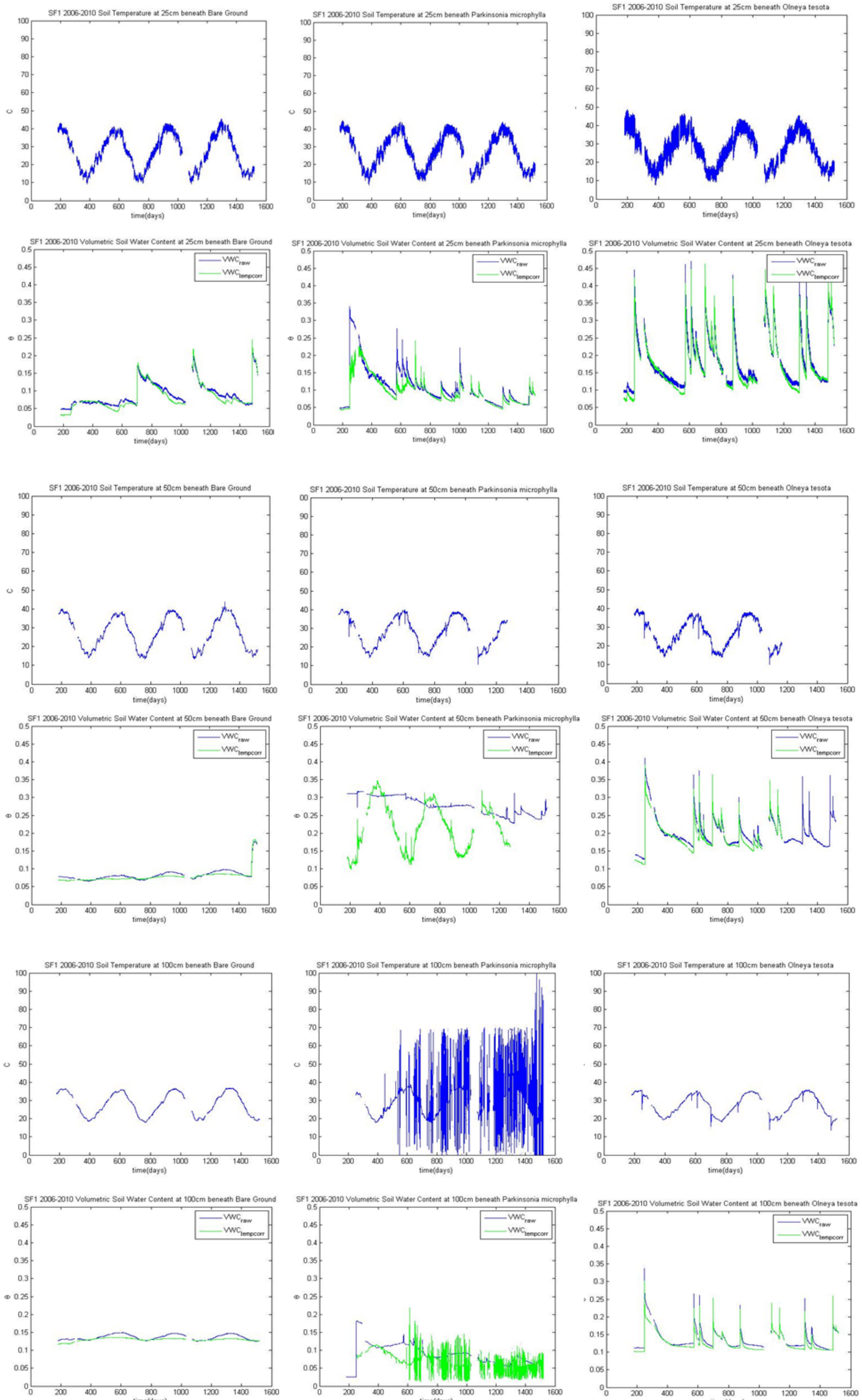

Figure D17. Fifteen minute soil temperature and volumetric water content (uncorrected in blue and temperature corrected in green) recorded at station SF1 at 25, 50, and 100cm in Yuma Wash.

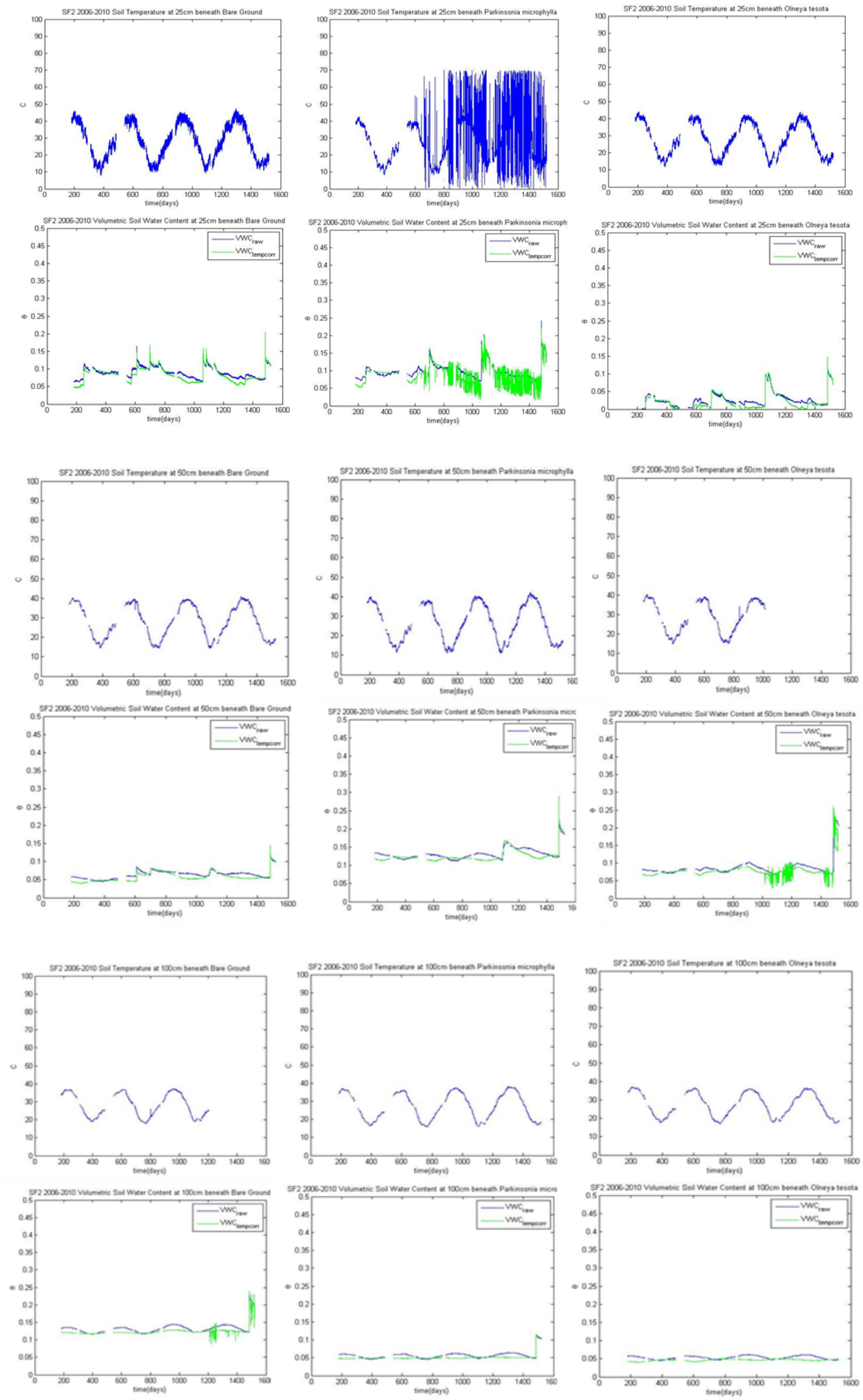

Figure D18. Fifteen minute soil temperature and volumetric water content (uncorrected in blue and temperature corrected in green) recorded at station SF2 at 25, 50, and 100cm in Yuma Wash.

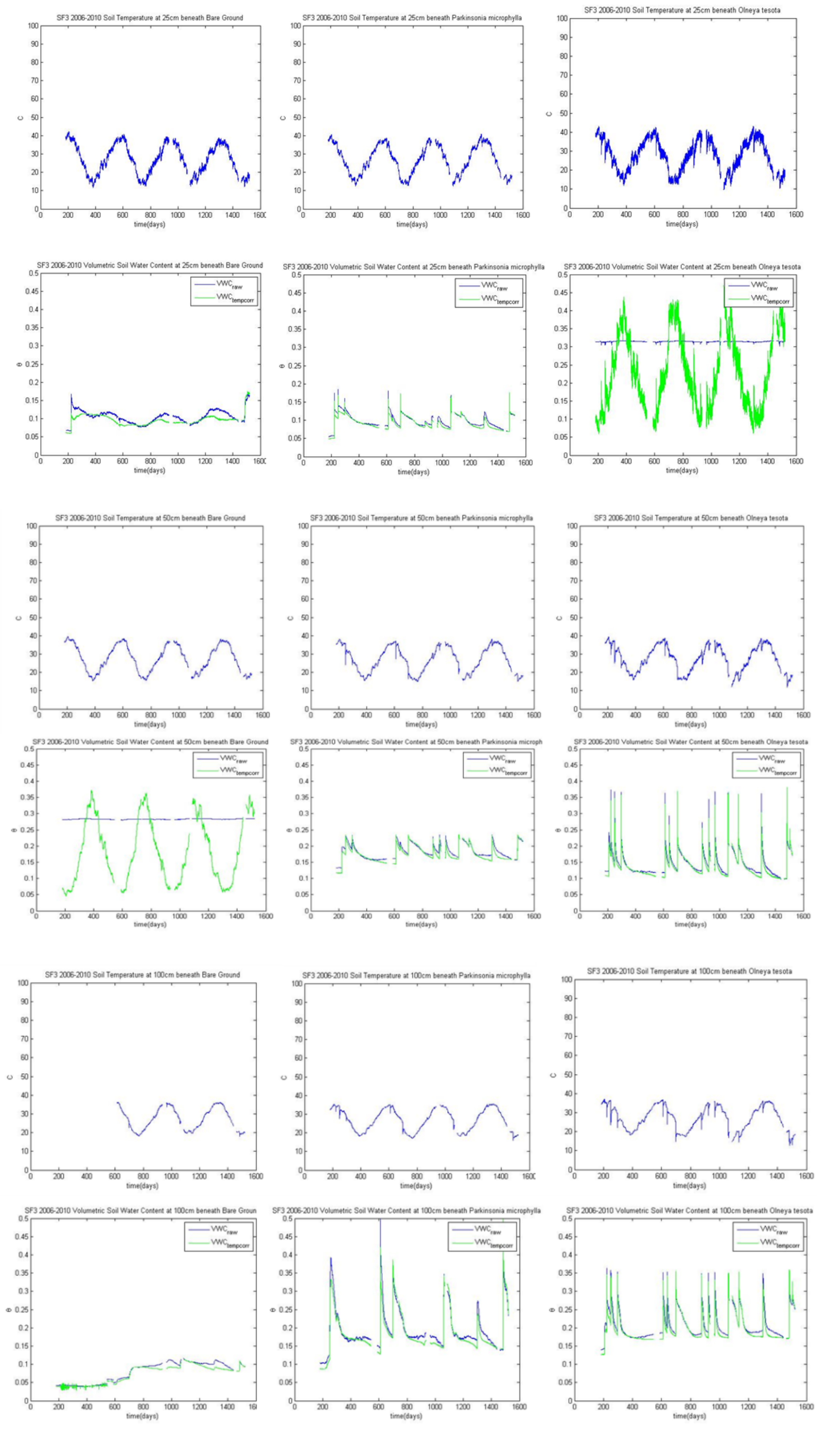

Figure D19. Fifteen minute soil temperature and volumetric water content (uncorrected in blue and temperature corrected in green) recorded at station SF3 at 25, 50, and 100cm in Yuma Wash.

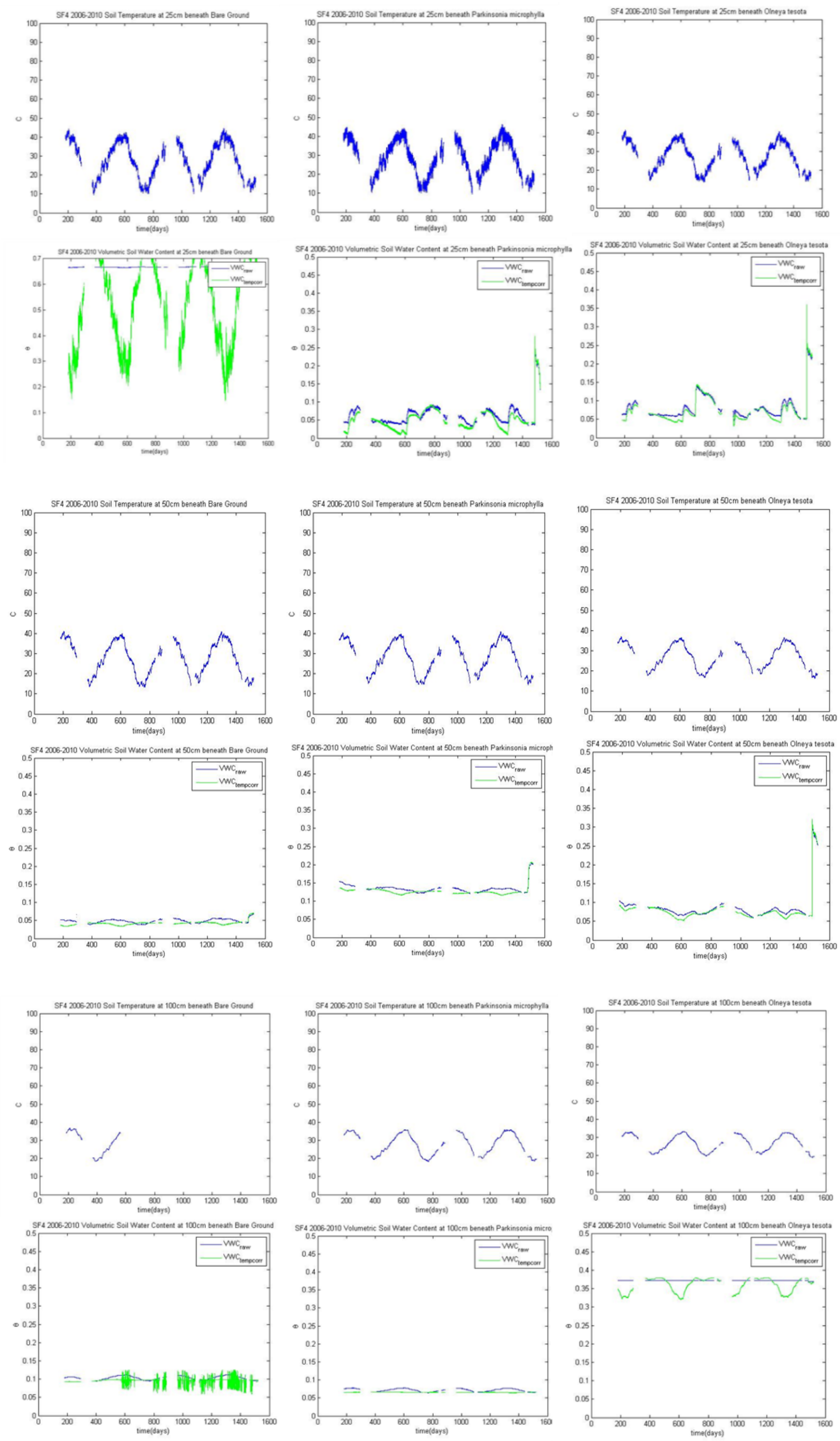

Figure D20. Fifteen minute soil temperature and volumetric water content (uncorrected in blue and temperature corrected in green) recorded at station SF4 at 25, 50, and 100cm in Yuma Wash.

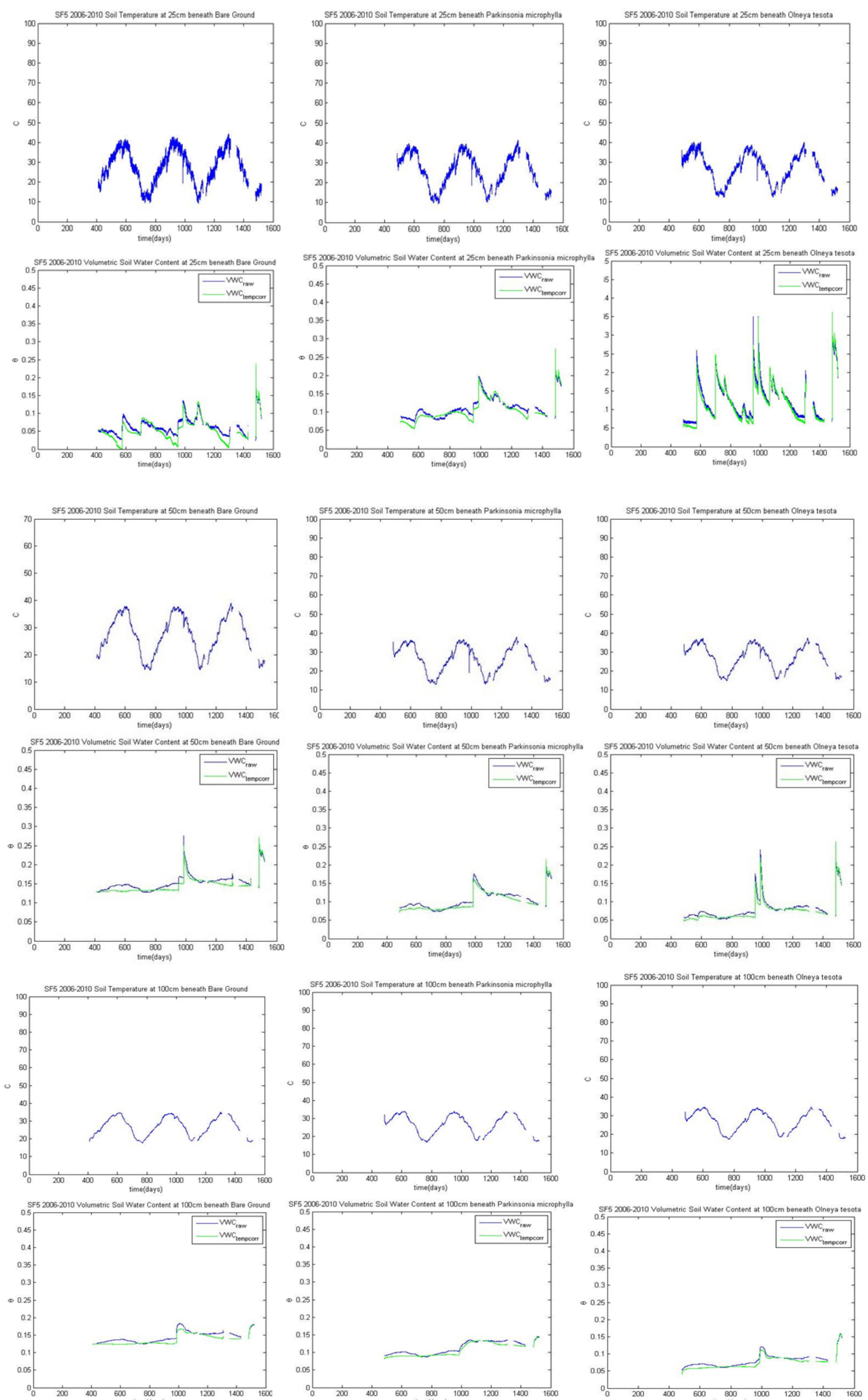

Figure D21. Fifteen minute soil temperature and volumetric water content (uncorrected in blue and temperature corrected in green) recorded at station SF5 at 25, 50, and 100cm in Yuma Wash.

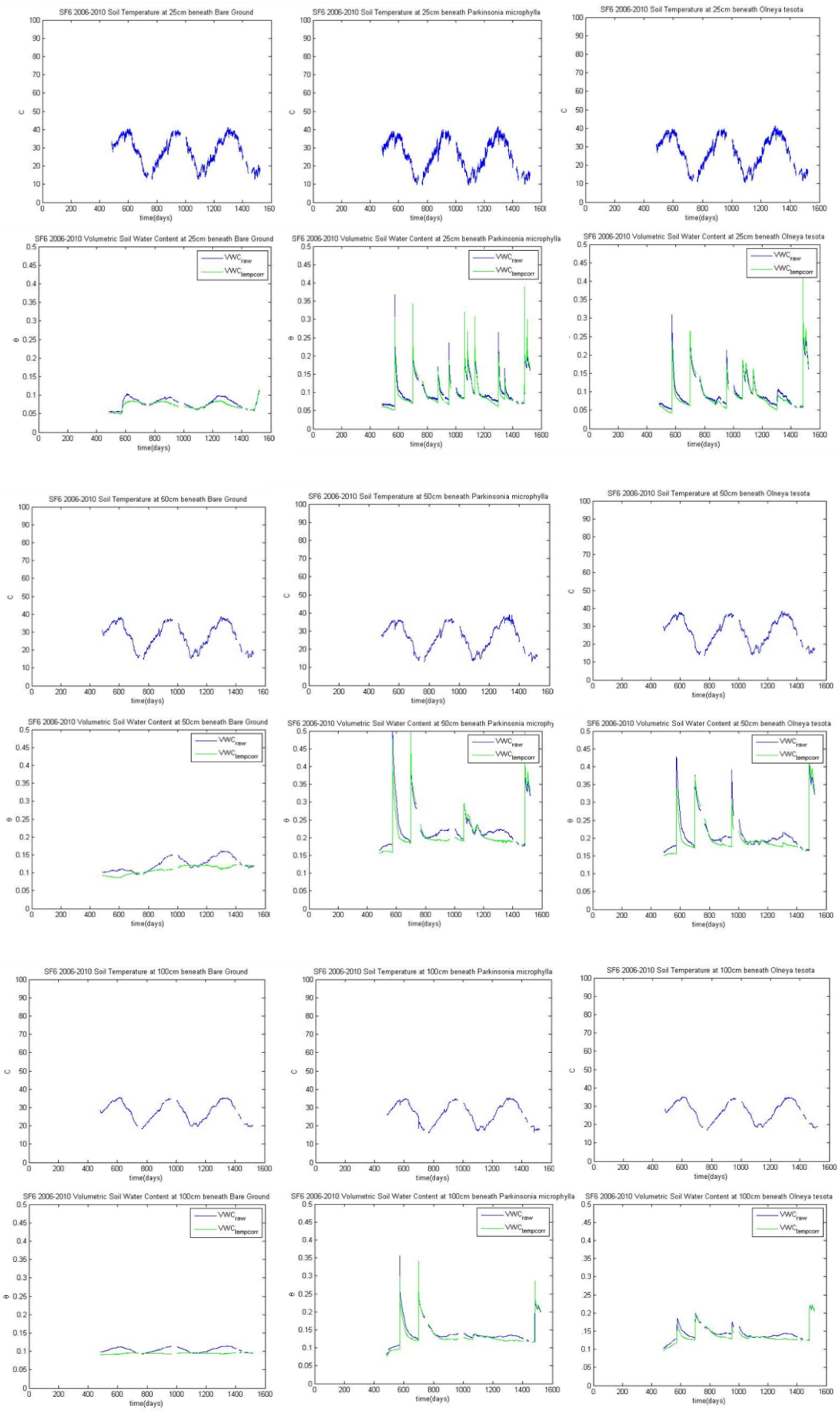

Figure D22. Fifteen minute soil temperature and volumetric water content (uncorrected in blue and temperature corrected in green) recorded at station SF6 at 25, 50, and 100cm in Yuma Wash.

Table D30. Probe name, depth, station, cover type, basin location and geomorphic surface for each probe installed at 2.5 cm and 25 cm in Yuma Wash. Cover types are: bare ground (BG), *P.microphylla* (Foothill Palo Verde—PV_, and *O.tesota* (Ironwood—IW).

Probe Name	Depth	Station	Cover Type	Basin Location	Geomorphic Surface
ECOV1_BG2.5	2.5 cm	ECOV1	BG	Lower	Terrace
ECOV2_BG2.5	2.5 cm	ECOV2	BG	Lower	Wash
MET1_BG2.5	2.5 cm	MET1	BG	Middle	Terrace
MET2_BG2.5	2.5 cm	MET2	BG	Middle	Wash
MET3_BG2.5	2.5 cm	MET3	BG	Upper	Wash
MET4_BG2.5	2.5 cm	MET4	BG	Upper	Terrace
SF1_PV25	25 cm	SF1	PV	Lower	Terrace
SF2_PV25	25 cm	SF2	PV	Lower	Wash
SF3_PV25	25 cm	SF3	PV	Middle	Terrace
SF4_PV25	25 cm	SF4	PV	Middle	Wash
SF5_PV25	25 cm	SF5	PV	Upper	Wash
SF6_PV25	25 cm	SF6	PV	Upper	Terrace
SF1_IW25	25 cm	SF1	IW	Lower	Terrace
SF2_IW25	25 cm	SF2	IW	Lower	Wash
SF3_IW25	25 cm	SF3	IW	Middle	Terrace
SF4_IW25	25 cm	SF4	IW	Middle	Wash
SF5_IW25	25 cm	SF5	IW	Upper	Wash
SF6_IW25	25 cm	SF6	IW	Upper	Terrace
SF1_BG25	25 cm	SF1	BG	Lower	Terrace
SF2_BG25	25 cm	SF2	BG	Lower	Wash
SF3_BG25	25 cm	SF3	BG	Middle	Terrace
SF4_BG25	25 cm	SF4	BG	Middle	Wash
SF5_BG25	25 cm	SF5	BG	Upper	Wash
SF6_BG25	25 cm	SF6	BG	Upper	Terrace

Table D31. Probe name, depth, station, cover type, basin location and geomorphic surface for each probe installed at 50 cm and 100 cm in Yuma Wash. Cover types are: bare ground (BG), *P.microphylla* (Foothill Palo Verde—PV_, and *O.tesota* (Ironwood—IW).

SF1_PV50	50 cm	SF1	PV	Lower	Terrace
SF2_PV50	50 cm	SF2	PV	Lower	Wash
SF3_PV50	50 cm	SF3	PV	Middle	Terrace
SF4_PV50	50 cm	SF4	PV	Middle	Wash
SF5_PV50	50 cm	SF5	PV	Upper	Wash
SF6_PV50	50 cm	SF6	PV	Upper	Terrace
SF1_IW50	50 cm	SF1	IW	Lower	Terrace
SF2_IW50	50 cm	SF2	IW	Lower	Wash
SF3_IW50	50 cm	SF3	IW	Middle	Terrace
SF4_IW50	50 cm	SF4	IW	Middle	Wash
SF5_IW50	50 cm	SF5	IW	Upper	Wash
SF6_IW50	50 cm	SF6	IW	Upper	Terrace
SF1_BG50	50 cm	SF1	BG	Lower	Terrace
SF2_BG50	50 cm	SF2	BG	Lower	Wash
SF3_BG50	50 cm	SF3	BG	Middle	Terrace
SF4_BG50	50 cm	SF4	BG	Middle	Wash
SF5_BG50	50 cm	SF5	BG	Upper	Wash
SF6_BG50	50 cm	SF6	BG	Upper	Terrace
SF1_PV100	100 cm	SF1	PV	Lower	Terrace
SF2_PV100	100 cm	SF2	PV	Lower	Wash
SF3_PV100	100 cm	SF3	PV	Middle	Terrace
SF4_PV100	100 cm	SF4	PV	Middle	Wash
SF5_PV100	100 cm	SF5	PV	Upper	Wash
SF6_PV100	100 cm	SF6	PV	Upper	Terrace
SF1_IW100	100 cm	SF1	IW	Lower	Terrace
SF2_IW100	100 cm	SF2	IW	Lower	Wash
SF3_IW100	100 cm	SF3	IW	Middle	Terrace
SF4_IW100	100 cm	SF4	IW	Middle	Wash
SF5_IW100	100 cm	SF5	IW	Upper	Wash
SF6_IW100	100 cm	SF6	IW	Upper	Terrace
SF1_BG100	100 cm	SF1	BG	Lower	Terrace
SF2_BG100	100 cm	SF2	BG	Lower	Wash
SF3_BG100	100 cm	SF3	BG	Middle	Terrace
SF4_BG100	100 cm	SF4	BG	Middle	Wash
SF5_BG100	100 cm	SF5	BG	Upper	Wash
SF6_BG100	100 cm	SF6	BG	Upper	Terrace

Table D32. Differences in temperature corrected and uncorrected 15-minute volumetric soil moisture (m^3/m^3) data at 2.5cm by probe.

2.5cm	ECOV1_BG2.5	ECOV2_BG2.5	MET1_BG2.5	MET2_BG2.5	MET3_BG2.5	MET4_BG2.5
Min	-0.022	-0.052	-0.072	-0.024	-0.084	-0.089
LQ	-0.001	-0.002	-0.002	-0.003	-0.003	-0.002
Median	0.007	0.006	0.006	0.008	0.005	0.007
Mean	0.008	0.007	0.007	0.009	0.006	0.007
UQ	0.015	0.015	0.015	0.020	0.014	0.016
Max	0.132	0.051	0.274	0.049	0.064	0.223
IQR	0.015	0.017	0.017	0.023	0.017	0.018

Table D33. Differences in temperature corrected and uncorrected 15-minute volumetric soil moisture (m^3/m^3) data at 25cm by probe.

25cm	SF1_BG25	SF2_BG25	SF3_BG25	SF4_BG25	SF5_BG25	SF6_BG25
Min	-0.01	-0.01	-0.016	NA	-0.013	-0.005
LQ	0.00	0.00	0.000	NA	0.001	0.001
Median	0.01	0.01	0.007	NA	0.009	0.005
Mean	0.01	0.01	0.009	NA	0.010	0.006
UQ	0.01	0.01	0.017	NA	0.019	0.012
Max	0.02	0.02	0.057	NA	0.034	0.023
IQR	0.02	0.02	0.017	NA	0.018	0.011
	SF1_IW25	**SF2_IW25**	**SF3_IW25**	**SF4_IW25**	**SF5_IW25**	**SF6_IW25**
Min	-0.03	-0.01	NA	-0.015	-0.019	-0.038
LQ	0.00	0.00	NA	0.001	0.001	-0.001
Median	0.01	0.01	NA	0.007	0.007	0.005
Mean	0.01	0.01	NA	0.007	0.007	0.005
UQ	0.02	0.02	NA	0.013	0.013	0.010
Max	0.06	0.02	NA	0.019	0.078	0.074
IQR	0.02	0.02	NA	0.012	0.012	0.011
	SF1_PV25	**SF2_PV25**	**SF3_PV25**	**SF4_PV2**	**SF5_PV25**	**SF6_PV25**
Min	-0.03	NA	-0.030	-0.013	-0.012	-0.046
LQ	0.00	NA	0.001	0.001	-0.001	-0.002
Median	0.00	NA	0.005	0.011	0.007	0.005
Mean	0.01	NA	0.005	0.011	0.007	0.004
UQ	0.01	NA	0.008	0.021	0.015	0.011
Max	0.19	NA	0.022	0.035	0.023	0.061
IQR	0.02	NA	0.008	0.020	0.016	0.013

Table D34. Differences in temperature corrected and uncorrected 15-minute volumetric soil moisture (m^3/m^3) data at 50cm by probe.

50cm	SF1_BG50	SF2_BG50	SF3_BG50	SF4_BG50	SF5_BG50	SF6_BG50
Min	-0.01	-0.005	NA	-0.006	-0.008	-0.007
LQ	0.00	-0.001	NA	0.000	0.001	0.002
Median	0.00	0.005	NA	0.007	0.008	0.012
Mean	0.00	0.006	NA	0.007	0.007	0.015
UQ	0.01	0.013	NA	0.013	0.015	0.023
Max	0.02	0.037	NA	0.018	0.123	0.051
IQR	0.01	0.014	NA	0.013	0.013	0.021
	SF1_IW50	**SF2_IW50**	**SF3_IW50**	**SF4_IW50**	**SF5_IW50**	**SF6_IW50**
Min	-0.016	-0.004	-0.076	-0.007	-0.008	-0.031
LQ	0.001	0.000	0.001	0.001	0.001	0.000
Median	0.010	0.007	0.006	0.006	0.006	0.011
Mean	0.010	0.007	0.006	0.006	0.006	0.012
UQ	0.017	0.013	0.012	0.011	0.011	0.021
Max	0.088	0.016	0.156	0.152	0.079	0.093
IQR	0.016	0.014	0.011	0.009	0.009	0.021
	SF1_PV50	**SF2_PV50**	**SF3_PV50**	**SF4_PV50**	**SF5_PV50**	**SF6_PV50**
Min	N/A	-0.011	-0.021	-0.006	-0.009	-0.058
LQ	N/A	-0.003	0.000	0.001	0.000	-0.001
Median	N/A	0.006	0.007	0.008	0.006	0.011
Mean	N/A	0.006	0.007	0.007	0.005	0.012
UQ	N/A	0.016	0.013	0.014	0.011	0.022
Max	N/A	0.026	0.049	0.019	0.016	0.132
IQR	N/A	0.019	0.013	0.013	0.011	0.023

Table D35. Differences in temperature corrected and uncorrected 15-minute volumetric soil moisture (m^3/m^3) data at 100cm by probe.

100cm	SF1_BG100	SF2_BG100	SF3_BG100	SF4_BG100	SF5_BG100	SF6_BG100
Min	-0.001	N/A	N/A	N/A	-0.002	-0.001
LQ	0.001	N/A	N/A	N/A	0.002	0.003
Median	0.007	N/A	N/A	N/A	0.007	0.009
Mean	0.007	N/A	N/A	N/A	0.007	0.010
UQ	0.012	N/A	N/A	N/A	0.012	0.016
Max	0.015	N/A	N/A	N/A	0.016	0.021
IQR	0.011	N/A	N/A	N/A	0.010	0.013
	SF1_IW100	**SF2_IW100**	**SF3_IW100**	**SF4_IW100**	**SF5_IW100**	**SF6_IW100**
Min	-0.019	-0.003	-0.015	N/A	-0.003	-0.003
LQ	0.002	0.001	0.001	N/A	0.002	0.002
Median	0.007	0.007	0.008	N/A	0.007	0.007
Mean	0.007	0.007	0.008	N/A	0.006	0.007
UQ	0.011	0.013	0.015	N/A	0.010	0.012
Max	0.043	0.016	0.034	N/A	0.013	0.018
IQR	0.009	0.013	0.014	N/A	0.008	0.010
	SF1_PV100	**SF2_PV100**	**SF3_PV100**	**SF4_PV100**	**SF5_PV100**	**SF6_PV100**
Min	N/A	-0.003	-0.047	-0.001	-0.003	-0.009
LQ	N/A	0.000	-0.001	0.002	0.002	0.001
Median	N/A	0.005	0.008	0.007	0.006	0.007
Mean	N/A	0.005	0.009	0.006	0.005	0.007
UQ	N/A	0.011	0.016	0.011	0.010	0.011
Max	N/A	0.014	0.161	0.012	0.013	0.059
IQR	N/A	0.011	0.017	0.009	0.008	0.010

Table D36. Differences in temperature corrected and uncorrected 15-minute volumetric soil moisture (m^3/m^3) data for all probes pooled by depth, by geomorphic surface, by season, and by location.

	Surface		Season				Location		
2.5cm	**T**	**W**	**S**	**F**	**W**	**Sp**	**L**	**M**	**U**
Min	-0.089	-0.084	-0.084	-0.037	-0.089	-0.012	-0.052	-0.072	-0.089
LQ	-0.002	-0.003	0.012	-0.001	-0.009	0.005	-0.001	-0.003	-0.003
Median	0.007	0.006	0.017	0.003	-0.005	0.011	0.007	0.007	0.006
Mean	0.007	0.007	0.020	0.004	-0.005	0.012	0.007	0.008	0.007
UQ	0.015	0.016	0.024	0.008	0.001	0.018	0.015	0.017	0.015
Max	0.274	0.064	0.274	0.082	0.120	0.145	0.132	0.274	0.223
IQR	0.017	0.019	0.012	0.009	0.010	0.013	0.016	0.020	0.018
25cm	**T**	**W**	**S**	**F**	**W**	**Sp**	**L**	**M**	**U**
Min	-0.046	-0.019	-0.001	-0.030	-0.046	-0.002	-0.033	-0.030	-0.046
LQ	0.000	0.000	0.013	0.003	-0.005	0.006	-0.001	0.001	0.000
Median	0.005	0.007	0.016	0.006	-0.003	0.009	0.006	0.007	0.006
Mean	0.007	0.008	0.018	0.007	-0.003	0.010	0.008	0.008	0.006
UQ	0.012	0.015	0.020	0.008	0.000	0.014	0.015	0.014	0.013
Max	0.188	0.078	0.188	0.158	0.025	0.040	0.188	0.057	0.078
IQR	0.013	0.015	0.007	0.005	0.005	0.008	0.016	0.013	0.013
50cm	**T**	**W**	**S**	**F**	**W**	**Sp**	**L**	**M**	**U**
Min	-0.076	-0.011	-0.021	-0.035	-0.076	0.001	-0.016	-0.076	-0.058
LQ	0.000	0.000	0.012	0.005	-0.004	0.006	-0.001	0.001	0.001
Median	0.008	0.007	0.015	0.007	-0.002	0.009	0.006	0.007	0.008
Mean	0.009	0.006	0.017	0.008	-0.002	0.010	0.006	0.007	0.009
UQ	0.015	0.012	0.017	0.009	0.000	0.012	0.013	0.012	0.015
Max	0.156	0.152	0.156	0.042	0.152	0.088	0.088	0.156	0.132
IQR	0.015	0.012	0.005	0.005	0.004	0.006	0.014	0.011	0.014
100cm	**T**	**W**	**S**	**F**	**W**	**Sp**	**L**	**M**	**U**
Min	-0.047	-0.003	0.009	-0.012	-0.047	0.001	-0.019	-0.047	-0.009
LQ	0.001	0.001	0.012	0.006	-0.001	0.005	0.001	0.001	0.002
Median	0.008	0.007	0.013	0.008	0.000	0.007	0.006	0.008	0.007
Mean	0.008	0.006	0.015	0.009	0.000	0.007	0.007	0.008	0.007
UQ	0.013	0.011	0.016	0.010	0.001	0.010	0.011	0.012	0.011
Max	0.161	0.016	0.161	0.040	0.008	0.021	0.043	0.161	0.059
IQR	0.011	0.010	0.004	0.004	0.003	0.005	0.010	0.011	0.009

Table D37. Number of soil moisture events recorded at each probe at lower basin stations ECOV1/SF1 and ECOV2/SF2.

	# total events	# summer events	# fall events	# winter events	# spring events
ECOV1_BG2.5	16	12	1	2	1
SF1_BG25	5	0	0	5	0
SF1_BG50	1	0	0	1	0
SF1_BG100	0	0	0	0	0
SF1_IW25	14	5	2	6	1
SF1_IW50	15	6	2	6	1
SF1_IW100	11	4	1	5	1
SF1_PV25	16	7	2	6	1
SF1_PV50	N/A	N/A	N/A	N/A	N/A
SF1_PV100	9	4	2	2	1
ECOV2_BG2.5	26	12	3	10	1
SF2_BG25	7	2	2	3	0
SF2_BG50	3	1	1	1	0
SF2_BG100	1	0	0	1	0
SF2_IW25	5	1	1	3	0
SF2_IW50	1	0	0	1	0
SF2_IW100	0	0	0	0	0
SF2_PV25	4	0	1	3	0
SF2_PV50	2	0	0	2	0
SF2_PV100	1	0	0	1	0

Table D38. Number of soil moisture events recorded at each probe at midbasin stations MET1/SF3 and MET2/SF4.

	# total events	# summer events	# fall events	# winter events	# spring events
MET1_BG2.5	25	11	4	9	1
SF3_BG25	1	0	0	1	0
SF3_BG50	N/A	N/A	N/A	N/A	N/A
SF3_BG100	0	0	0	0	0
SF3_IW25	N/A	N/A	N/A	N/A	N/A
SF3_IW50	15	7	4	3	1
SF3_IW100	15	7	4	3	1
SF3_PV25	13	6	4	2	1
SF3_PV50	13	6	4	2	1
SF3_PV100	5	2	2	1	0
MET2_BG2.5	25	12	4	8	1
SF4_BG25	N/A	N/A	N/A	N/A	N/A
SF4_BG50	1	0	0	1	0
SF4_BG100	0	0	0	0	0
SF4_IW25	8	5	1	2	0
SF4_IW50	2	0	0	2	0
SF4_IW100	N/A	N/A	N/A	N/A	N/A
SF4_PV25	6	4	0	2	0
SF4_PV50	1	0	0	1	0
SF4_PV100	0	0	0	0	0

Table D39. Number of soil moisture events recorded at each probe at upper basin stations MET3/SF5 and MET4/SF6.

	# total events	# summer events	# fall events	# winter events	# spring events
MET3_BG2.5	32	15	4	10	3
SF5_BG25	8	3	0	5	0
SF5_BG50	4	2	0	2	0
SF5_BG100	2	1	0	1	0
SF5_IW25	12	5	2	4	1
SF5_IW50	5	3	0	2	0
SF5_IW100	2	1	0	1	0
SF5_PV25	8	3	1	4	0
SF5_PV50	3	1	0	2	0
SF5_PV100	2	1	0	1	0
MET4_BG2.5	31	16	4	10	1
SF6_BG25	0	0	0	0	0
SF6_BG50	0	0	0	0	0
SF6_BG100	0	0	0	0	0
SF6_IW25	11	3	2	5	1
SF6_IW50	6	2	1	3	0
SF6_IW100	5	2	0	3	0
SF6_PV25	12	4	2	5	1
SF6_PV50	5	1	1	3	0
SF6_PV100	5	1	2	2	0

Table D40. Summary statistics by probe for fifteen minute volumetric soil moisture (m^3/m^3) at 2.5-25 cm.

	Min	Median	GMean	Mean	Max	IQR	Q1	Q3	SD	GSD	CV	GCV
ECOV1_BG2.5	0.01	0.04	0.05	0.06	0.34	0.04	0.03	0.07	0.04	1.7	65.7	0.60
ECOV2_BG2.5	0.01	0.04	0.04	0.05	0.24	0.03	0.03	0.06	0.04	1.8	74.5	0.65
MET1_BG2.5	0.06	0.10	0.12	0.13	0.47	0.07	0.08	0.15	0.07	1.5	55.1	0.47
MET2_BG2.5	0.02	0.05	0.05	0.06	0.24	0.04	0.04	0.08	0.03	1.6	54.8	0.52
MET3_BG2.5	0.04	0.10	0.11	0.12	0.33	0.07	0.08	0.15	0.06	1.5	46.9	0.45
MET4_BG2.5	0.04	0.11	0.13	0.15	0.48	0.11	0.08	0.19	0.10	1.7	67.1	0.63
SF1_PV25	0.05	0.09	0.10	0.11	0.34	0.06	0.07	0.13	0.05	1.5	48.2	0.43
SF2_PV25	0.07	0.09	0.10	0.10	0.24	0.02	0.09	0.11	0.02	1.2	22.5	0.20
SF3_PV25	0.06	0.09	0.10	0.10	0.18	0.02	0.09	0.11	0.02	1.2	17.9	0.18
SF4_PV25	0.03	0.06	0.06	0.06	0.27	0.03	0.04	0.08	0.03	1.4	48.6	0.37
SF5_PV25	0.07	0.11	0.11	0.11	0.26	0.03	0.09	0.12	0.03	1.2	25.5	0.23
SF6_PV25	0.06	0.09	0.10	0.10	0.37	0.03	0.08	0.12	0.04	1.3	35.0	0.31
SF1_IW25	0.09	0.16	0.17	0.18	0.47	0.09	0.13	0.22	0.07	1.4	38.9	0.37
SF2_IW25	0.01	0.02	0.02	0.03	0.14	0.02	0.01	0.03	0.02	2.2	82.6	0.97
SF3_IW25	0.30	0.31	0.31	0.31	0.32	0.00	0.31	0.32	0.00	1.0	0.37	0.00
SF4_IW25	0.05	0.07	0.08	0.08	0.35	0.03	0.06	0.09	0.03	1.3	42.6	0.33
SF5_IW25	0.06	0.11	0.12	0.13	0.35	0.07	0.08	0.15	0.05	1.4	41.7	0.40
SF6_IW25	0.05	0.08	0.09	0.10	0.38	0.03	0.07	0.10	0.04	1.4	43.1	0.36
SF1_BG25	0.05	0.08	0.08	0.09	0.24	0.04	0.07	0.11	0.03	1.4	37.6	0.35
SF2_BG25	0.06	0.09	0.09	0.09	0.20	0.02	0.08	0.10	0.02	1.1	17.8	0.18
SF3_BG25	0.07	0.11	0.10	0.11	0.17	0.02	0.09	0.12	0.02	1.1	16.9	0.17
SF4_BG25	0.66	0.67	0.67	0.67	0.67	0.00	0.67	0.67	0.00	1.0	0.12	0.00
SF5_BG25	0.02	0.06	0.06	0.06	0.23	0.03	0.05	0.07	0.02	1.4	38.3	0.36
SF6_BG25	0.05	0.08	0.08	0.08	0.11	0.02	0.07	0.09	0.01	1.2	17.3	0.18

Table D41. Summary statistics by probe for fifteen minute volumetric soil moisture (m^3/m^3) at 50-100 cm.

	Min	Median	GMean	Mean	Max	IQR	Q1	Q3	SD	GSD	CV	GCV
SF1_PV50	0.23	0.28	0.28	0.28	0.32	0.05	0.26	0.30	0.02	1.0	8.79	0.09
SF2_PV50	0.11	0.13	0.13	0.13	0.28	0.01	0.12	0.13	0.02	1.1	12.4	0.11
SF3_PV50	0.13	0.18	0.18	0.18	0.23	0.03	0.17	0.20	0.02	1.1	12.2	0.12
SF4_PV50	0.12	0.13	0.13	0.13	0.21	0.01	0.13	0.14	0.01	1.0	9.48	0.08
SF5_PV50	0.07	0.10	0.10	0.11	0.21	0.03	0.09	0.12	0.03	1.2	24.1	0.23
SF6_PV50	0.16	0.21	0.22	0.23	0.57	0.02	0.20	0.22	0.05	1.2	22.0	0.19
SF1_IW50	0.13	0.19	0.19	0.20	0.41	0.04	0.17	0.21	0.04	1.2	20.2	0.19
SF2_IW50	0.07	0.08	0.08	0.09	0.24	0.01	0.08	0.09	0.03	1.2	29.8	0.20
SF3_IW50	0.10	0.13	0.14	0.14	0.37	0.04	0.12	0.16	0.03	1.2	21.8	0.20
SF4_IW50	0.06	0.08	0.08	0.09	0.32	0.01	0.07	0.09	0.04	1.3	44.3	0.27
SF5_IW50	0.05	0.07	0.08	0.08	0.26	0.03	0.06	0.09	0.03	1.3	37.4	0.29
SF6_IW50	0.16	0.20	0.21	0.21	0.44	0.02	0.19	0.21	0.05	1.2	24.0	0.20
SF1_BG50	0.06	0.08	0.08	0.08	0.18	0.01	0.07	0.09	0.02	1.1	20.5	0.16
SF2_BG50	0.04	0.07	0.06	0.06	0.14	0.01	0.06	0.07	0.01	1.1	17.7	0.17
SF3_BG50	0.28	0.28	0.28	0.28	0.28	0.00	0.28	0.28	0.00	1.0	0.33	0.00
SF4_BG50	0.04	0.05	0.05	0.05	0.07	0.01	0.04	0.05	0.01	1.1	11.3	0.11
SF5_BG50	0.13	0.15	0.15	0.15	0.28	0.02	0.14	0.16	0.02	1.1	14.4	0.13
SF6_BG50	0.10	0.12	0.12	0.12	0.16	0.03	0.11	0.14	0.02	1.1	15.0	0.15
SF1_PV100	0.02	0.08	0.08	0.09	0.18	0.04	0.07	0.11	0.03	1.4	33.8	0.40
SF2_PV100	0.05	0.06	0.06	0.06	0.11	0.01	0.05	0.06	0.01	1.1	18.2	0.15
SF3_PV100	0.10	0.17	0.19	0.19	0.58	0.03	0.17	0.20	0.06	1.3	29.0	0.26
SF4_PV100	0.06	0.07	0.07	0.07	0.08	0.01	0.07	0.08	0.00	1.0	5.85	0.06
SF5_PV100	0.09	0.10	0.11	0.11	0.14	0.03	0.10	0.13	0.02	1.1	15.7	0.16
SF6_PV100	0.08	0.13	0.14	0.14	0.36	0.01	0.13	0.14	0.03	1.2	21.3	0.19
SF1_IW100	0.11	0.12	0.13	0.13	0.34	0.03	0.12	0.15	0.03	1.1	19.4	0.17
SF2_IW100	0.04	0.05	0.05	0.05	0.06	0.01	0.05	0.06	0.00	1.0	9.00	0.09
SF3_IW100	0.14	0.19	0.20	0.21	0.36	0.04	0.18	0.22	0.04	1.1	17.7	0.17
SF4_IW100	0.37	0.37	0.37	0.37	0.37	0.00	0.37	0.37	0.00	1.0	0.15	0.00
SF5_IW100	0.05	0.07	0.08	0.08	0.16	0.02	0.07	0.09	0.02	1.2	23.1	0.21
SF6_IW100	0.10	0.14	0.14	0.14	0.22	0.01	0.13	0.14	0.02	1.1	14.4	0.13
SF1_BG100	0.12	0.14	0.14	0.14	0.15	0.01	0.13	0.14	0.01	1.0	5.49	0.05
SF2_BG100	0.12	0.13	0.13	0.13	0.24	0.01	0.12	0.14	0.02	1.1	12.4	0.11
SF3_BG100	0.04	0.09	0.07	0.08	0.12	0.06	0.04	0.10	0.03	1.4	34.6	0.41
SF4_BG100	0.09	0.10	0.10	0.10	0.11	0.01	0.10	0.11	0.01	1.0	5.05	0.05
SF5_BG100	0.12	0.14	0.14	0.14	0.18	0.02	0.13	0.15	0.02	1.1	10.6	0.10
SF6_BG100	0.09	0.10	0.10	0.10	0.11	0.01	0.10	0.11	0.01	1.0	6.0	0.06

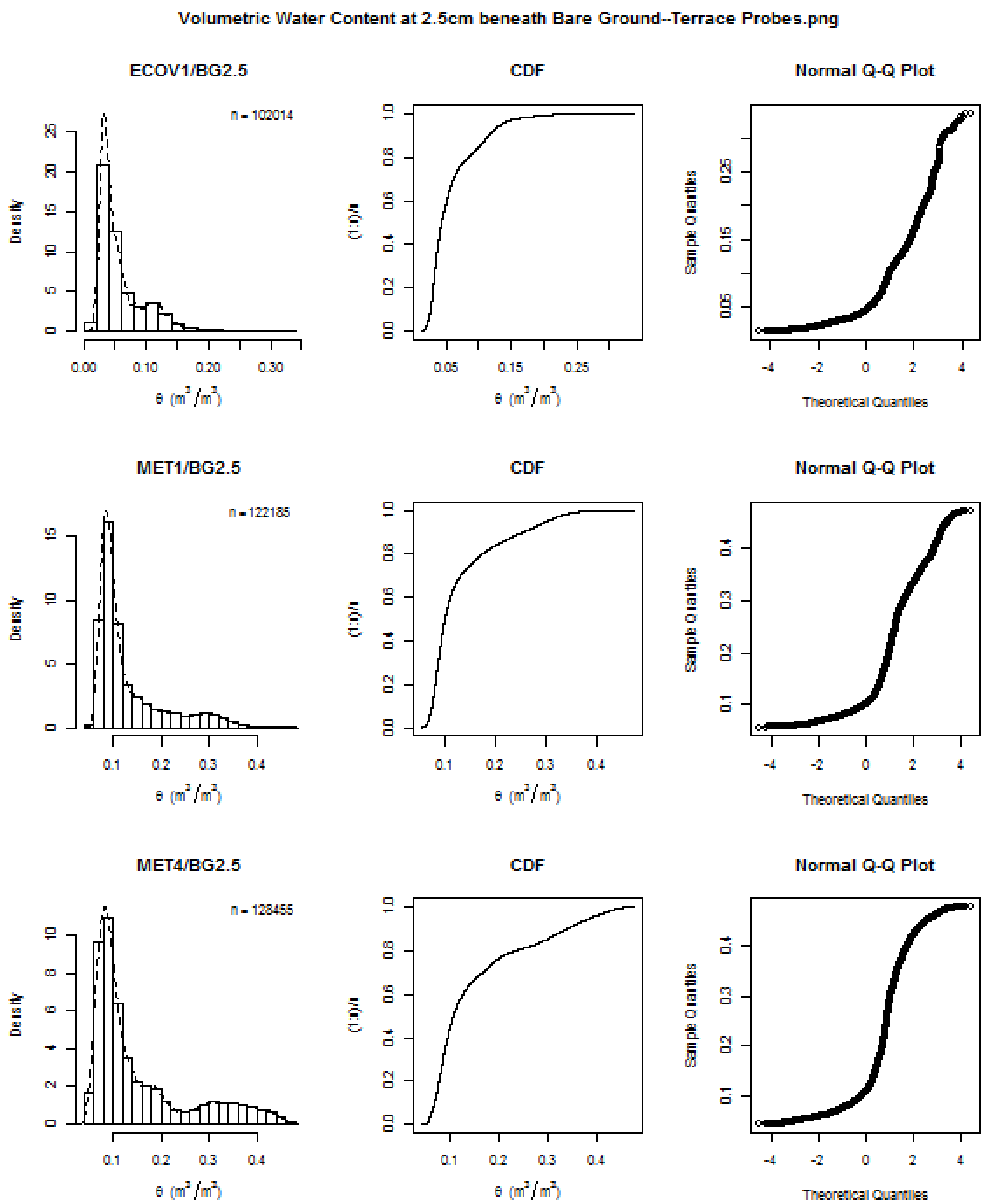

Figure D23. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 2.5cm beneath bare ground at terrace stations ECOV1, MET1, and MET4 in the Yuma Wash watershed.

Volumetric Water Content at 2.5cm beneath Bare Ground--Wash Probes.png

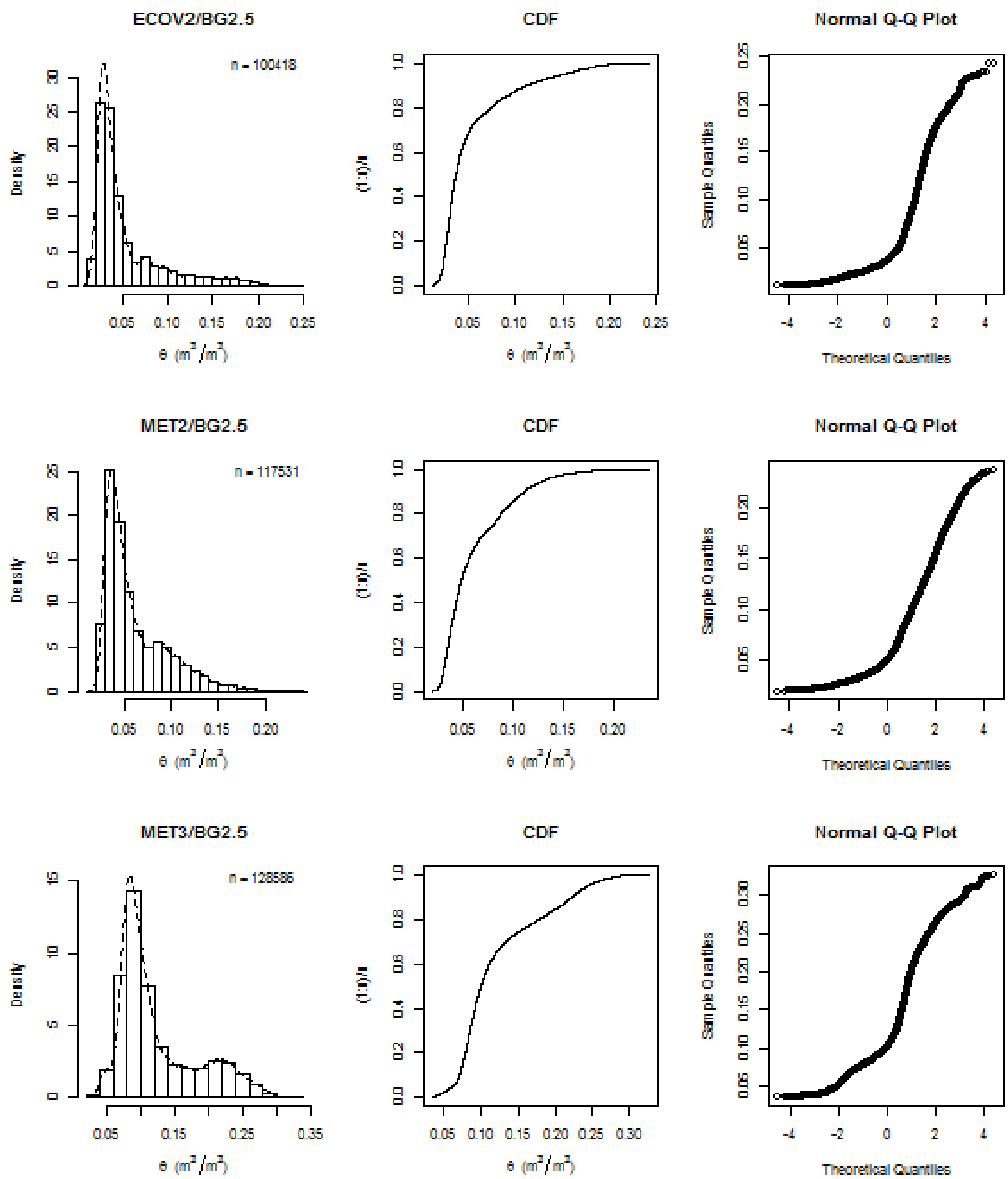

Figure D24. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 2.5cm beneath bare ground at wash stations ECOV2, MET2, and MET3 in the Yuma Wash watershed.

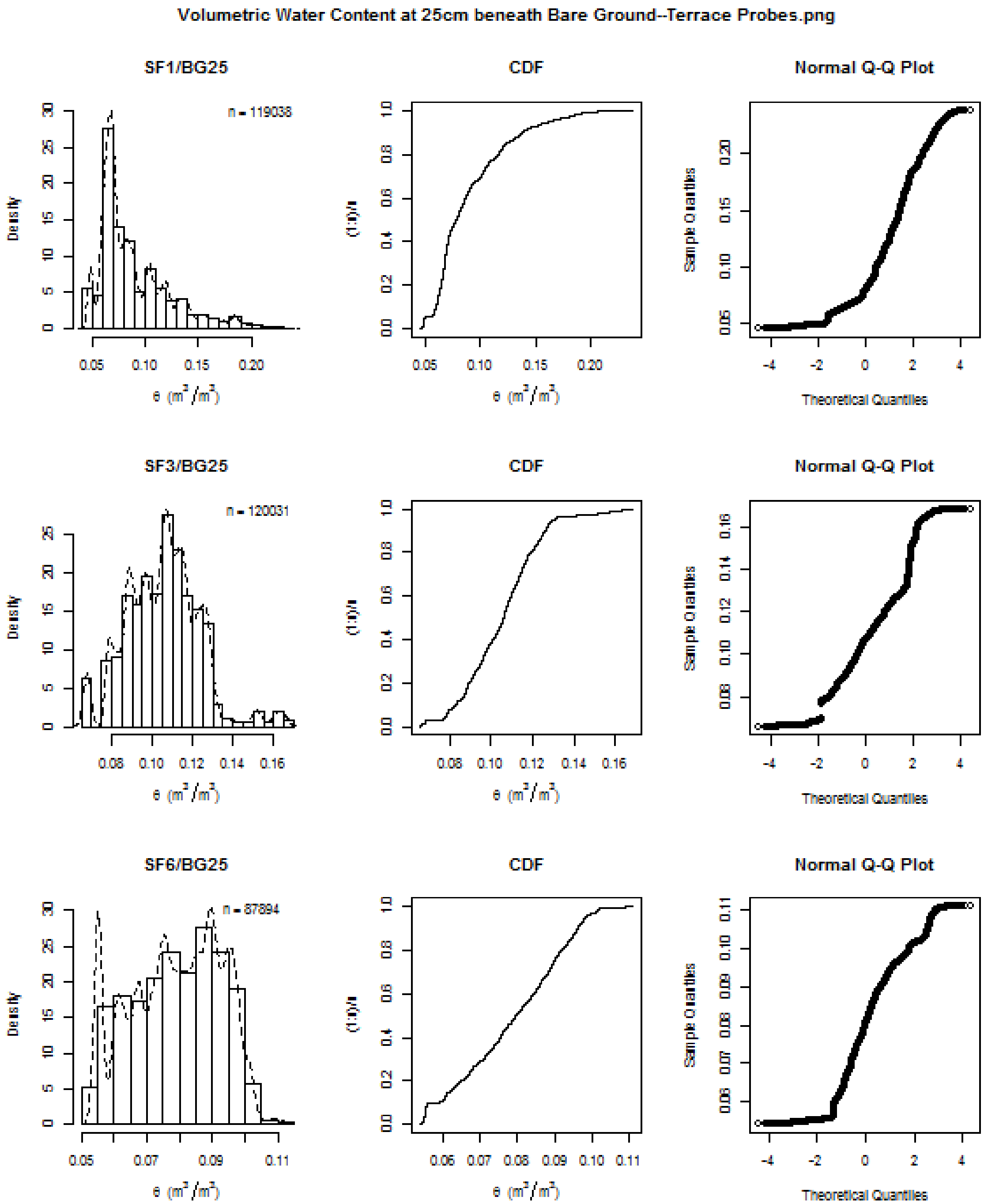

Figure D25. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 25cm beneath bare ground at terrace stations SF1, SF3, and SF6 in the Yuma Wash watershed.

Volumetric Water Content at 25cm beneath Bare Ground--Wash Probes.png

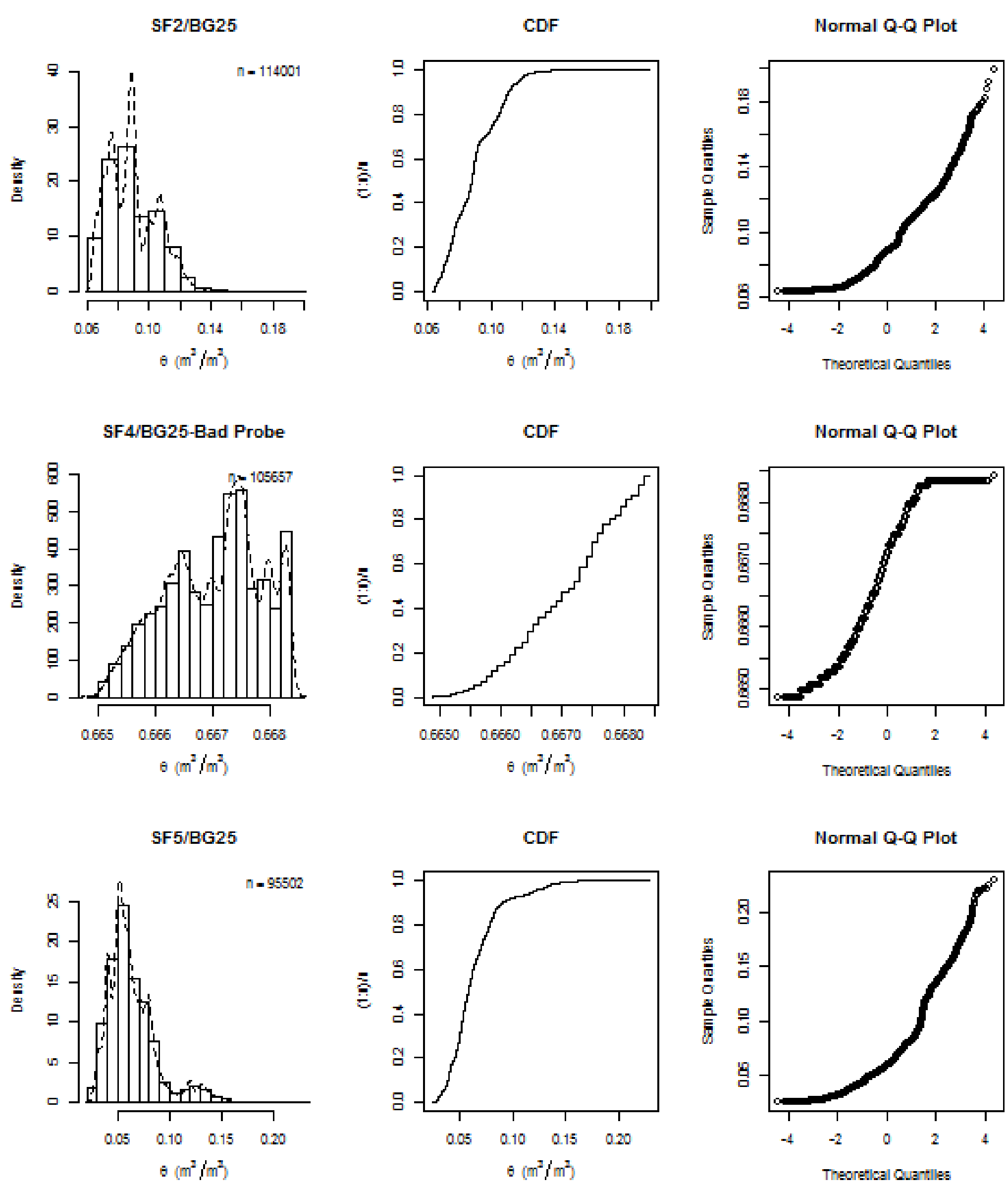

Figure D26. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 25cm beneath bare ground at wash stations SF2, SF4, and SF5 in the Yuma Wash watershed.

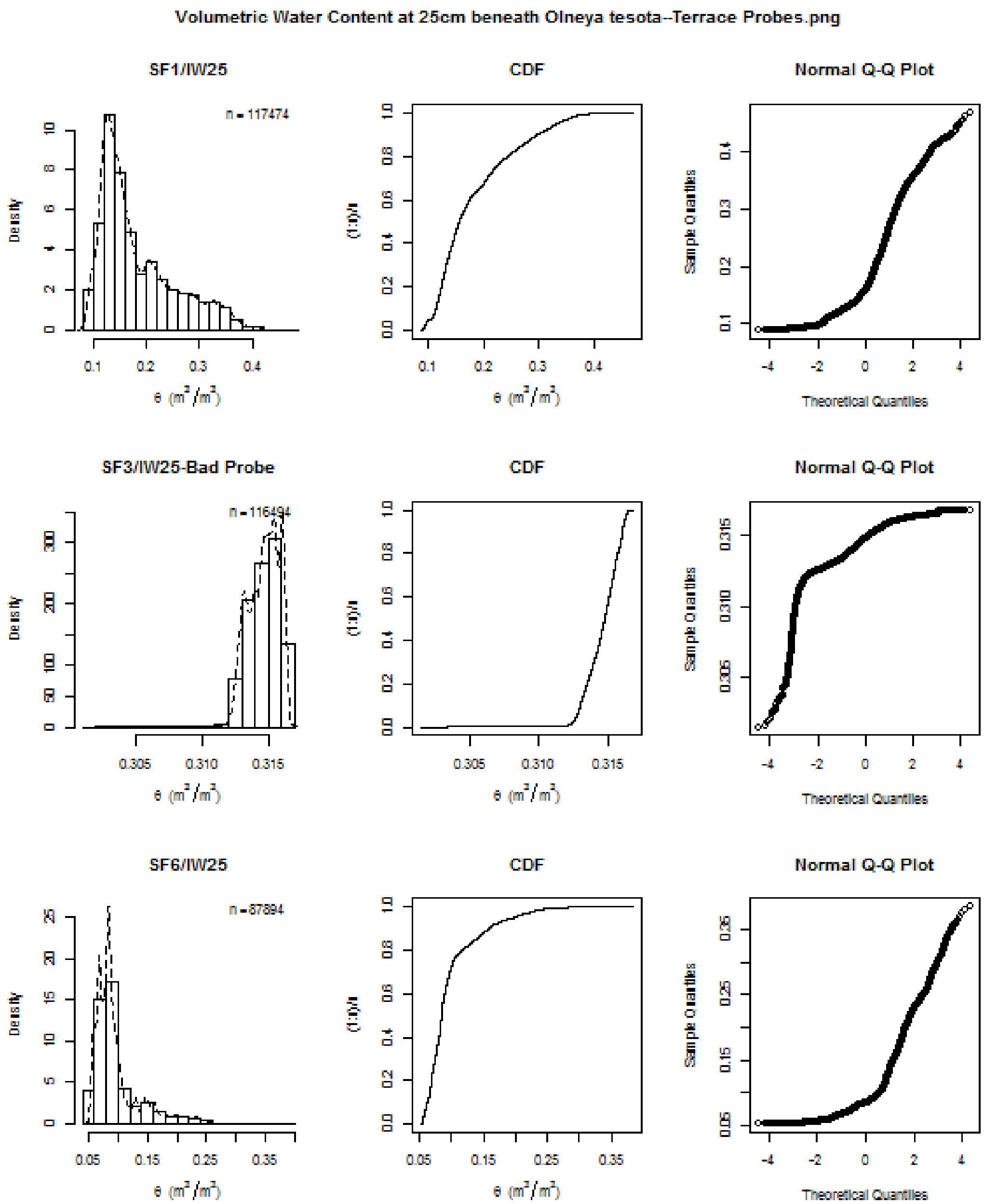

Figure D27. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 25cm beneath *Olneya tesota* at terrace stations SF1, SF3, and SF6 in the Yuma Wash watershed.

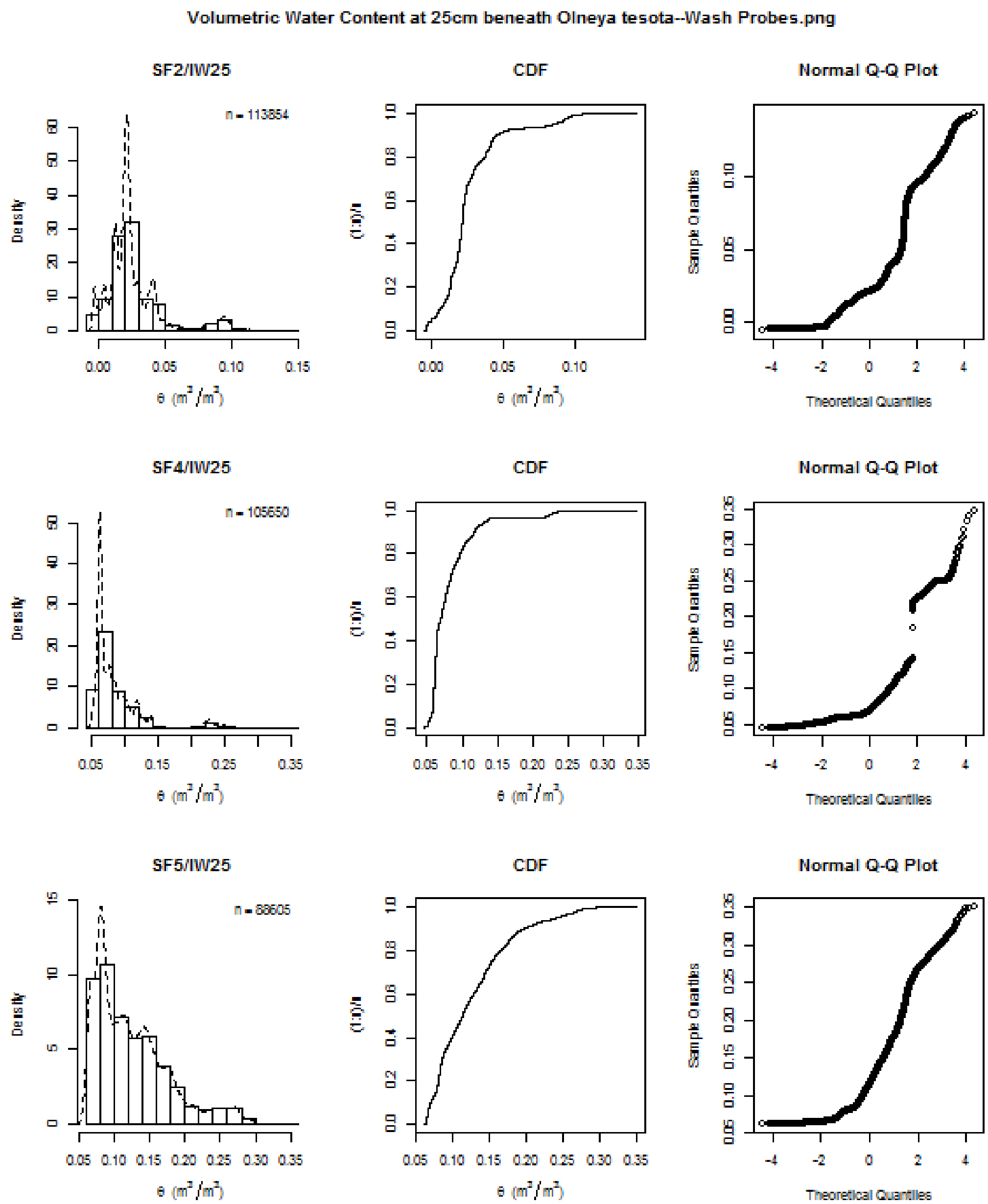

Figure D28. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 25cm beneath *Olneya tesota* at wash stations SF2, SF4, and SF5 in the Yuma Wash watershed.

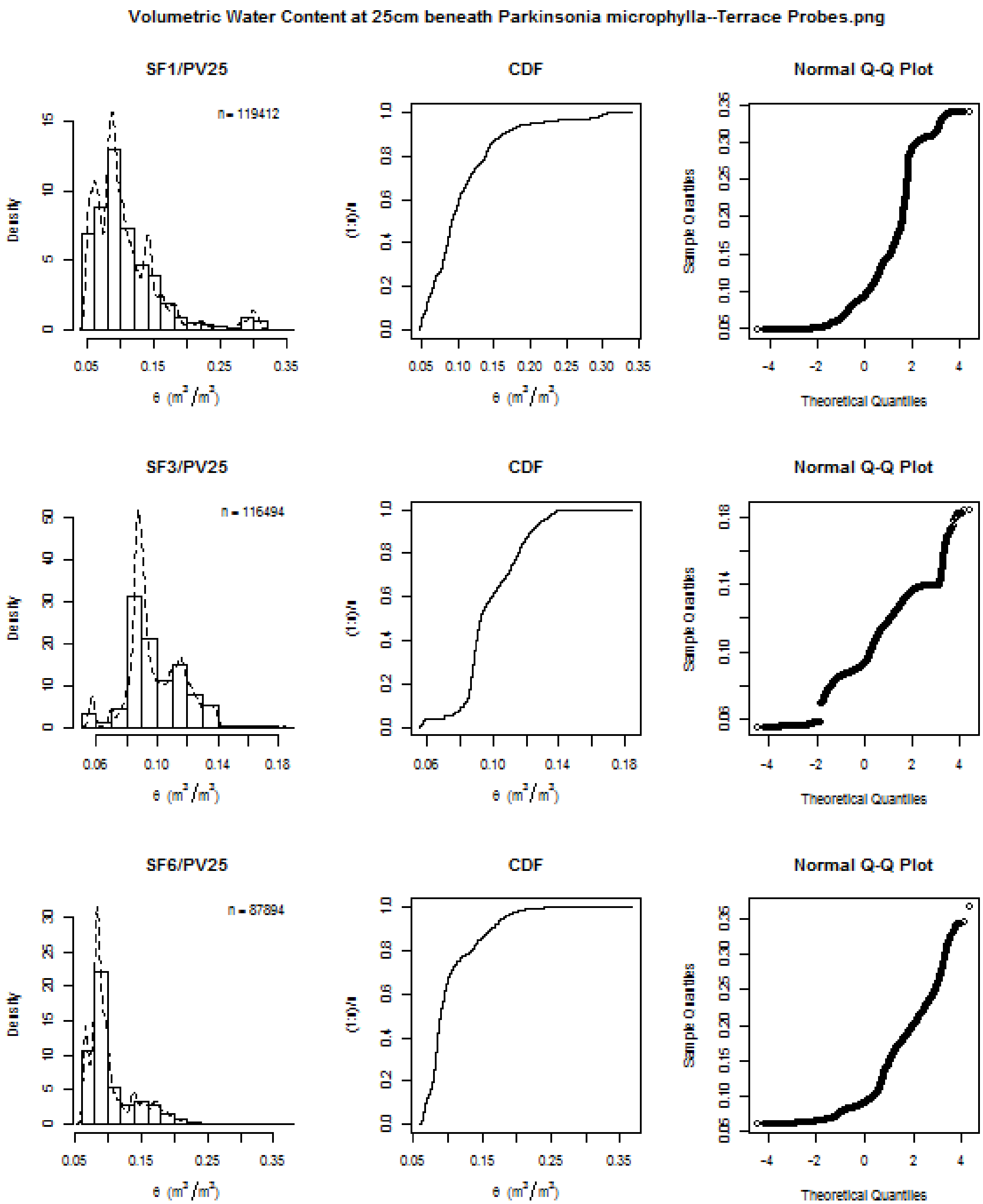

Figure D29. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 25cm beneath *Parkinsonia microphylla* at terrace stations SF1, SF3, and SF6 in the Yuma Wash watershed.

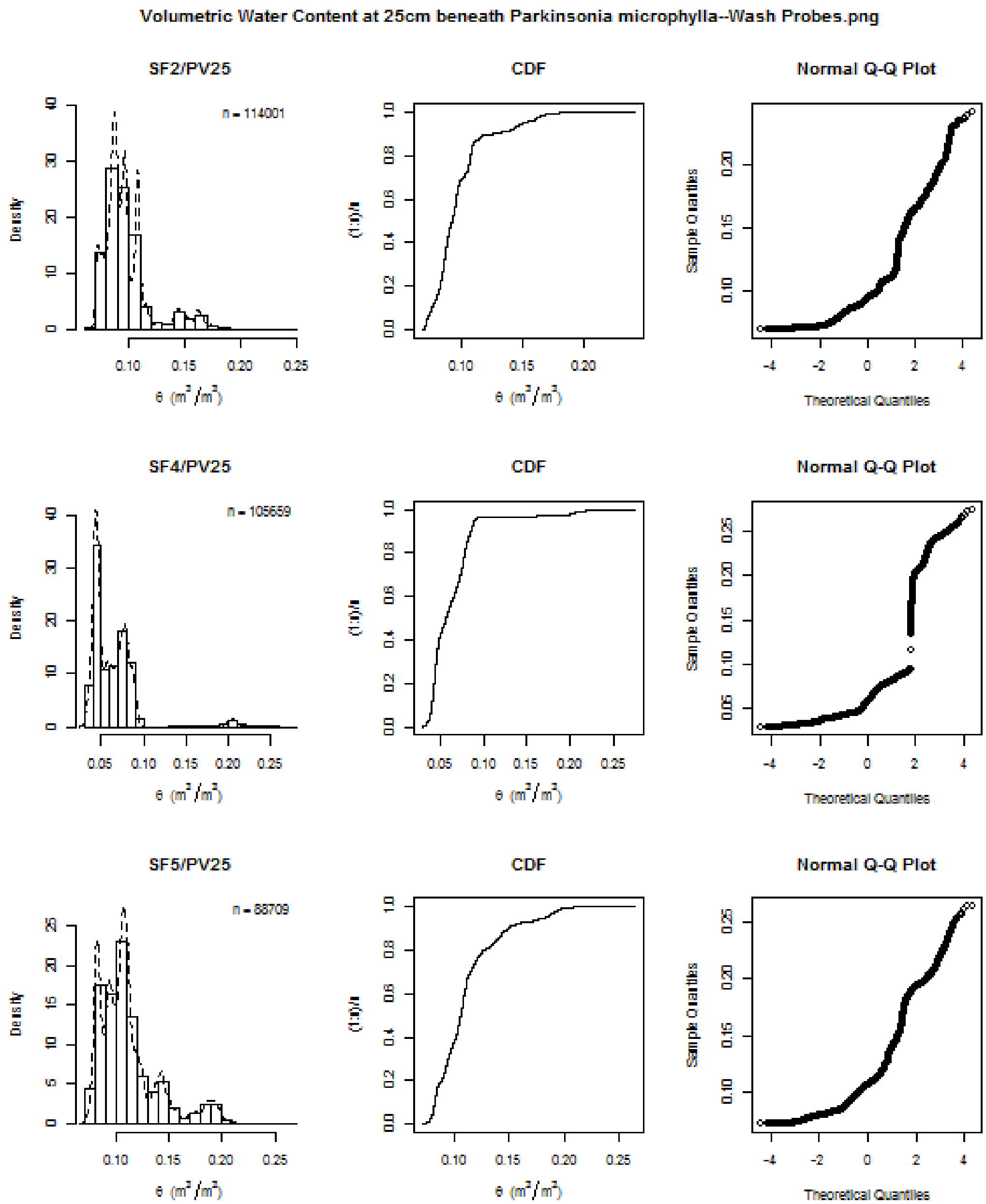

Figure D30. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 25cm beneath *Parkinsonia microphylla* at wash stations SF2, SF4, and SF5 in the Yuma Wash watershed.

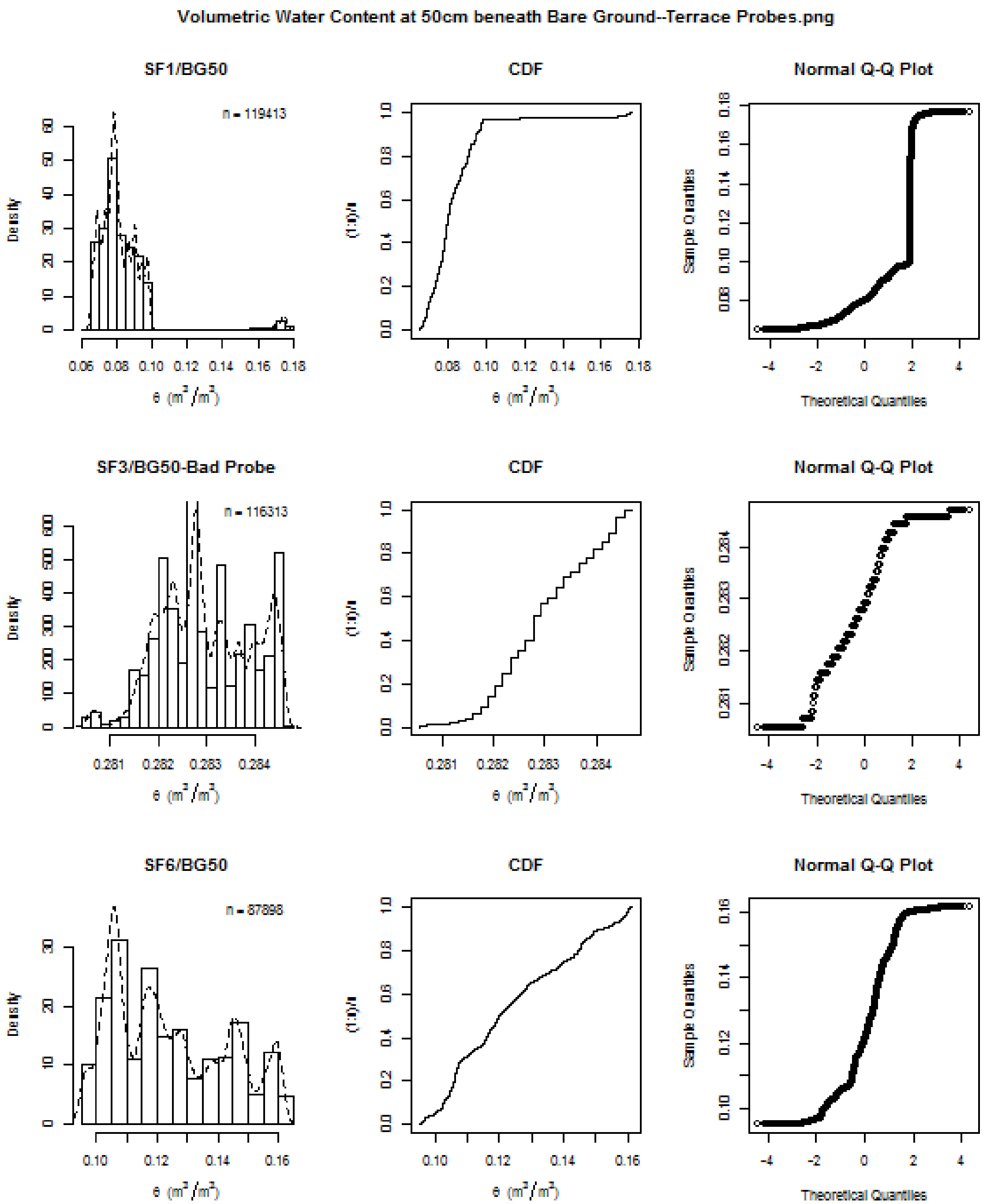

Figure D31. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 50cm beneath bare ground at terrace stations SF1, SF3, and SF6 in the Yuma Wash watershed.

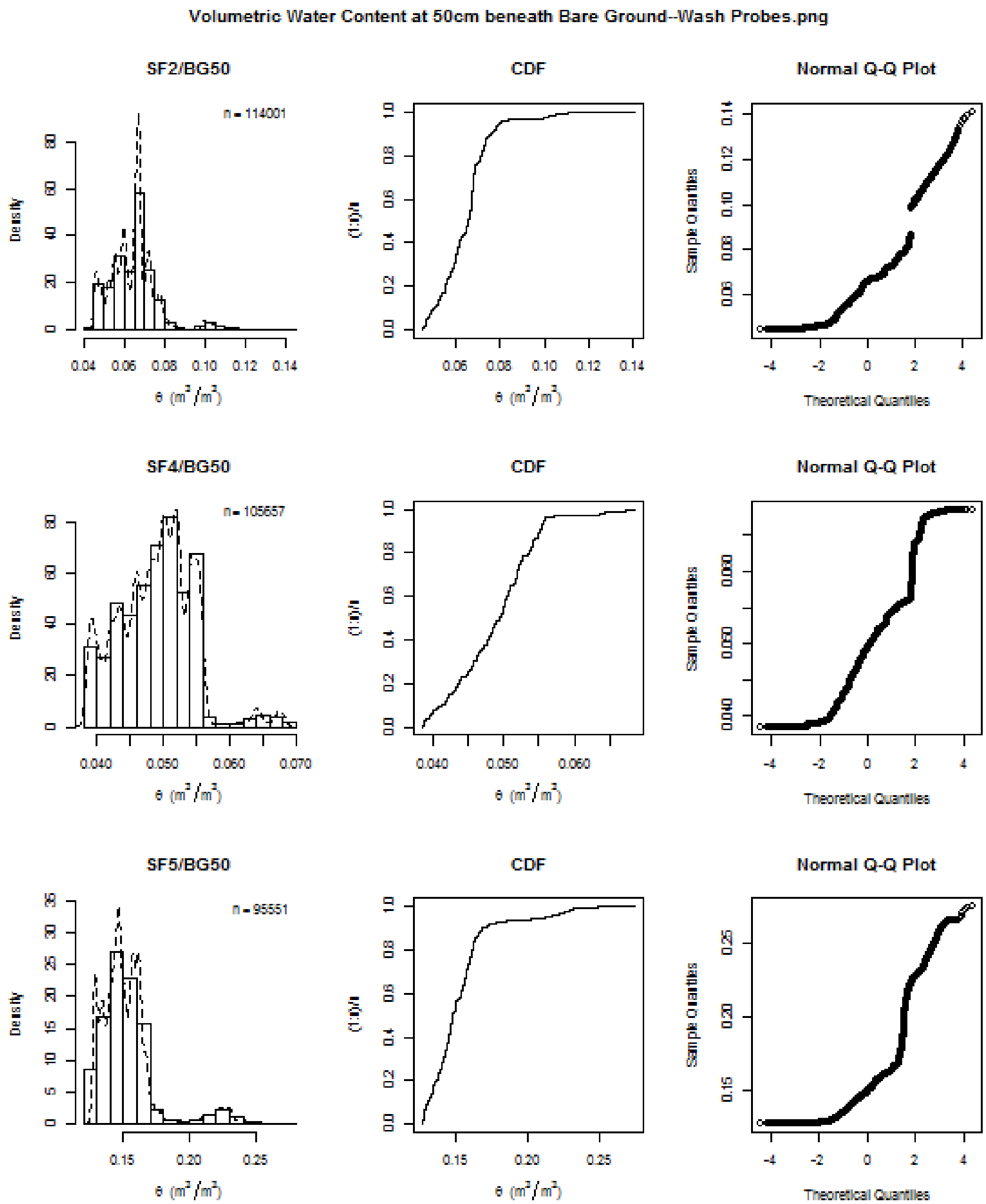

Figure D32. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 50cm beneath bare ground at wash stations SF2, SF4, and SF5 in the Yuma Wash watershed.

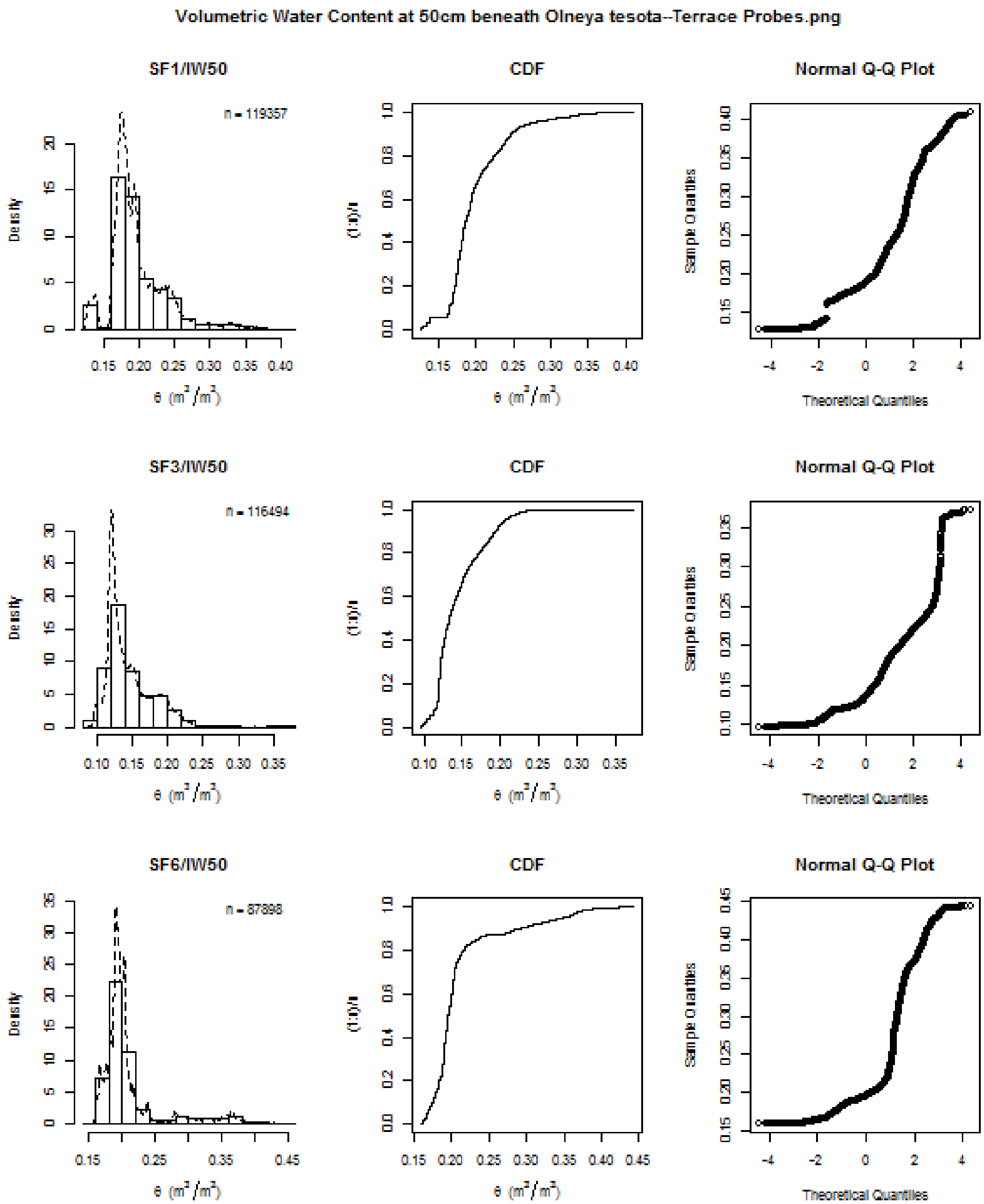

Figure D33. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 50cm beneath *Olneya tesota* at terrace stations SF1, SF3, and SF6 in the Yuma Wash watershed.

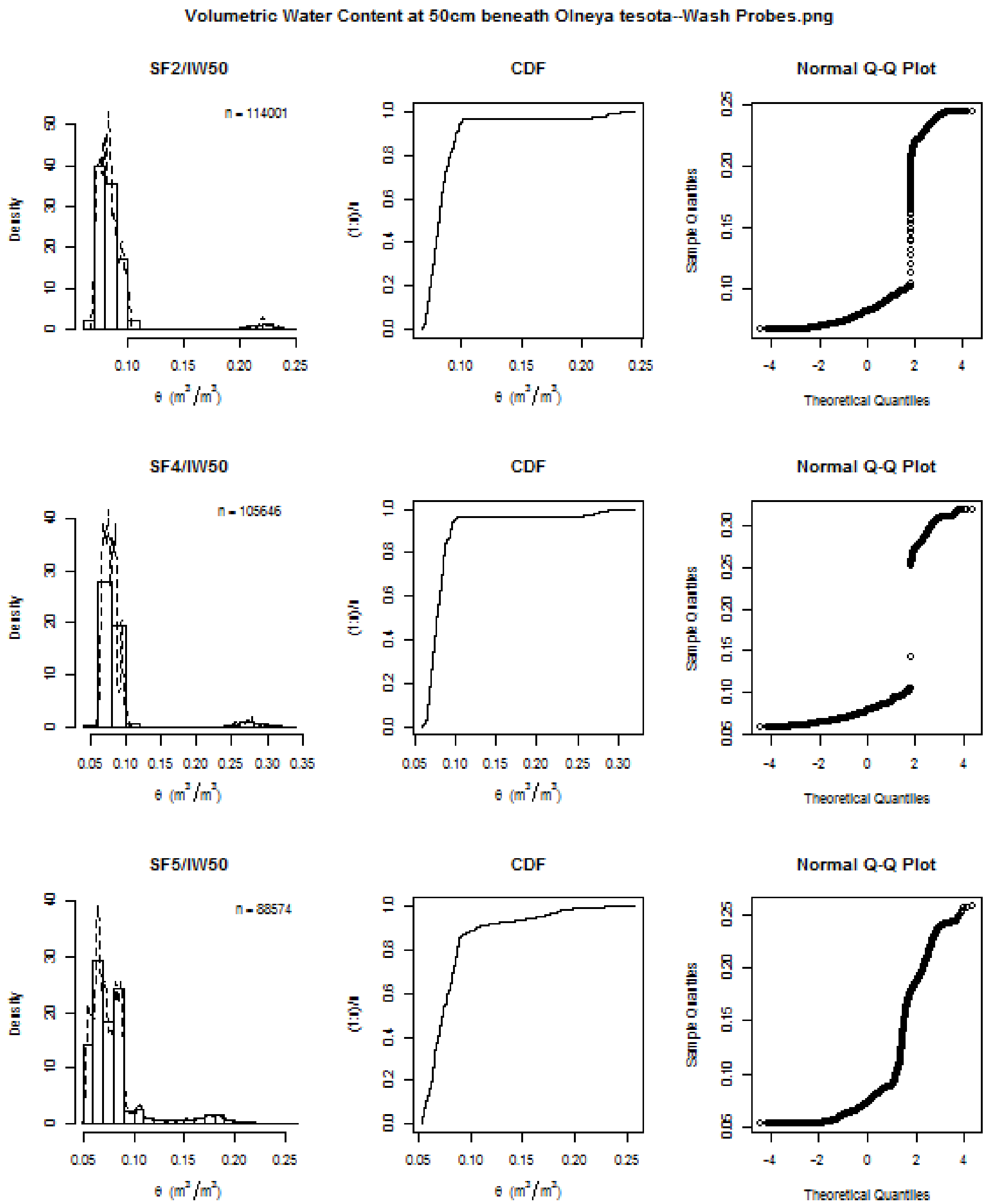

Figure D34. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 50cm beneath *Olneya tesota* at wash stations SF2, SF4, and SF5 in the Yuma Wash watershed.

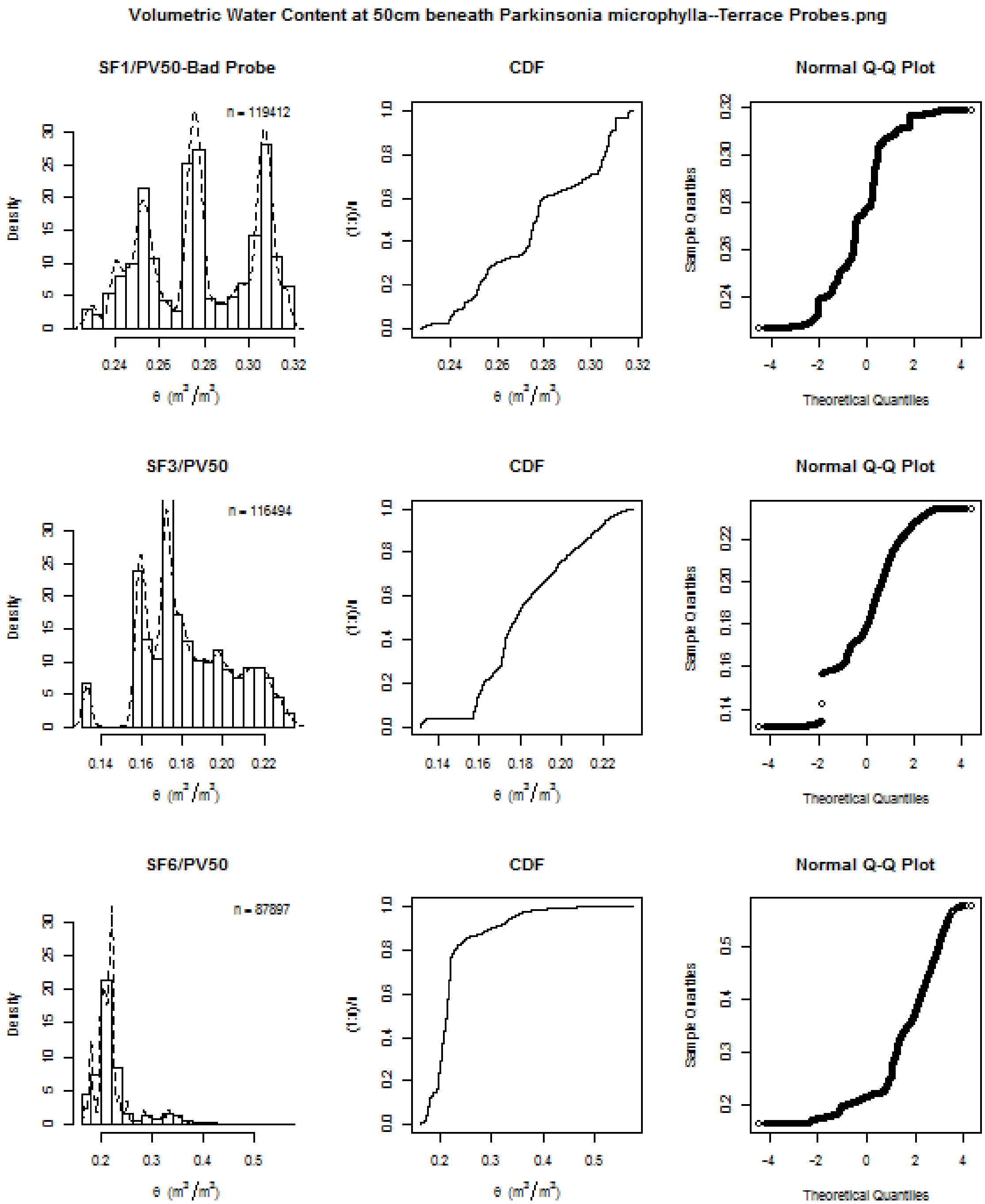

Figure D35. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 50cm beneath *Parkinsonia microphylla* at terrace stations SF1, SF3, and SF6 in the Yuma Wash watershed.

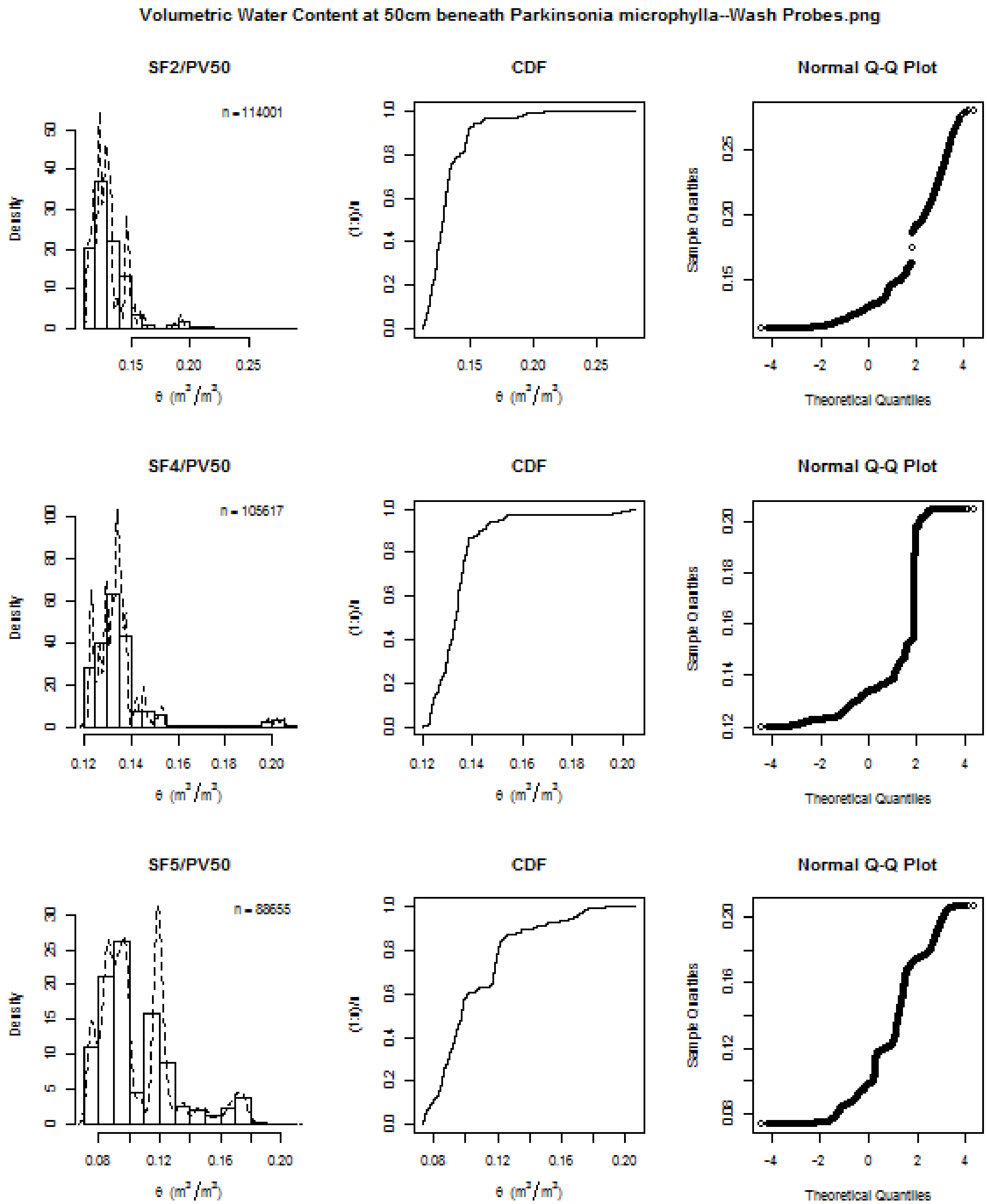

Figure D36. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 50cm beneath *Parkinsonia microphylla* at wash stations SF2, SF4, and SF5 in the Yuma Wash watershed.

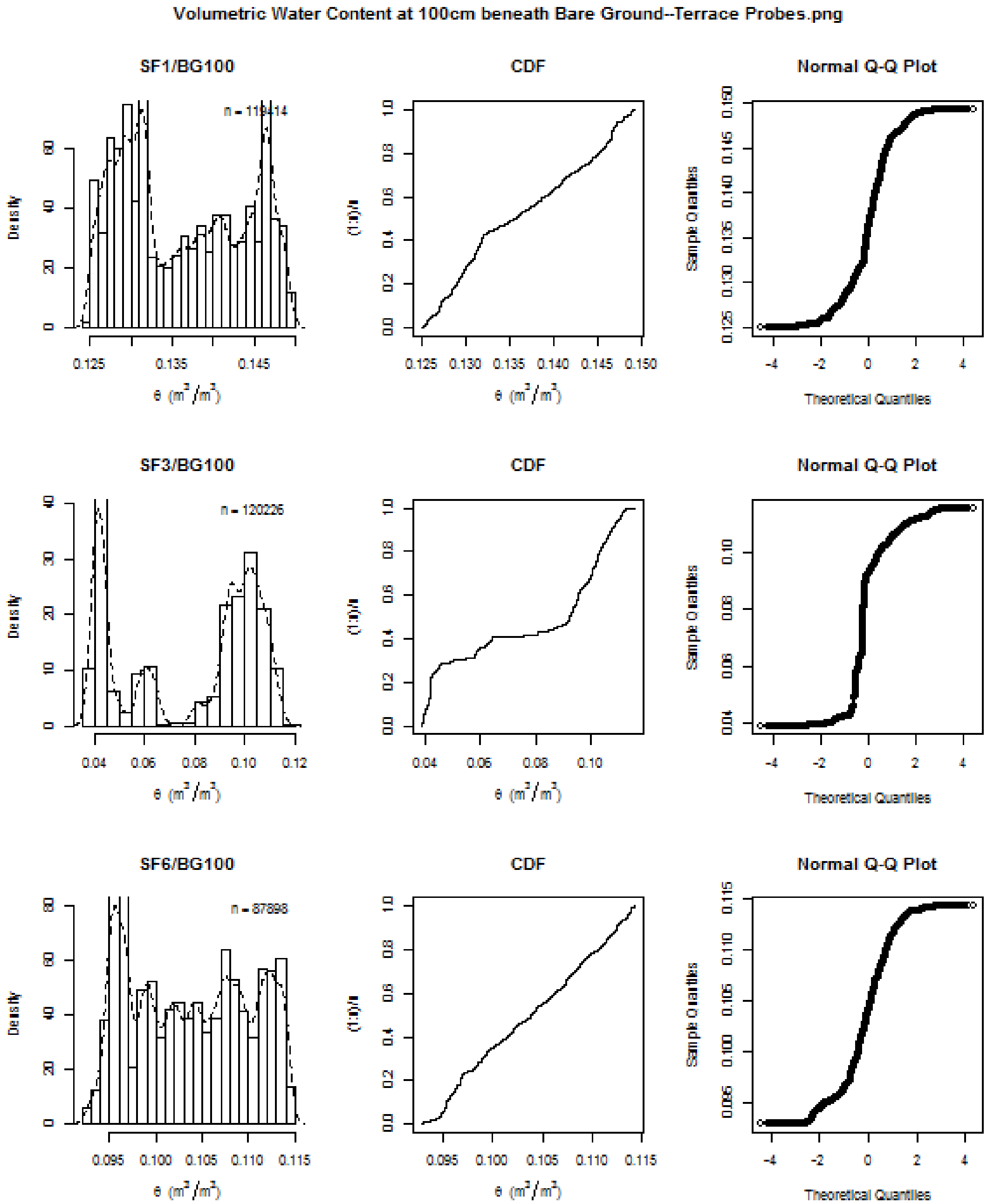

Figure D37. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 100cm beneath bare ground at terrace stations SF1, SF3, and SF6 in the Yuma Wash watershed.

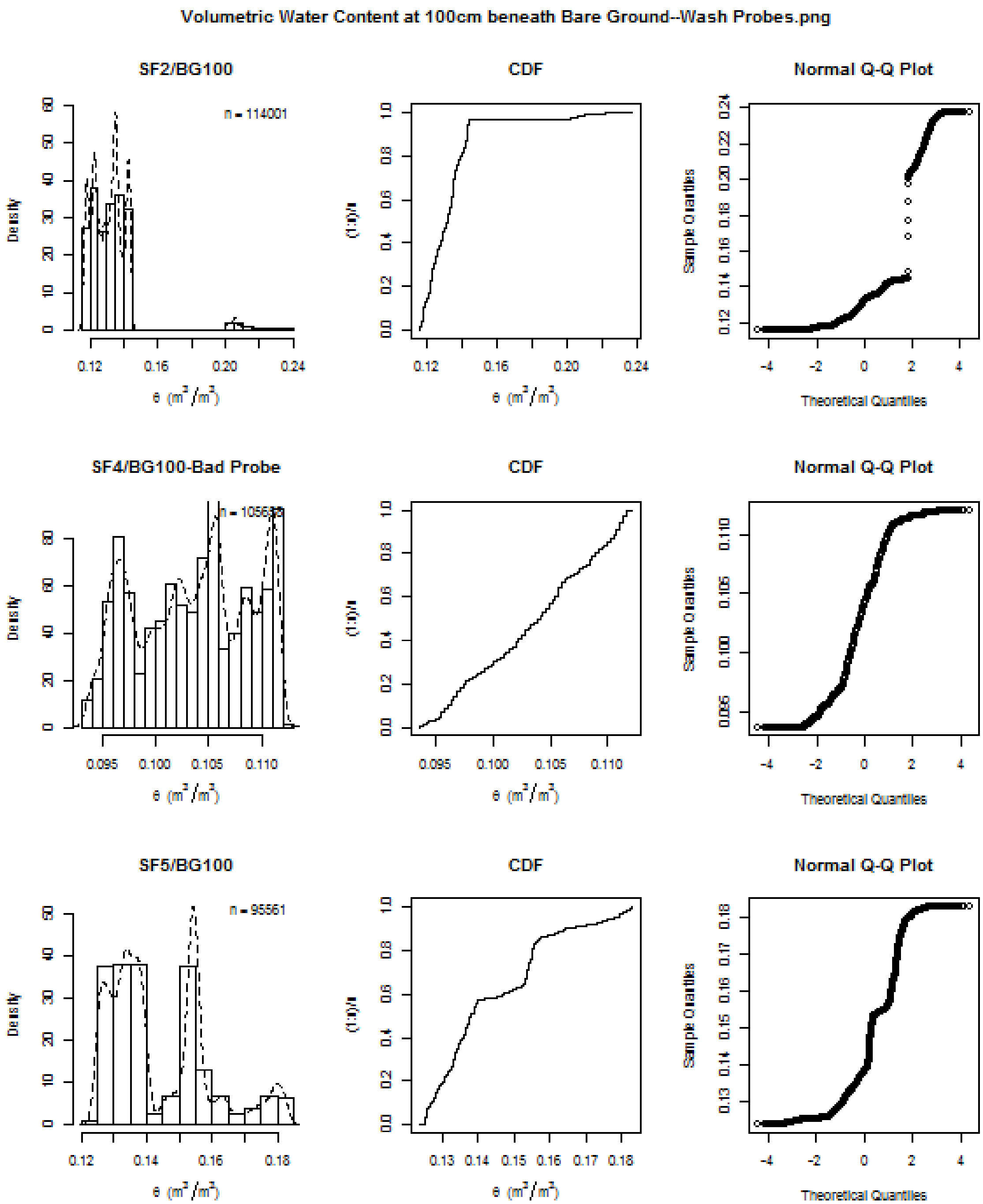

Figure D38. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 100cm beneath bare ground at wash stations SF2, SF4, and SF5 in the Yuma Wash watershed.

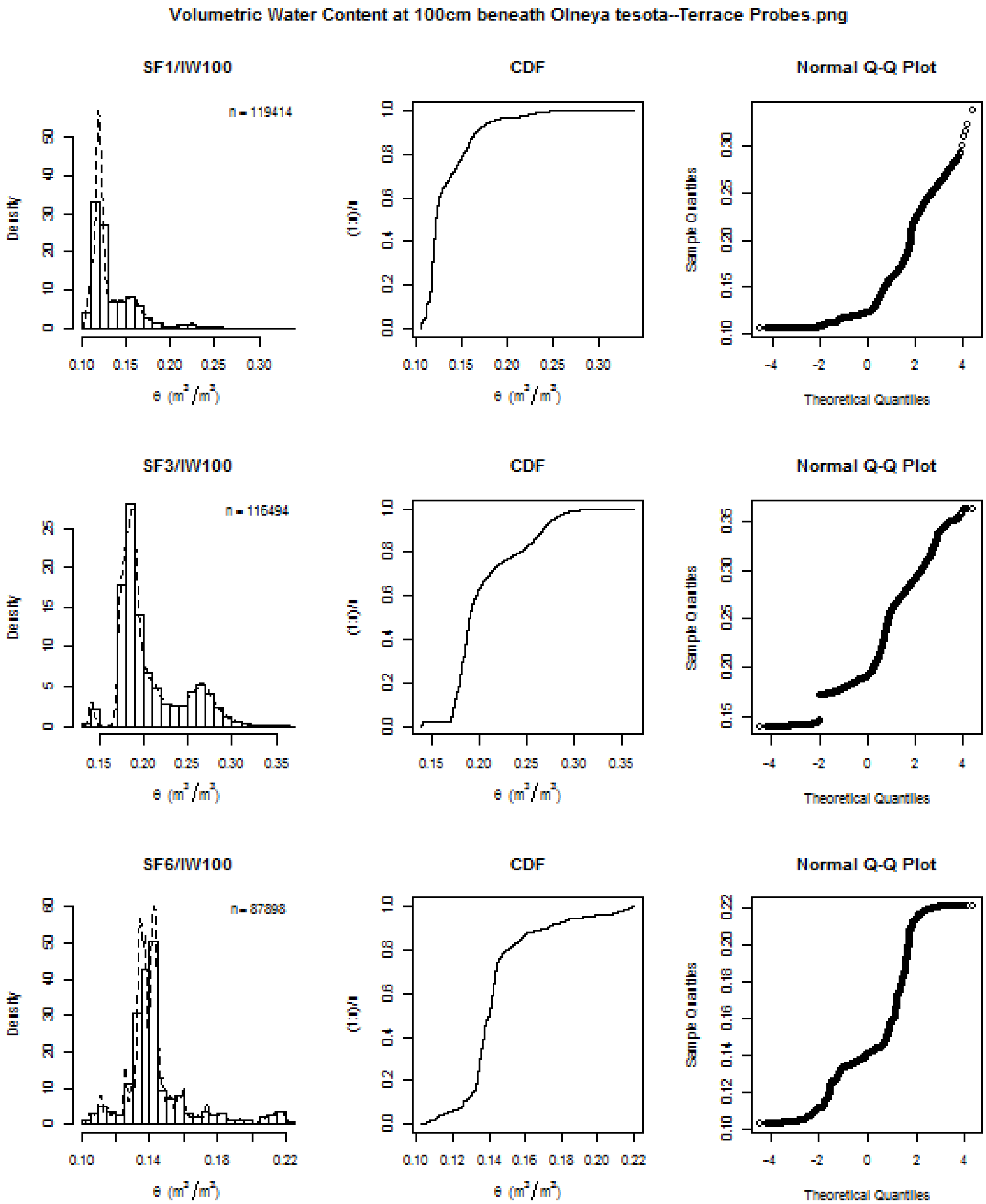

Figure D39. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 100cm beneath *Olneya tesota* at terrace stations SF1, SF3, and SF6 in the Yuma Wash watershed.

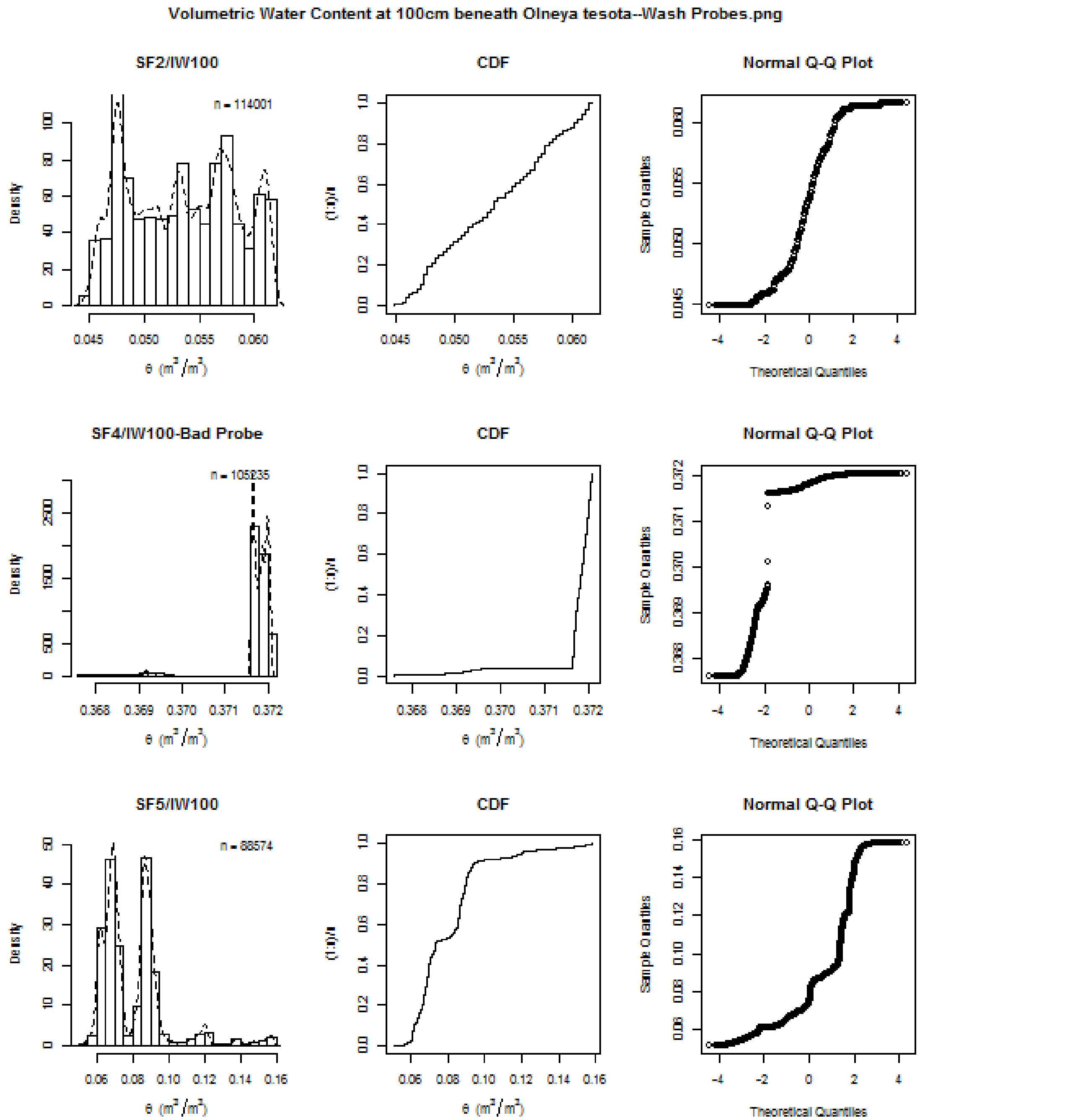

Figure D40. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 100cm beneath *Olneya tesota* at wash stations SF2, SF4, and SF5 in the Yuma Wash watershed.

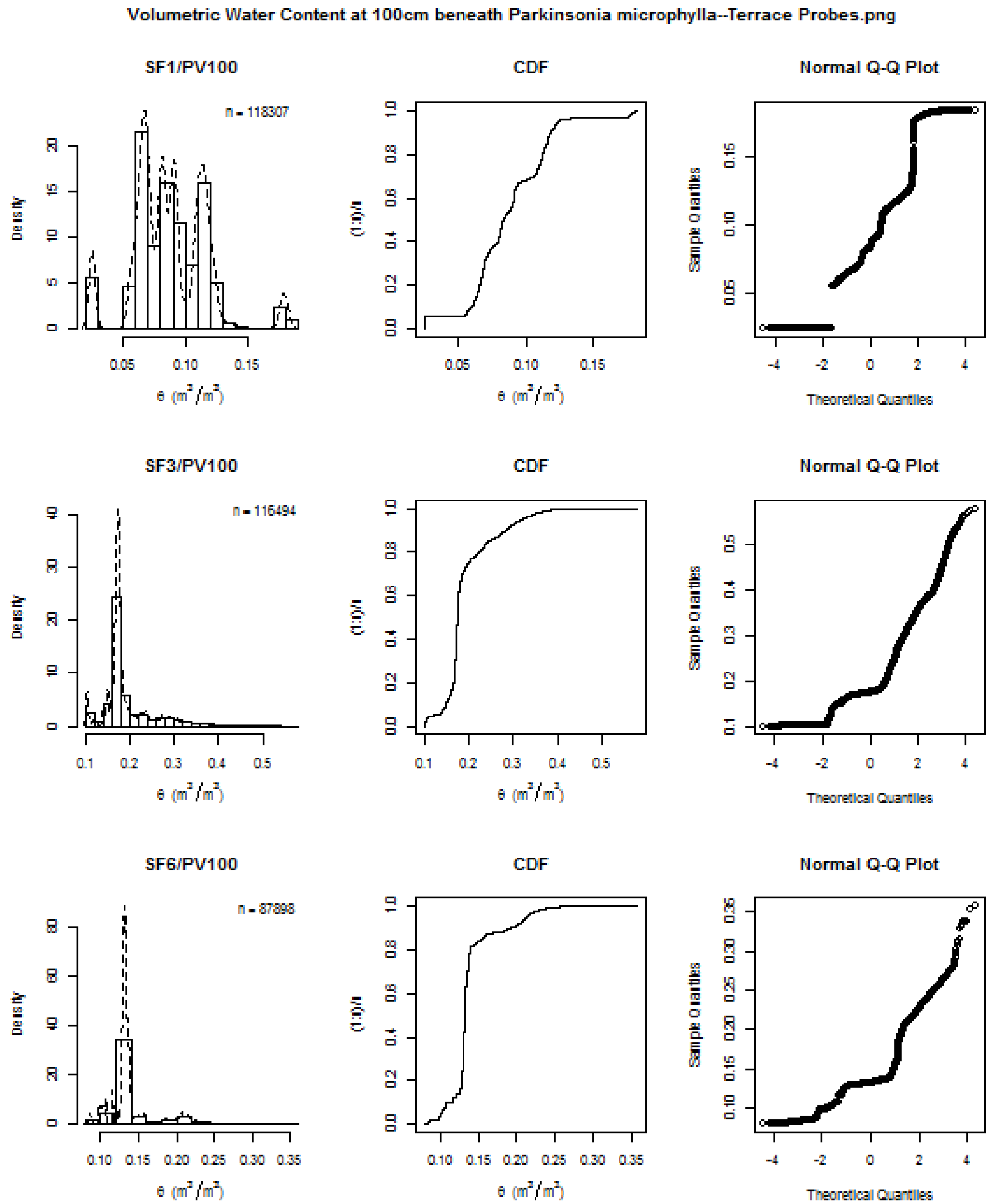

Figure D41. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 100cm beneath *Parkinsonia microphylla* at terrace stations SF1, SF3, and SF6 in the Yuma Wash watershed.

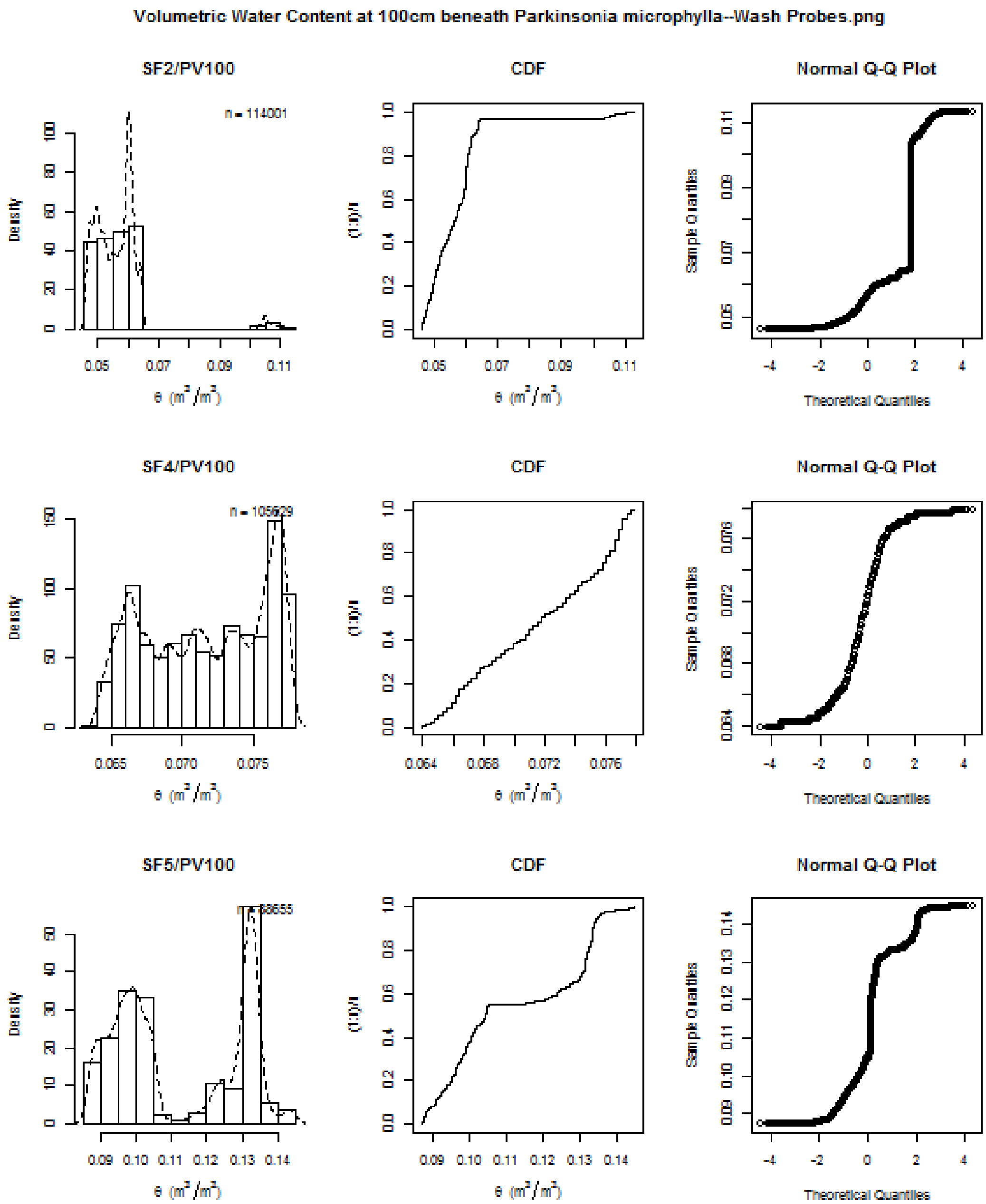

Figure D42. Histograms, cumulative distribution frequencies, and QQ plots for 15 minute volumetric soil moisture data recorded at 100cm beneath *Olneya tesota* at wash stations SF2, SF4, and SF5 in the Yuma Wash watershed.

Table D42. Bivariate pooling summary statistics for 15-minute soil moisture at 2.5cm depth by station (SF1-SF6), by location (L=lower, M=middle, U=upper), by cover type (BG=bare ground), by geomorphic surface (T=terrace, W=wash), and by season (S=summer, F=fall, W=winter, and Sp=spring).

	Depth	Min	Median	GMean	Mean	Max	IQR	SD	GSD	CV	GCV	Q1	Q3
ECOV1	2.5	0.01	0.04	0.05	0.06	0.34	0.04	0.04	1.7	65.7	0.60	0.03	0.07
ECOV2	2.5	0.01	0.04	0.04	0.05	0.24	0.03	0.04	1.8	74.5	0.65	0.03	0.06
MET1	2.5	0.06	0.10	0.12	0.13	0.47	0.07	0.07	1.5	55.1	0.47	0.08	0.15
MET2	2.5	0.02	0.05	0.05	0.06	0.24	0.04	0.03	1.6	54.8	0.52	0.04	0.08
MET3	2.5	0.04	0.10	0.11	0.12	0.33	0.07	0.06	1.5	46.9	0.45	0.08	0.15
MET4	2.5	0.04	0.11	0.13	0.15	0.48	0.11	0.10	1.7	67.1	0.63	0.08	0.19
L	2.5	0.01	0.04	0.05	0.06	0.34	0.04	0.04	1.7	70.0	0.63	0.03	0.07
M	2.5	0.02	0.08	0.08	0.10	0.47	0.06	0.07	1.8	68.6	0.67	0.05	0.11
U	2.5	0.04	0.10	0.12	0.14	0.48	0.09	0.09	1.6	61.5	0.55	0.08	0.17
BG	2.5	0.01	0.08	0.08	0.10	0.48	0.07	0.08	1.9	**75.7**	0.77	0.05	0.12
T	2.5	0.01	0.09	0.09	0.12	0.48	0.07	0.09	1.9	**74.2**	0.76	0.07	0.14
W	2.5	0.01	0.07	0.07	0.08	0.33	0.07	0.06	1.9	**67.8**	0.72	0.04	0.10
S	2.5	0.01	0.08	0.08	0.09	0.47	0.06	0.06	1.8	67.4	0.66	0.05	0.11
F	2.5	0.02	0.07	0.07	0.08	0.40	0.05	0.05	1.7	64.6	0.63	0.04	0.10
W	2.5	0.02	0.11	0.11	0.14	0.48	0.11	0.10	2.0	**70.1**	0.81	0.07	0.18
Sp	2.5	0.01	0.07	0.06	0.07	0.35	0.06	0.04	1.8	62.6	0.67	0.03	0.09
2006	2.5	0.02	0.08	0.08	0.10	0.47	0.07	0.07	1.8	68.9	0.66	0.05	0.12
2007	2.5	0.01	0.08	0.07	0.08	0.36	0.06	0.05	1.9	63.6	0.71	0.04	0.10
2008	2.5	0.02	0.09	0.09	0.11	0.45	0.09	0.08	2.0	72.2	0.77	0.05	0.14
2009	2.5	0.02	0.08	0.08	0.10	0.46	0.07	0.07	2.0	77.2	0.76	0.04	0.11
2010	2.5	0.03	0.13	0.14	0.18	0.48	0.18	0.12	2.2	68.0	0.91	0.09	0.28
Su06	2.5	0.03	0.07	0.08	0.10	0.47	0.07	0.08	1.9	78.4	0.68	0.05	0.12
Fa06	2.5	0.03	0.11	0.10	0.12	0.36	0.08	0.07	1.7	55.5	0.60	0.07	0.14
Wi06-07	2.5	0.02	0.08	0.06	0.07	0.17	0.06	0.03	1.7	45.9	0.56	0.04	0.10
Sp07	2.5	0.01	0.04	0.04	0.05	0.13	0.05	0.03	1.8	53.7	0.62	0.03	0.07
Su07	2.5	0.01	0.08	0.08	0.09	0.36	0.05	0.06	1.8	60.9	0.64	0.06	0.11
Fa07	2.5	0.03	0.08	0.08	0.09	0.29	0.04	0.04	1.6	50.1	0.47	0.06	0.10
Wi07-08	2.5	0.03	0.14	0.13	0.15	0.42	0.10	0.08	1.8	53.3	0.62	0.09	0.19
Sp08	2.5	0.02	0.08	0.07	0.08	0.35	0.06	0.05	1.8	65.2	0.64	0.04	0.10
Su08	2.5	0.02	0.09	0.08	0.10	0.41	0.07	0.06	1.8	64.0	0.67	0.05	0.12
Fa08	2.5	0.02	0.07	0.06	0.07	0.40	0.05	0.05	1.8	68.6	0.63	0.04	0.09
Wi08-09	2.5	0.03	0.15	0.15	0.18	0.46	0.15	0.10	1.9	57.6	0.70	0.10	0.25
Sp09	2.5	0.02	0.08	0.06	0.07	0.22	0.06	0.04	1.7	49.1	0.59	0.04	0.09
Su09	2.5	0.02	0.08	0.07	0.08	0.35	0.06	0.05	1.8	60.0	0.63	0.04	0.10
Fa09	2.5	0.02	0.05	0.05	0.05	0.10	0.04	0.02	1.6	40.3	0.47	0.03	0.07
Wi09-10	2.5	0.02	0.11	0.11	0.15	0.48	0.13	0.11	2.2	76.5	0.91	0.06	0.19

Table D43. Bivariate pooling summary statistics for 15-minute soil moisture at 25cm depth by station (SF1-SF6), location (L=lower, M=middle, U=upper), cover type (BG=bare ground, PV=*P.microphylla*, IW=*O.tesota*), geomorphic surface (T=terrace, W=wash), and season.

	Depth	Min	Median	GMean	Mean	Max	IQR	SD	GSD	CV	GCV	Q1	Q3
SF1	25	0.05	0.11	0.11	0.13	0.47	0.07	0.07	1.6	53.7	0.51	0.08	0.15
SF2	25	0.01	0.08	0.06	0.07	0.24	0.07	0.04	2.3	53.2	1.01	0.03	0.10
SF3	25	0.06	0.10	0.10	0.10	0.18	0.03	0.02	1.2	17.8	0.18	0.09	0.11
SF4	25	0.03	0.06	0.07	0.07	0.35	0.03	0.03	1.4	46.9	0.38	0.05	0.08
SF5	25	0.02	0.09	0.09	0.10	0.35	0.05	0.05	1.6	45.9	0.47	0.07	0.12
SF6	25	0.05	0.09	0.09	0.09	0.38	0.02	0.03	1.4	37.2	0.31	0.07	0.10
L	25	0.01	0.09	0.08	0.10	0.47	0.05	0.06	2.1	62.1	0.88	0.07	0.12
M	25	0.03	0.09	0.08	0.09	0.35	0.04	0.03	1.4	34.6	0.35	0.06	0.11
U	25	0.02	0.09	0.09	0.10	0.38	0.04	0.04	1.5	42.3	0.40	0.07	0.11
BG	25	0.02	0.09	0.08	0.09	0.24	0.04	0.03	1.4	30.6	0.32	0.07	0.10
IW	25	0.01	0.09	0.08	0.10	0.47	0.08	0.07	2.4	70.5	1.08	0.06	0.14
PV	25	0.03	0.09	0.09	0.10	0.37	0.03	0.04	1.4	37.8	0.37	0.08	0.11
T	25	0.05	0.09	0.10	0.11	0.47	0.04	0.05	1.5	46.4	0.39	0.08	0.12
W	25	0.01	0.08	0.07	0.08	0.35	0.04	0.04	1.9	51.6	0.73	0.06	0.10
S	25	0.01	0.09	0.08	0.09	0.47	0.04	0.05	1.9	55.8	0.70	0.07	0.10
F	25	0.00	0.08	0.08	0.09	0.45	0.03	0.04	1.7	47.9	0.61	0.07	0.10
W	25	0.00	0.10	0.10	0.11	0.43	0.06	0.06	1.7	50.6	0.59	0.07	0.13
Sp	25	0.00	0.09	0.08	0.08	0.43	0.04	0.03	1.6	38.4	0.49	0.06	0.10
2006	25	0.01	0.09	0.08	0.10	0.45	0.06	0.06	2.1	65.2	0.89	0.06	0.12
2007	25	0.00	0.09	0.08	0.09	0.47	0.05	0.05	1.8	50.8	0.66	0.06	0.11
2008	25	0.01	0.09	0.09	0.10	0.43	0.03	0.04	1.7	45.0	0.54	0.08	0.11
2009	25	0.01	0.09	0.08	0.09	0.43	0.03	0.04	1.6	44.5	0.50	0.07	0.10
2010	25	0.01	0.12	0.12	0.14	0.43	0.12	0.08	1.9	54.0	0.70	0.07	0.19
Su06	25	0.01	0.07	0.07	0.08	0.45	0.05	0.06	2.3	74.5	1.02	0.05	0.10
Fa06	25	0.02	0.11	0.11	0.12	0.31	0.04	0.06	1.7	52.0	0.60	0.09	0.13
Wi06-07	25	0.00	0.09	0.08	0.09	0.21	0.05	0.04	1.9	47.3	0.71	0.06	0.11
Sp07	25	0.00	0.07	0.07	0.08	0.14	0.04	0.03	1.7	37.8	0.56	0.06	0.10
Su07	25	0.00	0.09	0.08	0.10	0.47	0.04	0.05	1.9	56.7	0.75	0.06	0.11
Fa07	25	0.00	0.09	0.08	0.09	0.45	0.03	0.04	1.7	41.8	0.59	0.07	0.10
Wi07-08	25	0.01	0.10	0.10	0.11	0.40	0.04	0.05	1.5	43.1	0.45	0.08	0.13
Sp08	25	0.01	0.09	0.09	0.09	0.43	0.03	0.04	1.6	41.3	0.48	0.08	0.11
Su08	25	0.01	0.09	0.08	0.09	0.35	0.03	0.04	1.7	46.4	0.59	0.08	0.11
Fa08	25	0.01	0.08	0.08	0.09	0.31	0.03	0.04	1.8	44.9	0.65	0.07	0.10
Wi08-09	25	0.03	0.10	0.10	0.11	0.41	0.05	0.05	1.5	45.7	0.42	0.08	0.14
Sp09	25	0.02	0.09	0.08	0.08	0.18	0.03	0.03	1.5	32.7	0.41	0.07	0.10
Su09	25	0.02	0.09	0.08	0.09	0.43	0.03	0.05	1.6	49.5	0.52	0.08	0.10
Fa09	25	0.01	0.08	0.07	0.08	0.20	0.02	0.03	1.6	38.8	0.51	0.06	0.09
Wi09-10	25	0.01	0.10	0.10	0.12	0.43	0.11	0.07	2.0	60.3	0.80	0.07	0.17

Table D44. Bivariate pooling summary statistics for 15-minute soil moisture at 50cm depth by station (SF1-SF6), location (L=lower, M=middle, U=upper), cover type (BG=bare ground, PV=*P.microphylla*, IW=*O.tesota*), geomorphic surface (T=terrace, W=wash), and season.

	Depth	Min	Median	GMean	Mean	Max	IQR	SD	GSD	CV	GCV	Q1	Q3
SF1	50	0.06	0.13	0.13	0.14	0.41	0.11	0.07	1.6	46.4	0.49	0.08	0.19
SF2	50	0.04	0.08	0.09	0.09	0.28	0.05	0.03	1.4	35.8	0.35	0.07	0.12
SF3	50	0.10	0.17	0.16	0.16	0.37	0.06	0.03	1.2	20.4	0.21	0.13	0.19
SF4	50	0.04	0.08	0.08	0.09	0.32	0.08	0.04	1.6	47.1	0.47	0.05	0.13
SF5	50	0.05	0.11	0.11	0.11	0.28	0.07	0.04	1.4	35.0	0.37	0.08	0.15
SF6	50	0.10	0.19	0.18	0.19	0.57	0.07	0.06	1.4	33.0	0.33	0.14	0.21
L	50	0.04	0.09	0.10	0.11	0.41	0.07	0.05	1.5	47.8	0.45	0.07	0.14
M	50	0.04	0.13	0.11	0.12	0.37	0.09	0.05	1.6	44.0	0.53	0.07	0.16
U	50	0.05	0.14	0.14	0.15	0.57	0.09	0.06	1.5	42.2	0.44	0.10	0.19
BG	50	0.04	0.08	0.08	0.09	0.28	0.07	0.04	1.5	44.5	0.45	0.06	0.13
IW	50	0.05	0.12	0.12	0.13	0.44	0.11	0.06	1.6	47.9	0.49	0.08	0.18
PV	50	0.07	0.14	0.15	0.16	0.57	0.06	0.05	1.3	31.5	0.30	0.12	0.19
T	50	0.06	0.17	0.15	0.16	0.57	0.08	0.06	1.5	35.8	0.39	0.12	0.20
W	50	0.04	0.09	0.09	0.10	0.32	0.06	0.04	1.5	40.5	0.42	0.07	0.13
S	50	0.05	0.13	0.12	0.13	0.57	0.08	0.06	1.6	47.5	0.49	0.08	0.16
F	50	0.04	0.12	0.11	0.12	0.53	0.09	0.05	1.6	42.5	0.47	0.08	0.17
W	50	0.04	0.12	0.11	0.13	0.48	0.10	0.07	1.7	51.5	0.56	0.07	0.18
Sp	50	0.05	0.13	0.12	0.13	0.30	0.08	0.05	1.5	37.4	0.42	0.09	0.16
2006	50	0.05	0.12	0.11	0.12	0.41	0.07	0.06	1.6	51.4	0.53	0.07	0.15
2007	50	0.04	0.12	0.11	0.12	0.57	0.08	0.06	1.6	50.8	0.51	0.07	0.16
2008	50	0.04	0.12	0.11	0.13	0.39	0.09	0.05	1.6	43.0	0.47	0.08	0.17
2009	50	0.04	0.13	0.12	0.13	0.36	0.09	0.05	1.5	39.8	0.45	0.08	0.17
2010	50	0.04	0.17	0.16	0.18	0.47	0.10	0.08	1.7	46.6	0.56	0.12	0.22
Su06	50	0.05	0.12	0.10	0.12	0.41	0.07	0.06	1.6	51.0	0.50	0.08	0.14
Fa06	50	0.05	0.13	0.12	0.14	0.37	0.11	0.07	1.7	52.1	0.59	0.07	0.19
Wi06-07	50	0.04	0.12	0.10	0.11	0.23	0.07	0.05	1.6	44.9	0.51	0.07	0.13
Sp07	50	0.05	0.12	0.11	0.12	0.19	0.08	0.04	1.5	37.3	0.43	0.08	0.16
Su07	50	0.05	0.11	0.11	0.13	0.57	0.08	0.07	1.7	56.8	0.54	0.08	0.15
Fa07	50	0.04	0.12	0.11	0.12	0.53	0.10	0.05	1.6	42.1	0.47	0.08	0.17
Wi07-08	50	0.04	0.11	0.11	0.12	0.48	0.09	0.07	1.7	55.2	0.56	0.07	0.17
Sp08	50	0.05	0.13	0.12	0.13	0.30	0.09	0.05	1.5	38.3	0.42	0.09	0.17
Su08	50	0.05	0.13	0.12	0.13	0.39	0.08	0.05	1.5	40.2	0.43	0.09	0.17
Fa08	50	0.04	0.13	0.12	0.13	0.36	0.09	0.05	1.6	39.9	0.46	0.08	0.17
Wi08-09	50	0.04	0.12	0.12	0.13	0.36	0.11	0.06	1.6	44.5	0.51	0.08	0.18
Sp09	50	0.05	0.13	0.12	0.13	0.22	0.08	0.05	1.5	35.8	0.41	0.09	0.16
Su09	50	0.05	0.13	0.12	0.13	0.36	0.09	0.05	1.5	39.8	0.45	0.09	0.18
Fa09	50	0.05	0.11	0.11	0.12	0.21	0.07	0.04	1.5	38.5	0.43	0.08	0.15
Wi09-10	50	0.04	0.16	0.14	0.16	0.47	0.11	0.08	1.7	49.9	0.58	0.10	0.21

Table D45. Bivariate pooling summary statistics for 15-minute soil moisture at 100cm depth by station (SF1-SF6), location (L=lower, M=middle, U=upper), cover type (BG=bare ground, PV=*P.microphylla*, IW=*O.tesota*), geomorphic surface (T=terrace, W=wash), and by season.

	Depth	Min	Median	GMean	Mean	Max	IQR	SD	GSD	CV	GCV	Q1	Q3
SF1	100	0.02	0.12	0.11	0.12	0.34	0.03	0.03	1.4	27.0	0.35	0.11	0.14
SF2	100	0.04	0.06	0.07	0.08	0.24	0.07	0.04	1.5	47.5	0.45	0.05	0.12
SF3	100	0.04	0.17	0.14	0.16	0.58	0.09	0.07	1.7	45.0	0.60	0.10	0.19
SF4	100	0.06	0.09	0.09	0.09	0.11	0.03	0.02	1.2	19.0	0.19	0.07	0.10
SF5	100	0.05	0.12	0.11	0.11	0.18	0.05	0.03	1.3	27.6	0.30	0.09	0.13
SF6	100	0.08	0.13	0.13	0.13	0.36	0.03	0.03	1.2	21.6	0.20	0.11	0.14
L	100	0.02	0.12	0.09	0.10	0.34	0.07	0.04	1.6	40.0	0.47	0.06	0.13
M	100	0.04	0.11	0.12	0.13	0.58	0.10	0.07	1.7	50.6	0.54	0.08	0.18
U	100	0.05	0.13	0.12	0.12	0.36	0.04	0.03	1.3	25.4	0.27	0.10	0.14
BG	100	0.04	0.12	0.11	0.12	0.24	0.03	0.03	1.4	24.3	0.31	0.10	0.14
IW	100	0.04	0.12	0.11	0.13	0.36	0.10	0.06	1.7	47.7	0.54	0.07	0.17
PV	100	0.02	0.10	0.10	0.11	0.58	0.07	0.06	1.6	51.6	0.50	0.07	0.13
T	100	0.02	0.13	0.13	0.14	0.58	0.06	0.05	1.5	38.4	0.43	0.11	0.17
W	100	0.04	0.09	0.09	0.09	0.24	0.06	0.03	1.5	37.2	0.39	0.06	0.13
S	100	0.02	0.11	0.11	0.12	0.58	0.07	0.05	1.6	44.6	0.47	0.08	0.14
F	100	0.04	0.12	0.11	0.12	0.39	0.06	0.05	1.5	40.4	0.44	0.08	0.14
W	100	0.04	0.12	0.10	0.12	0.54	0.07	0.05	1.6	47.1	0.50	0.07	0.14
Sp	100	0.04	0.11	0.11	0.11	0.35	0.05	0.04	1.5	34.3	0.39	0.09	0.14
2006	100	0.02	0.11	0.10	0.12	0.39	0.08	0.07	1.9	59.6	0.69	0.06	0.14
2007	100	0.04	0.11	0.10	0.11	0.58	0.06	0.05	1.6	43.8	0.47	0.07	0.14
2008	100	0.05	0.11	0.11	0.12	0.35	0.05	0.04	1.5	38.2	0.41	0.09	0.14
2009	100	0.05	0.12	0.11	0.12	0.35	0.06	0.04	1.5	36.9	0.40	0.08	0.14
2010	100	0.05	0.12	0.12	0.13	0.54	0.08	0.07	1.7	50.5	0.53	0.09	0.17
Su06	100	0.02	0.10	0.09	0.11	0.39	0.07	0.07	1.9	63.2	0.69	0.06	0.13
Fa06	100	0.04	0.13	0.11	0.14	0.35	0.15	0.08	1.9	56.1	0.72	0.05	0.20
Wi06-07	100	0.04	0.12	0.09	0.11	0.19	0.08	0.05	1.7	44.1	0.55	0.05	0.13
Sp07	100	0.04	0.11	0.10	0.11	0.18	0.06	0.04	1.5	35.2	0.41	0.08	0.13
Su07	100	0.05	0.11	0.11	0.12	0.58	0.07	0.05	1.5	45.3	0.44	0.07	0.14
Fa07	100	0.05	0.11	0.11	0.11	0.39	0.06	0.04	1.5	38.6	0.41	0.07	0.13
Wi07-08	100	0.05	0.10	0.10	0.12	0.39	0.06	0.06	1.6	48.5	0.49	0.08	0.14
Sp08	100	0.05	0.12	0.11	0.12	0.35	0.05	0.04	1.4	34.6	0.37	0.09	0.14
Su08	100	0.06	0.11	0.11	0.12	0.35	0.05	0.04	1.4	36.0	0.37	0.09	0.14
Fa08	100	0.05	0.12	0.11	0.12	0.35	0.05	0.04	1.4	34.6	0.38	0.10	0.14
Wi08-09	100	0.05	0.12	0.11	0.12	0.34	0.05	0.05	1.5	42.5	0.45	0.09	0.14
Sp09	100	0.05	0.12	0.11	0.11	0.19	0.05	0.04	1.4	33.2	0.38	0.09	0.14
Su09	100	0.05	0.12	0.11	0.12	0.35	0.06	0.04	1.5	36.4	0.39	0.08	0.14
Fa09	100	0.05	0.11	0.11	0.11	0.19	0.06	0.04	1.4	33.0	0.37	0.08	0.14
Wi09-10	100	0.05	0.12	0.11	0.13	0.54	0.08	0.06	1.6	51.2	0.53	0.08	0.16

Table D46. Trivariate pooling summary statistics for 15-minute soil moisture by depth, cover type (BG=bare ground, PV=Palo verde-*P.microphylla*, IW=Ironwood-*O.tesota*), and geomorphic surface (T=terrace, W=wash).

Factor	Depth	Min	Median	Mean	Max	IQR	SD	CV	Q1	Q3
T-BG	2.5	0.01	0.09	0.12	0.48	0.07	0.09	74.2	0.07	0.14
W-BG	2.5	0.01	0.07	0.08	0.33	0.07	0.06	67.9	0.04	0.10
T-BG	25	0.05	0.09	0.09	0.24	0.04	0.03	28.6	0.07	0.11
W-BG	25	0.02	0.08	0.08	0.23	0.03	0.02	30.8	0.06	0.09
T-IW	25	0.05	0.13	0.15	0.47	0.09	0.07	50.3	0.09	0.18
W-IW	25	0.01	0.06	0.07	0.35	0.07	0.05	74.4	0.03	0.10
T-PV	25	0.05	0.09	0.10	0.37	0.03	0.04	37.2	0.08	0.12
W-PV	25	0.03	0.09	0.09	0.27	0.03	0.03	37.3	0.07	0.11
T-BG	50	0.06	0.09	0.10	0.18	0.04	0.03	26.8	0.08	0.12
W-BG	50	0.04	0.06	0.09	0.28	0.08	0.05	54.5	0.05	0.14
T-IW	50	0.10	0.18	0.18	0.44	0.05	0.05	27.4	0.15	0.20
W-IW	50	0.05	0.08	0.08	0.32	0.02	0.03	37.5	0.07	0.09
T-PV	50	0.13	0.20	0.20	0.57	0.05	0.04	21.0	0.17	0.22
W-PV	50	0.07	0.13	0.13	0.28	0.01	0.02	17.9	0.12	0.13
T-BG	100	0.04	0.11	0.11	0.15	0.03	0.03	28.6	0.10	0.13
W-BG	100	0.09	0.13	0.13	0.24	0.03	0.02	17.0	0.11	0.14
T-IW	100	0.10	0.15	0.16	0.36	0.06	0.04	27.0	0.13	0.19
W-IW	100	0.04	0.06	0.07	0.16	0.02	0.02	28.5	0.05	0.07
T-PV	100	0.02	0.13	0.14	0.58	0.07	0.06	43.8	0.10	0.17
W-PV	100	0.05	0.07	0.08	0.14	0.03	0.03	32.7	0.06	0.09

Table D47. Trivariate pooling summary statistics for 15-minute soil moisture by depth, location (L=lower, M=middle, U=upper), and geomorphic surface (T=terrace, W=wash).

Factor	Depth	Min	Median	Mean	Max	IQR	SD	CV	Q1	Q3
L-T	2.5	0.01	0.04	0.06	0.34	0.04	0.04	65.8	0.03	0.07
L-W	2.5	0.01	0.04	0.05	0.24	0.03	0.04	74.5	0.03	0.06
M-T	2.5	0.06	0.10	0.13	0.47	0.07	0.07	55.1	0.08	0.15
M-W	2.5	0.02	0.05	0.06	0.24	0.04	0.03	54.9	0.04	0.08
U-T	2.5	0.04	0.11	0.15	0.48	0.11	0.10	67.2	0.08	0.19
U-W	2.5	0.02	0.06	0.06	0.23	0.03	0.02	38.4	0.05	0.07
L-T	25	0.05	0.11	0.13	0.47	0.07	0.07	53.7	0.08	0.15
L-W	25	0.01	0.08	0.07	0.24	0.07	0.04	53.2	0.03	0.10
M-T	25	0.06	0.10	0.10	0.18	0.03	0.02	17.8	0.09	0.11
M-W	25	0.03	0.06	0.07	0.35	0.03	0.03	46.9	0.05	0.08
U-T	25	0.05	0.09	0.09	0.38	0.02	0.03	37.2	0.07	0.10
U-W	25	0.02	0.09	0.10	0.35	0.05	0.05	45.9	0.07	0.12
L-T	50	0.06	0.13	0.14	0.41	0.11	0.07	46.4	0.08	0.19
L-W	50	0.04	0.08	0.09	0.28	0.05	0.03	35.8	0.07	0.12
M-T	50	0.10	0.17	0.16	0.37	0.06	0.03	20.4	0.13	0.19
M-W	50	0.04	0.08	0.09	0.32	0.08	0.04	47.1	0.05	0.13
U-T	50	0.10	0.19	0.19	0.57	0.07	0.06	33.0	0.14	0.21
U-W	50	0.05	0.11	0.11	0.28	0.07	0.04	35.0	0.08	0.15
L-T	100	0.02	0.12	0.12	0.34	0.03	0.03	27.0	0.11	0.14
L-W	100	0.04	0.06	0.08	0.24	0.07	0.04	47.5	0.05	0.12
M-T	100	0.04	0.17	0.16	0.58	0.09	0.07	45.0	0.10	0.19
M-W	100	0.06	0.09	0.09	0.11	0.03	0.02	19.0	0.07	0.10
U-T	100	0.08	0.13	0.13	0.36	0.03	0.03	21.6	0.11	0.14
U-W	100	0.05	0.12	0.11	0.18	0.05	0.03	27.6	0.09	0.13

Table D48. Trivariate pooling summary statistics for 15-minute soil moisture by depth, location (L=lower, M=middle, U=upper), and cover type (BG=bare ground, PV=Palo verde-*P.microphylla*, IW=Ironwood-*O.tesota*).

Factor	Depth	Min	Median	Mean	Max	IQR	SD	CV	Q1	Q3
L-BG	2.5	0.01	0.04	0.06	0.34	0.04	0.04	70.1	0.03	0.07
M-BG	2.5	0.02	0.08	0.10	0.47	0.06	0.07	68.7	0.05	0.11
U-BG	2.5	0.02	0.08	0.12	0.48	0.07	0.09	79.5	0.06	0.13
L-BG	25	0.05	0.09	0.09	0.24	0.03	0.03	29.7	0.07	0.10
L-IW	25	0.01	0.10	0.11	0.47	0.14	0.09	89.5	0.02	0.16
L-PV	25	0.05	0.09	0.10	0.34	0.03	0.04	39.1	0.08	0.11
M-BG	25	0.07	0.11	0.11	0.17	0.02	0.02	17.0	0.09	0.12
M-IW	25	0.05	0.07	0.08	0.35	0.03	0.03	42.7	0.06	0.09
M-PV	25	0.03	0.09	0.08	0.27	0.04	0.03	36.9	0.06	0.10
U-BG	25	0.02	0.07	0.07	0.23	0.03	0.02	30.1	0.06	0.09
U-IW	25	0.05	0.09	0.11	0.38	0.06	0.05	44.4	0.08	0.14
U-PV	25	0.06	0.10	0.11	0.37	0.03	0.03	30.6	0.08	0.12
L-BG	50	0.04	0.07	0.07	0.18	0.01	0.02	23.4	0.07	0.08
L-IW	50	0.07	0.14	0.14	0.41	0.11	0.06	45.2	0.08	0.19
L-PV	50	0.11	0.13	0.13	0.28	0.01	0.02	12.5	0.12	0.13
M-BG	50	0.04	0.05	0.05	0.07	0.01	0.01	11.4	0.04	0.05
M-IW	50	0.06	0.11	0.12	0.37	0.06	0.05	39.2	0.08	0.14
M-PV	50	0.12	0.16	0.16	0.23	0.05	0.03	18.9	0.13	0.18
U-BG	50	0.10	0.14	0.14	0.28	0.03	0.03	18.1	0.12	0.15
U-IW	50	0.05	0.17	0.15	0.44	0.12	0.08	53.2	0.07	0.20
U-PV	50	0.07	0.17	0.17	0.57	0.12	0.07	43.4	0.10	0.21
L-BG	100	0.12	0.13	0.13	0.24	0.01	0.01	9.5	0.13	0.14
L-IW	100	0.04	0.11	0.09	0.34	0.07	0.04	47.0	0.05	0.12
L-PV	100	0.02	0.06	0.07	0.18	0.03	0.03	37.3	0.05	0.09
M-BG	100	0.04	0.10	0.09	0.12	0.01	0.02	26.4	0.09	0.11
M-IW	100	0.14	0.19	0.21	0.36	0.04	0.04	17.7	0.18	0.22
M-PV	100	0.06	0.12	0.14	0.58	0.10	0.07	54.1	0.07	0.18
U-BG	100	0.09	0.13	0.12	0.18	0.03	0.02	18.7	0.10	0.14
U-IW	100	0.05	0.12	0.11	0.22	0.07	0.04	33.4	0.07	0.14
U-PV	100	0.08	0.13	0.13	0.36	0.03	0.03	22.3	0.10	0.13

Table D49. Kruskal Wallis tests for differences in ranks sums of volumetric soil moisture (θ m^3/m^3), bivariate analysis of weekly averages from 15-minute data by depth and cover, depth and location, and depth and geomorphic surface. Wilcoxon tests for differences in rank sums by depth.

Kruskal Wallis Tests for Differences in Volumetric Soil Moisture (θ m^3/m^3) by Factor								
	2.5 cm		**25 cm**		**50 cm**		**100cm**	
by cover		α = 0.05		α = 0.05		α = 0.05		α = 0.05
	H	p.value	H	p.value	H	p.value	H	p.value
All	N/A	N/A	29	5.64E-07	593	1.88E-129	64	1.51E-14
Summer	N/A	N/A	8	2.01E-02	156	1.71E-34	33	6.59E-08
Fall	N/A	N/A	17	2.22E-04	103	3.94E-23	6	6.19E-02
Winter	N/A	N/A	28	9.06E-07	218	5.80E-48	19	6.37E-05
Spring	N/A	N/A	8	1.92E-02	110	7.96E-25	17	1.49E-04
by location								
All	334	3.36E-73	9	1.38E-02	191	3.67E-42	136	3.32E-30
Summer	91	1.56E-20	13	1.69E-03	75	4.03E-17	22	1.80E-05
Fall	94	4.07E-21	0.35	8.04E-01	50	1.33E-11	25	3.26E-06
Winter	105	1.69E-23	18	1.08E-04	56	7.09E-13	73	1.22E-16
Spring	104	2.09E-23	17	1.31E-04	32	9.58E-08	22	1.63E-05
by geomorphic surface								
All	63	1.96E-15	254	4.49E-57	822	7.95E-181	532	7.77E-118
Summer	17	3.52E-05	86	1.55E-20	234	6.40E-53	131	2.50E-30
Fall	8	6.06E-03	48	3.85E-12	167	2.68E-38	101	9.40E-24
Winter	27	2.32E-07	56	7.87E-14	242	1.14E-54	214	1.56E-48
Spring	28	1.41E-07	84	5.29E-20	181	3.43E-41	103	3.78E-24
by depth								

	H	p.value
All	630	3.93E-136
	W	p.value
2.5-25	1291831	1.17E-03
2.5-50	918198	3.78E-56
2.5-100	1043523	4.68E-46
25-50	2291223	2.18E-88
25-100	2608154	7.19E-72
50-100	3962689	2.17E-10

Table D50. Mann Whitney Wilcoxon tests for differences in ranks sums of volumetric soil moisture (θ m^3/m^3), bivariate analysis of weekly averages from 15-minute data by depth and cover.

	2.5 cm		25 cm		50 cm		100cm	
BY COVER		α = 0.05		α = 0.05		α = 0.05		α = 0.05
	W	p.value	W	p.value	W	p.value	W	p.value
BG-PV								
All seasons	N/A	N/A	339875	1.99E-09	102994	3.10E-123	590223	5.35E-16
Summer	N/A	N/A	23494	1.22E-03	7758	3.51E-31	45706	4.97E-11
Fall	N/A	N/A	9348	3.50E-05	3651	5.75E-21	17731	1.06E-02
Winter	N/A	N/A	37302	8.21E-06	10423	3.12E-48	65441	4.62E-04
Spring	N/A	N/A	19040	8.23E-01	5566	7.35E-25	28727	5.19E-06
BG-IW								
All seasons	N/A	N/A	314330	8.30E-02	219257	9.52E-60	375472	7.80E-03
Summer	N/A	N/A	22828	5.85E-01	14874	2.21E-18	27821	7.89E-01
Fall	N/A	N/A	10231	9.88E-01	7035	8.47E-11	11959	3.25E-01
Winter	N/A	N/A	30305	1.96E-05	23890	6.52E-25	38519	1.31E-04
Spring	N/A	N/A	17150	9.73E-02	11715	1.76E-10	19079	8.98E-01
PV-IW								
All seasons	N/A	N/A	368124	4.06E-02	286433	1.38E-21	456112	9.71E-08
Summer	N/A	N/A	29545	2.52E-01	34315	1.25E-07	23348	4.08E-03
Fall	N/A	N/A	14479	5.53E-03	17256	6.26E-08	11619	1.63E-01
Winter	N/A	N/A	40087	1.83E-02	53464	4.33E-05	39753	4.12E-03
Spring	N/A	N/A	21442	2.08E-03	25667	7.78E-07	16151	1.43E-02

Table D51. Mann Whitney Wilcoxon tests for differences in ranks sums of volumetric soil moisture (θ m^3/m^3), bivariate analysis of weekly averages from 15-minute data by depth and location.

	2.5 cm		**25 cm**		**50 cm**		**100cm**	
BY LOCATION		α = 0.05		α = 0.05		α = 0.05		α = 0.05
	W	p.value	W	p.value	W	p.value	W	p.value
L-M								
All seasons	29081	6.87E-29	4.07E+05	0.006	351502	1.19E-03	365570	1.33E-18
Summer	1944	3.67E-11	26051	1.26E-01	25675	4.44E-02	29831	2.98E-03
Fall	488	3.53E-11	12246	4.94E-01	10393	3.25E-02	11044	3.09E-05
Winter	4189	2.41E-07	53984	2.97E-04	43802	8.33E-02	43485	1.65E-08
Spring	978	6.58E-09	17331	1.16E-02	14925	8.36E-01	14496	3.28E-05
L-U								
All seasons	108431	1.74E-68	4.41E+05	0.553	516458	6.06E-43	580514	1.02E-27
Summer	7846	5.38E-20	36820	3.87E-04	38221	5.32E-18	30508	1.43E-03
Fall	3302	1.07E-17	13613	8.98E-01	16968	1.55E-12	17487	1.68E-05
Winter	12592	8.18E-23	52107	5.48E-01	58262	4.32E-15	71160	2.51E-18
Spring	5791	1.71E-24	16771	3.09E-05	23174	1.22E-06	26511	4.75E-04
M-U								
All seasons	94587	3.53E-18	3.06E+05	0.022	445657	5.41E-21	364986	6.61E-01
Summer	6941	4.14E-04	20056	6.99E-02	29560	2.19E-09	24434	1.26E-01
Fall	3753	5.69E-08	9771	7.99E-01	15340	4.54E-06	12305	9.21E-01
Winter	11747	4.35E-09	37543	8.00E-05	47360	4.29E-06	39776	8.04E-01
Spring	3209	4.30E-04	14388	2.03E-01	24684	1.46E-06	17451	4.13E-02

Table D52. Mann Whitney Wilcoxon tests for differences in ranks sums of volumetric soil moisture (θ m^3/m^3), trivariate analysis of weekly averages from 15-minute data by depth, cover and geomorphic surface.

Depth	Cover	Geomorphic Surface	W	p.value
				$\alpha = 0.05$
25 cm	BG vs PV	Terrace	106497	2.19E-05
50 cm	BG vs PV	Terrace	720	1.79E-102
100cm	BG vs PV	Terrace	82702	4.33E-21
25 cm	BG vs PV	Wash	60438	5.79E-08
50 cm	BG vs PV	Wash	61652	7.57E-38
100cm	BG vs PV	Wash	214503	1.88E-108
			W	p.value
25 cm	BG vs IW	Terrace	40650	7.45E-33
50 cm	BG vs IW	Terrace	8462	1.50E-103
100cm	BG vs IW	Terrace	33218	1.07E-90
25 cm	BG vs IW	Wash	91718	1.75E-05
50 cm	BG vs IW	Wash	80939	4.37E-17
100cm	BG vs IW	Wash	150875	2.34E-116
			W	p.value
25 cm	IW vs PV	Terrace	108914	2.44E-19
50 cm	IW vs PV	Terrace	56939	3.42E-11
100cm	IW vs PV	Terrace	161527	4.21E-16
25 cm	IW vs PV	Wash	78699	2.80E-17
50 cm	IW vs PV	Wash	19380	5.06E-110
100cm	IW vs PV	Wash	50418	2.95E-15
			W	p.value
2.5 cm	BG vs BG	Terrace/Wash	181311	1.96E-15
25 cm	BG vs BG	Terrace/Wash	106168	8.67E-13
50 cm	BG vs BG	Terrace/Wash	110421	1.50E-22
100cm	BG vs BG	Terrace/Wash	80213	5.31E-22
25 cm	PV vs PV	Terrace/Wash	142934	1.61E-07
50 cm	PV vs PV	Terrace/Wash	148082	6.29E-116
100cm	PV vs PV	Terrace/Wash	202774	1.34E-78
25 cm	IW vs IW	Terrace/Wash	124056	3.53E-51
50 cm	IW vs IW	Terrace/Wash	231176	4.43E-141
100cm	IW vs IW	Terrace/Wash	155217	6.21E-123

Table D53. Mann Whitney Wilcoxon tests for differences in ranks sums of volumetric soil moisture (θ m^3/m^3), trivariate analysis of weekly averages from 15-minute data by depth, geomorphic surface, and location.

Depth	Location	Geomorphic Surface	W	pvalue
				α = 0.05
2.5 cm	U vs L	Terrace	27267	2.68E-34
25 cm	U vs L	Terrace	79015	4.64E-15
50 cm	U vs L	Terrace	107363	3.92E-25
100cm	U vs L	Terrace	124477	5.20E-03
2.5 cm	U vs L	Wash	27000	3.49E-36
25 cm	U vs L	Wash	145134	3.93E-15
50 cm	U vs L	Wash	148389	1.23E-17
100cm	U vs L	Wash	173614	9.74E-48
2.5 cm	U vs M	Terrace	18627	3.13E-01
25 cm	U vs M	Terrace	45284	7.48E-21
50 cm	U vs M	Terrace	90541	1.00E-08
100cm	U vs M	Terrace	79566	9.81E-14
2.5 cm	U vs M	Wash	29265	4.05E-33
25 cm	U vs M	Wash	97413	1.55E-22
50 cm	U vs M	Wash	144669	3.01E-25
100cm	U vs M	Wash	99588	1.72E-25
2.5 cm	M vs L	Terrace	25803	1.59E-32
25 cm	M vs L	Terrace	87257	1.01E-03
50 cm	M vs L	Terrace	81437	3.60E-08
100cm	M vs L	Terrace	203903	5.30E-25
2.5 cm	M vs L	Wash	18237	1.53E-06
25 cm	M vs L	Wash	76905	1.08E-03
50 cm	M vs L	Wash	117601	1.38E-03
100cm	M vs L	Wash	116527	6.25E-15

Table D54. Mann Whitney Wilcoxon tests for differences in ranks sums of volumetric soil moisture (θ m^3/m^3), trivariate analysis of weekly averages from 15-minute data by depth, cover, and location.

Depth	Location	Cover	W	pvalue
				α = 0.05
2.5 cm	U vs M	BG	94587	3.53E-18
25 cm	U vs M	BG	5268	3.08E-48
50 cm	U vs M	BG	46695	8.09E-70
100cm	U vs M	BG	82922	2.85E-48
25 cm	U vs M	PV	67604	2.27E-21
50 cm	U vs M	PV	45881	6.81E-01
100cm	U vs M	PV	48880	3.39E-01
25 cm	U vs M	IW	32990	7.96E-17
50 cm	U vs M	IW	54592	2.65E-04
100cm	U vs M	IW	1258	4.83E-65
2.5 cm	U vs L	BG	108431	1.74E-68
25 cm	U vs L	BG	29582	3.53E-20
50 cm	U vs L	BG	101115	3.48E-99
100cm	U vs L	BG	36508	2.75E-10
25 cm	U vs L	PV	55597	6.47E-03
50 cm	U vs L	PV	28108	5.45E-03
100cm	U vs L	PV	91359	2.96E-75
25 cm	U vs L	IW	55474	3.89E-03
50 cm	U vs L	IW	46949	3.27E-01
100cm	U vs L	IW	66426	4.16E-14
2.5 cm	M vs L	BG	29081	6.87E-29
25 cm	M vs L	BG	17833	2.66E-19
50 cm	M vs L	BG	56966	4.42E-62
100cm	M vs L	BG	127050	4.18E-118
25 cm	M vs L	PV	83646	5.54E-15
50 cm	M vs L	PV	11747	3.59E-31
100cm	M vs L	PV	23193	2.24E-47
25 cm	M vs L	IW	30091	8.49E-01
50 cm	M vs L	IW	77380	3.68E-08
100cm	M vs L	IW	1257	4.02E-74

Table D55. Kruskal Wallis tests for differences in ranks sums of mean event volumetric soil moisture (θ m^3/m^3), bivariate analysis from 15-minute data during wetting events by depth and cover, depth and location, and depth and geomorphic surface. Wilcoxon tests for differences in rank sums by depth.

Kruskal Wallis Tests for Differences in Volumetric Soil Moisture (θ m^3/m^3) by Factor								
	2.5 cm		**25 cm**		**50 cm**		**100cm**	
by cover		α = 0.05		α = 0.05		α = 0.05		α = 0.05
	H	p.value	H	p.value	H	p.value	H	p.value
All	N/A	N/A	5.87	5.30E-02	6.14	4.65E-02	7.45	2.41E-02
Summer	N/A	N/A	1.93	0.3807	2.76	0.2518	3.96	0.1380
Fall	N/A	N/A	1.26	0.5337	3.24	0.1982	N/A	N/A
Winter	N/A	N/A	11.20	0.0037	5.63	0.0599	1.26	0.5317
Spring	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
by location								
All	37.75	6.36E-09	12.80	1.66E-03	4.36	1.13E-01	38.04	5.50E-09
Summer	20.34	3.82E-05	6.92	0.0315	0.92	0.6317	15.86	0.0004
Fall	7.11	0.0285	4.04	0.1324	5.42	0.0666	N/A	N/A
Winter	12.29	0.0021	2.98	0.2258	3.17	0.2052	10.16	0.0062
Spring	4.13	0.1271	N/A	N/A	N/A	N/A	N/A	N/A
by geomorphic surface								
All	10.64	1.11E-03	6.30	1.21E-02	10.26	1.36E-03	4.49	3.40E-02
Summer	2.06	1.52E-01	8.53	0.0035	10.97	0.0009	2.70	0.1003
Fall	4.37	0.0367	0.35	0.5529	2.60	0.1069	N/A	N/A
Winter	13.22	0.0003	1.13	0.2883	5.48	0.0192	2.21	0.1372
Spring	0.02	0.8815	N/A	N/A	N/A	N/A	N/A	N/A

by depth		
	H	p.value
All		
	W	p.value
2.5-25	10583	4.64E-01
2.5-50	3400	9.69E-08
2.5-100	3282	2.46E-03
25-50	2279	6.02E-11
25-100	2423	9.33E-05
50-100	2697	3.94E-02

Table D56. Mann Whitney Wilcoxon tests for differences in ranks sums of mean event volumetric soil moisture (θ m^3/m^3), bivariate analysis from 15-minute data during wetting events by depth and cover.

	2.5 cm		**25 cm**		**50 cm**		**100cm**	
BY COVER		α = 0.05		α = 0.05		α = 0.05		α = 0.05
	W	p.value	W	p.value	W	p.value	W	p.value
BG-PV								
All seasons	N/A	N/A	614	0.9564	53	0.0256	47	0.2587
Summer	N/A	N/A	37	0.2007	3	0.0848	6	0.5597
Fall	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Winter	N/A	N/A	128	0.5383	15	0.3636	9	0.6667
Spring	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BG-IW								
All seasons	N/A	N/A	383	0.0746	98	0.0165	40	0.6252
Summer	N/A	N/A	32	0.2965	16	0.3068	4	0.6667
Fall	N/A	N/A	6	0.5818	0	0.2500	N/A	N/A
Winter	N/A	N/A	55	0.0037	18	0.0583	13	0.9231
Spring	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PV-IW								
All seasons	N/A	N/A	1839	0.0271	556	0.7261	518	0.0079
Summer	N/A	N/A	204	0.5692	86	0.4614	28	0.0605
Fall	N/A	N/A	42	0.6027	27	0.4452	8	0.2468
Winter	N/A	N/A	95	0.0040	44	0.0846	29	0.2991
Spring	N/A	N/A	5	1.0000	1	1.0000	0	0.6667

Table D57. Mann Whitney Wilcoxon tests for differences in ranks sums of mean event volumetric soil moisture (θ m^3/m^3), trivariate analysis from 15-minute data during wetting periods by depth, cover and geomorphic surface.

Depth	**Cover**	**Geomorphic Surface**	**W**	**p.value**
				α = 0.05
25 cm	BG vs PV	Terrace	N/A	N/A
50 cm	BG vs PV	Terrace	N/A	N/A
100cm	BG vs PV	Terrace	N/A	N/A
25 cm	BG vs PV	Wash	N/A	N/A
50 cm	BG vs PV	Wash	N/A	N/A
100cm	BG vs PV	Wash	N/A	N/A
			W	p.value
25 cm	BG vs IW	Terrace	N/A	N/A
50 cm	BG vs IW	Terrace	N/A	N/A
100cm	BG vs IW	Terrace	N/A	N/A
25 cm	BG vs IW	Wash	N/A	N/A
50 cm	BG vs IW	Wash	N/A	N/A
100cm	BG vs IW	Wash	N/A	N/A
			W	p.value
25 cm	IW vs PV	Terrace	820	2.45E-05
50 cm	IW vs PV	Terrace	297	6.30E-01
100cm	IW vs PV	Terrace	413	1.83E-02
25 cm	IW vs PV	Wash	212	7.61E-01
50 cm	IW vs PV	Wash	31	4.14E-01
100cm	IW vs PV	Wash	1	4.00E-01
			W	p.value
2.5 cm	BG vs BG	Terrace/Wash	3897	0.0011
25 cm	BG vs BG	Terrace/Wash	77	0.0110
50 cm	BG vs BG	Terrace/Wash	N/A	N/A
100cm	BG vs BG	Terrace/Wash	N/A	N/A
25 cm	PV vs PV	Terrace/Wash	319	0.4186
50 cm	PV vs PV	Terrace/Wash	100	0.0010
100cm	PV vs PV	Terrace/Wash	N/A	N/A
25 cm	IW vs IW	Terrace/Wash	481	0.0008
50 cm	IW vs IW	Terrace/Wash	174	0.3765
100cm	IW vs IW	Terrace/Wash	N/A	N/A

Table D58. Kruskal Wallis tests for differences in ranks sums of event magnitude volumetric soil moisture ($\Delta\theta$ m^3/m^3), bivariate analysis from 15-minute data during wetting events by depth and cover, depth and location, and depth and geomorphic surface. Wilcoxon tests for differences in rank sums by depth.

Kruskal Wallis Tests for Differences in Volumetric Soil Moisture (θ m^3/m^3) by Factor								
	2.5 cm		**25 cm**		**50 cm**		**100cm**	
by cover		α = 0.05		α = 0.05		α = 0.05		α = 0.05
	H	p.value	H	p.value	H	p.value	H	p.value
All	N/A	N/A	3	0.1897	9.492	0.0087	2.65	0.2649
Summer	N/A	N/A	0.91	0.6348	4.68	0.0965	2.25	0.3252
Fall	N/A	N/A	0.41	0.8161	4.22	0.1215	N/A	N/A
Winter	N/A	N/A	1.44	0.4868	0.49	0.7836	0.33	0.8494
Spring	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
by location								
All	2.37	0.3055	8.93	0.0114	0.282	0.8685	23.82	6.73E-06
Summer	2.60	0.2726	11.89	0.0026	0.24	0.8874	8.94	0.0115
Fall	2.21	0.3317	4.88	0.0874	2.45	0.2931	N/A	N/A
Winter	0.00	0.9987	0.44	0.8018	0.59	0.7433	4.63	0.0989
Spring	0.00	1.0000	N/A	N/A	N/A	N/A	N/A	N/A
by geomorphic surface								
All	0.02	0.8858	4.89	0.0269	5.13	0.0234	2.42	1.20E-01
Summer	1.15	0.2827	5.98	0.0145	3.37	0.0665	1.88	0.1708
Fall	0.01	0.9093	1.26	0.2623	1.86	0.1724	N/A	N/A
Winter	1.02	0.3124	0.25	0.6137	0.31	0.5784	0.06	0.8043
Spring	0.56	0.4561	N/A	N/A	N/A	N/A	N/A	N/A

by depth		
	H	p.value
All	7.94	0.0473
	W	p.value
2.5-25	11883	0.0091
2.5-50	5974	0.9901
2.5-100	5107	0.1267
25-50	4251	0.0705
25-100	3613	0.6497
50-100	2495	0.2451

Table D59. Mann Whitney Wilcoxon tests for differences in ranks sums of event magnitude volumetric soil moisture ($\Delta\theta$ m^3/m^3), bivariate analysis from 15-minute data during wetting events by depth and cover.

	2.5 cm		25 cm		50 cm		100cm	
BY COVER		$\alpha = 0.05$		$\alpha = 0.05$		$\alpha = 0.05$		$\alpha = 0.05$
	W	p.value	W	p.value	W	p.value	W	p.value
BG-PV								
All seasons	N/A	N/A	584	0.7019	84	0.3485	37	0.7692
Summer	N/A	N/A	54	0.7583	7	0.3757	4	1
Fall	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Winter	N/A	N/A	136	0.7271	21	0.8981	9	0.6666
Spring	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BG-IW								
All seasons	N/A	N/A	418	0.1796	86	0.0067	24	0.1610
Summer	N/A	N/A	41	0.6792	9	0.0796	2	0.4
Fall	N/A	N/A	7	0.7272	0	0.25	N/A	N/A
Winter	N/A	N/A	103	0.2868	35	0.5945	12	1
Spring	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PV-IW								
All seasons	N/A	N/A	1744	0.1025	698	0.0288	439	0.1944
Summer	N/A	N/A	190	0.3628	46	0.1597	38	0.2321
Fall	N/A	N/A	42	0.6026	10	0.1375	15	1
Winter	N/A	N/A	166	0.3755	67	0.6340	36.5	0.6724
Spring	N/A	N/A	4	1	0	0.6667	0	0.6667

Table D60. Mann Whitney Wilcoxon tests for differences in ranks sums of event magnitude volumetric soil moisture ($\Delta\theta$ m^3/m^3), trivariate analysis from 15-minute data during wetting periods by depth, cover and geomorphic surface.

Depth	Cover	Geomorphic Surface	W	p.value
				$\alpha = 0.05$
25 cm	BG vs PV	Terrace	N/A	N/A
50 cm	BG vs PV	Terrace	N/A	N/A
100cm	BG vs PV	Terrace	N/A	N/A
25 cm	BG vs PV	Wash	N/A	N/A
50 cm	BG vs PV	Wash	N/A	N/A
100cm	BG vs PV	Wash	N/A	N/A
			W	p.value
25 cm	BG vs IW	Terrace	N/A	N/A
50 cm	BG vs IW	Terrace	N/A	N/A
100cm	BG vs IW	Terrace	N/A	N/A
25 cm	BG vs IW	Wash	N/A	N/A
50 cm	BG vs IW	Wash	N/A	N/A
100cm	BG vs IW	Wash	N/A	N/A
			W	p.value
25 cm	IW vs PV	Terrace	686	0.0214
50 cm	IW vs PV	Terrace	429	0.0546
100cm	IW vs PV	Terrace	337	0.4011
25 cm	IW vs PV	Wash	255	0.4718
50 cm	IW vs PV	Wash	30	0.4908
100cm	IW vs PV	Wash	4	0.8000
			W	p.value
2.5 cm	BG vs BG	Terrace/Wash	3028	0.8873
25 cm	BG vs BG	Terrace/Wash	39	0.6768
50 cm	BG vs BG	Terrace/Wash	N/A	N/A
100cm	BG vs BG	Terrace/Wash	N/A	N/A
25 cm	PV vs PV	Terrace/Wash	462	0.1286
50 cm	PV vs PV	Terrace/Wash	48	0.7211
100cm	PV vs PV	Terrace/Wash	N/A	N/A
25 cm	IW vs IW	Terrace/Wash	438.5	0.0148
50 cm	IW vs IW	Terrace/Wash	180	0.2860
100cm	IW vs IW	Terrace/Wash	N/A	N/A

Table D61. Mann Whitney Wilcoxon tests for differences in ranks sums of mean event volumetric soil moisture (θ m^3/m^3), bivariate analysis from 15-minute data during wetting events by depth and location.

	2.5 cm		**25 cm**		**50 cm**		**100cm**	
BY LOCATION		α = 0.05		α = 0.05		α = 0.05		α = 0.05
	W	p.value	W	p.value	W	p.value	W	p.value
L-M								
All seasons	605	4.93E-04	1021	0.0017	453	0.0767	2	4.30E-08
Summer	147	0.0055	172	0.0128	57	0.3929	0	0.0006
Fall	15	0.9333	41	0.1135	16	0.4970	0	0.0238
Winter	51	0.0236	76	0.9806	57	0.6027	0	0.0028
Spring	2	1	2	0.6667	2	0.6667	2	0.6667
L-U								
All seasons	2256	1.06E-09	1259	0.7838	278	0.5815	233	9.48E-02
Summer	633	2.79E-06	99	2.02E-01	26	6.06E-01	28	6.51E-01
Fall	31	0.0080	34	0.8371	6	0.7	4	0.8
Winter	208	0.0003	365	0.1126	83	0.1513	48	0.2766
Spring	8	0.1333	1	0.4000	N/A	N/A	N/A	N/A
M-U								
All seasons	2036	7.77E-03	1038	0.0009	467	0.0930	8	1.83E-08
Summer	450	0.1041	181	0.1004	49	0.5556	0	0.0004
Fall	51	0.0499	34	0.0734	24	0.0121	0	0.0714
Winter	216	0.1675	90	0.2777	69	0.1519	0	0.0040
Spring	7	0.2667	N/A	N/A	N/A	N/A	N/A	N/A

Table D62. Mann Whitney Wilcoxon tests for differences in ranks sums of mean event volumetric soil moisture (θ m^3/m^3), trivariate analysis from 15-minute data during wetting periods by depth, geomorphic surface, and location.

Depth	Location	Geomorphic Surface	W	pvalue
				α = 0.05
2.5 cm	U vs L	Terrace	410	1.48E-04
25 cm	U vs L	Terrace	305	1.24E-01
50 cm	U vs L	Terrace	138	1.27E-02
100cm	U vs L	Terrace	158	1.14E-02
2.5 cm	U vs L	Wash	735	7.65E-08
25 cm	U vs L	Wash	320	1.86E-02
50 cm	U vs L	Wash	46	3.85E-01
100cm	U vs L	Wash	5	8.57E-01
2.5 cm	U vs M	Terrace	351	5.56E-01
25 cm	U vs M	Terrace	196	2.84E-01
50 cm	U vs M	Terrace	305	8.35E-09
100cm	U vs M	Terrace	8	4.46E-06
2.5 cm	U vs M	Wash	700	2.31E-07
25 cm	U vs M	Wash	304	3.27E-03
50 cm	U vs M	Wash	18	5.21E-01
100cm	U vs M	Wash	N/A	N/A
2.5 cm	M vs L	Terrace	350	1.94E-05
25 cm	M vs L	Terrace	140	1.95E-02
50 cm	M vs L	Terrace	85	4.48E-04
100cm	M vs L	Terrace	400	6.78E-08
2.5 cm	M vs L	Wash	348	6.74E-01
25 cm	M vs L	Wash	68	7.01E-02
50 cm	M vs L	Wash	16	4.76E-01
100cm	M vs L	Wash	N/A	N/A

Table D63. Mann Whitney Wilcoxon tests for differences in ranks sums of event magnitude volumetric soil moisture ($\Delta\theta$ m^3/m^3), bivariate analysis from 15-minute data during wetting events by depth and location.

	2.5 cm		**25 cm**		**50 cm**		**100cm**	
BY LOCATION		$\alpha = 0.05$		$\alpha = 0.05$		$\alpha = 0.05$		$\alpha = 0.05$
	W	p.value	W	p.value	W	p.value	W	p.value
L-M								
All seasons	851	0.1197	984	0.0057	314	0.5124	31	2.04E-06
Summer	194	0.0828	174	0.0098	37	0.5355	8	0.0081
Fall	19	0.6828	39	0.1810	8	0.4969	0	0.0238
Winter	100	0.9479	62	0.5416	53	0.8238	5	0.0503
Spring	2	1.0000	2	0.6667	1	1.0000	0	0.6667
L-U								
All seasons	1486	0.2878	1367	0.6587	261	0.8661	182	8.71E-01
Summer	409	0.5386	157	0.4421	32	1	28	0.6510
Fall	23	0.2828	43	0.2522	8	0.2	3	1
Winter	120	1	291	0.9511	50	0.5190	36.5	1
Spring	4	1	1	0.4	N/A	N/A	N/A	N/A
M-U								
All seasons	1496	0.6500	969	0.0091	370	0.9798	52	3.40E-04
Summer	308	0.4042	225	0.0007	65	0.6947	8	0.0255
Fall	44	0.2344	35	0.0512	17	0.3757	6	1
Winter	172	0.9639	58	0.5812	42	0.6026	5	0.0727
Spring	4	1	N/A	N/A	N/A	N/A	N/A	N/A

Table D64. Mann Whitney Wilcoxon tests for differences in ranks sums of event magnitude volumetric soil moisture ($\Delta\theta$ m^3/m^3), trivariate analysis from 15-minute data during wetting periods by depth, geomorphic surface, and location.

Depth	Location	Geomorphic Surface	W	pvalue
				$\alpha = 0.05$
2.5 cm	U vs L	Terrace	280	0.4836
25 cm	U vs L	Terrace	474	0.2614
50 cm	U vs L	Terrace	117	0.1623
100cm	U vs L	Terrace	112	0.6123
2.5 cm	U vs L	Wash	472	0.3884
25 cm	U vs L	Wash	222	0.9711
50 cm	U vs L	Wash	30	0.6165
100cm	U vs L	Wash	0	0.0714
2.5 cm	U vs M	Terrace	334	0.3853
25 cm	U vs M	Terrace	250	0.0045
50 cm	U vs M	Terrace	196	0.1984
100cm	U vs M	Terrace	50	0.0276
2.5 cm	U vs M	Wash	419	0.7679
25 cm	U vs M	Wash	237	0.2837
50 cm	U vs M	Wash	25	0.9527
100cm	U vs M	Wash	N/A	N/A
2.5 cm	M vs L	Terrace	259	1.19E-01
25 cm	M vs L	Terrace	152	3.96E-02
50 cm	M vs L	Terrace	247	5.87E-01
100cm	M vs L	Terrace	374	2.66E-06
2.5 cm	M vs L	Wash	359	5.31E-01
25 cm	M vs L	Wash	74	1.20E-01
50 cm	M vs L	Wash	10	7.62E-01
100cm	M vs L	Wash	N/A	N/A

Table D65. Mann Whitney Wilcoxon tests for differences in ranks sums of mean event volumetric soil moisture (θ m^3/m^3), trivariate analysis from 15-minute data during wetting periods by depth, cover, and location.

Depth	Location	Cover	W	pvalue
				α = 0.05
2.5 cm	U vs M	BG	N/A	N/A
25 cm	U vs M	BG	N/A	N/A
50 cm	U vs M	BG	N/A	N/A
100cm	U vs M	BG	N/A	N/A
25 cm	U vs M	PV	N/A	N/A
50 cm	U vs M	PV	N/A	N/A
100cm	U vs M	PV	N/A	N/A
25 cm	U vs M	IW	N/A	N/A
50 cm	U vs M	IW	N/A	N/A
100cm	U vs M	IW	N/A	N/A
2.5 cm	U vs L	BG	2256	1.06E-09
25 cm	U vs L	BG	32	2.38E-01
50 cm	U vs L	BG	16	2.86E-02
100cm	U vs L	BG	0	6.67E-01
25 cm	U vs L	PV	269	6.34E-02
50 cm	U vs L	PV	12	4.00E-01
100cm	U vs L	PV	68	1.50E-03
25 cm	U vs L	IW	145	6.47E-02
50 cm	U vs L	IW	80	7.16E-01
100cm	U vs L	IW	36	8.60E-01
2.5 cm	M vs L	BG	N/A	N/A
25 cm	M vs L	BG	N/A	N/A
50 cm	M vs L	BG	N/A	N/A
100cm	M vs L	BG	N/A	N/A
25 cm	M vs L	PV	N/A	N/A
50 cm	M vs L	PV	N/A	N/A
100cm	M vs L	PV	N/A	N/A
25 cm	M vs L	IW	N/A	N/A
50 cm	M vs L	IW	N/A	N/A
100cm	M vs L	IW	N/A	N/A

Table D66. Mann Whitney Wilcoxon tests for differences in ranks sums of event magnitude volumetric soil moisture ($\Delta\theta$ m^3/m^3), trivariate analysis from 15-minute data during wetting periods by depth, cover, and location.

Depth	Location	Cover	W	pvalue
				$\alpha = 0.05$
2.5 cm	U vs M	BG	N/A	N/A
25 cm	U vs M	BG	N/A	N/A
50 cm	U vs M	BG	N/A	N/A
100cm	U vs M	BG	N/A	N/A
25 cm	U vs M	PV	N/A	N/A
50 cm	U vs M	PV	N/A	N/A
100cm	U vs M	PV	N/A	N/A
25 cm	U vs M	IW	N/A	N/A
50 cm	U vs M	IW	N/A	N/A
100cm	U vs M	IW	N/A	N/A
2.5 cm	U vs L	BG	1486	0.2878
25 cm	U vs L	BG	52	0.7921
50 cm	U vs L	BG	8	1.0000
100cm	U vs L	BG	0	0.6667
25 cm	U vs L	PV	257	0.1274
50 cm	U vs L	PV	9	0.8889
100cm	U vs L	PV	44	0.4036
25 cm	U vs L	IW	169	0.2156
50 cm	U vs L	IW	93	0.8273
100cm	U vs L	IW	21	0.1259
2.5 cm	M vs L	BG	N/A	N/A
25 cm	M vs L	BG	N/A	N/A
50 cm	M vs L	BG	N/A	N/A
100cm	M vs L	BG	N/A	N/A
25 cm	M vs L	PV	N/A	N/A
50 cm	M vs L	PV	N/A	N/A
100cm	M vs L	PV	N/A	N/A
25 cm	M vs L	IW	N/A	N/A
50 cm	M vs L	IW	N/A	N/A
100cm	M vs L	IW	N/A	N/A

Table D67. Kruskal-Wallis and Mann-Whitney Wilcoxon tests for differences in ranks sums of volumetric soil moisture (θ m^3/m^3) by depth and year for three years with four seasons of records (2007-2009), bivariate analysis of weekly averages from 15-minute data.

Kruskal Wallis and Wilcoxon Tests for Differences in Volumetric Soil Moisture between Years		
2.5cm		(α = 0.05)
Kruskal	H	p.value
all years	72	7.43E-15
Wilcoxon	W	p.value
2007-2008	32022	2.85E-08
2007-2009	37270	6.82E-02
2008-2009	53627	2.28E-04
25cm		(α = 0.05)
Kruskal	H	p.value
all years	105	7.16E-22
Wilcoxon	W	p.value
2007-2008	230057	5.57E-07
2007-2009	267981	5.68E-01
2008-2009	338253	9.73E-08
50cm		(α = 0.05)
Kruskal	H	p.value
all years	87	6.12E-18
Wilcoxon	W	p.value
2007-2008	240488	1.25E-03
2007-2009	234734	1.74E-05
2008-2009	281497	3.70E-01
100cm		(α = 0.05)
Kruskal	H	p.value
all years	17.53	1.52E-03
Wilcoxon	W	p.value
2007-2008	2.90E+05	0.0570
2007-2009	2.86E+05	0.0088
2008-2009	3.27E+05	0.6154

Table D68. Kruskal-Wallis and Mann-Whitney Wilcoxon tests for differences in ranks sums of volumetric soil moisture (θ m^3/m^3) by depth and season, bivariate analysis of weekly averages from 15-minute data.

Kruskal-Wallis and Wilcoxon Tests for Differences in Volumetric Soil Moisture between Seasons					
2.5cm			**50cm**		
Kruskal	H	p.value	Kruskal	H	p.value
all seasons	140.221	3.39E-30	all seasons	1.99	5.74E-01
Wilcoxon	W	p.value	Wilcoxon	W	p.value
Winter-Spring	60785	1.21E-27	Winter-Spring	2.45E+05	0.8013
Winter-Summer	68428	1.70E-09	Winter-Summer	2.95E+05	0.5815
Winter-Fall	47982	1.24E-13	Winter-Fall	2.07E+05	0.4901
Spring-Summer	21603	1.42E-09	Spring-Summer	1.90E+05	0.8103
Spring-Fall	16324	6.50E-04	Spring-Fall	1.35E+05	0.2398
Summer-Fall	31002	2.65E-02	Summer-Fall	1.65E+05	0.1351
25cm			**100cm**		
Kruskal	H	p.value	Kruskal	H	p.value
all seasons	97.434	5.54E-21	all seasons	4.672	1.97E-01
Wilcoxon	W	p.value	Wilcoxon	W	p.value
Winter-Spring	318395	3.15E-18	Winter-Spring	2.80E+05	0.3568
Winter-Summer	370665	1.98E-12	Winter-Summer	3.36E+05	0.1688
Winter-Fall	250870	7.59E-12	Winter-Fall	2.21E+05	0.0576
Spring-Summer	188198	2.37E-01	Spring-Summer	2.14E+05	0.1735
Spring-Fall	127915	6.24E-01	Spring-Fall	1.44E+05	0.2361
Summer-Fall	164554	3.85E-01	Summer-Fall	1.84E+05	0.8540

Table D69. Kruskal-Wallis and Mann-Whitney Wilcoxon tests for differences in ranks sums of mean event volumetric soil moisture (θ m^3/m^3) by depth and year for three years with four seasons of records (2007-2009), bivariate analysis from 15-minute data during wetting periods.

Kruskal Wallis and Wilcoxon Tests for Differences in Volumetric Soil Moisture between Years		
2.5cm		(α = 0.05)
Kruskal	H	p.value
all years (includes 2006 and 2010)	21	0.000349
Wilcoxon	W	p.value
2007-2008	853	0.52
2007-2009	418	0.65
2008-2009	930	0.26
25cm		(α = 0.05)
Kruskal	H	p.value
all years (includes 2006 and 2010)	23.38	0.000106
Wilcoxon	W	p.value
2007-2008	680	0.44
2007-2009	312	0.78
2008-2009	491	0.26
50cm		(α = 0.05)
Kruskal	H	p.value
all years (includes 2006 and 2010)	6.47	0.1669
Wilcoxon	W	p.value
2007-2008	220	0.36
2007-2009	69	0.58
2008-2009	63	0.50
100cm		(α = 0.05)
Kruskal	H	p.value
all years (includes 2006 and 2010)	8.40	0.0778
Wilcoxon	W	p.value
2007-2008	114	0.97
2007-2009	66	0.72
2008-2009	68	0.64

Table D70. Kruskal-Wallis and Mann-Whitney Wilcoxon tests for differences in ranks sums of event magnitude volumetric soil moisture ($\Delta\theta$ m^3/m^3) by depth and year for three years with four seasons of records (2007-2009), bivariate analysis from 15-minute data during wetting periods.

Kruskal Wallis and Wilcoxon Tests for Differences in Volumetric Soil Moisture between Years		
2.5cm		(α = 0.05)
Kruskal	H	p.value
all years	7.74	0.1016
Wilcoxon	W	p.value
2007-2008	1083	0.2040
2007-2009	418	0.6539
2008-2009	714	0.4027
25cm		(α = 0.05)
Kruskal	H	p.value
all years	13.14	0.0106
Wilcoxon	W	p.value
2007-2008	977	0.0300
2007-2009	341	0.3949
2008-2009	359	0.4192
50cm		(α = 0.05)
Kruskal	H	p.value
all years	4.09	0.3936
Wilcoxon	W	p.value
2007-2008	241	0.1308
2007-2009	60	1.0000
2008-2009	47	0.1351
100cm		(α = 0.05)
Kruskal	H	p.value
all years	6.19	0.1852
Wilcoxon	W	p.value
2007-2008	151	0.1149
2007-2009	79	0.2319
2008-2009	58	0.9228

Table D71. Kruskal-Wallis and Mann-Whitney Wilcoxon tests for differences in ranks sums of mean event volumetric soil moisture (θ m^3/m^3) by depth and season, bivariate analysis from 15-minute data during wetting periods.

Kruskal and Wilcoxon Tests for Differences in Volumetric Soil Moisture between Seasons					
2.5cm		α = 0.05	**50cm**		α = 0.05
Kruskal	H	p.value	Kruskal	H	p.value
all seasons	17.06	6.87E-04	all seasons	7.38	0.0607
Wilcoxon	W	p.value	Wilcoxon	W	p.value
Winter-Spring	259	1.54E-01	Winter-Spring	70	0.1718
Winter-Summer	2723	5.84E-05	Winter-Summer	606	0.0202
Winter-Fall	648	3.65E-02	Winter-Fall	290	0.0753
Spring-Summer	357	5.08E-01	Spring-Summer	36	0.6685
Spring-Fall	77	9.01E-01	Spring-Fall	14	0.4324
Summer-Fall	649	2.50E-01	Summer-Fall	181	0.5817
25cm			**100cm**		
Kruskal	H	p.value	Kruskal	H	p.value
all seasons	20.98	1.06E-04	all seasons	1.703	0.6361
Wilcoxon	W	p.value	Wilcoxon	W	p.value
Winter-Spring	259	1.74E-02	Winter-Spring	40	0.5049
Winter-Summer	1896	5.84E-05	Winter-Summer	262.5	0.6300
Winter-Fall	757	6.27E-02	Winter-Fall	103	0.6391
Spring-Summer	118	4.92E-01	Spring-Summer	22	0.3354
Spring-Fall	30	4.48E-02	Spring-Fall	7	0.1703
Summer-Fall	351	2.48E-02	Summer-Fall	110	0.5558

Table D72. Kruskal-Wallis and Mann-Whitney Wilcoxon tests for differences in ranks sums of event magnitude volumetric soil moisture ($\Delta\theta$ m^3/m^3) by depth and season, bivariate analysis from 15-minute data during wetting periods.

Kruskal and Wilcoxon Tests for Differences in Volumetric Soil Moisture between Seasons					
2.5cm		$\alpha = 0.05$	**50cm**		$\alpha = 0.05$
Kruskal	H	p.value	Kruskal	H	p.value
all seasons	15.42	1.49E-03	all seasons	1.82	0.6087
Wilcoxon	W	p.value	Wilcoxon	W	p.value
Winter-Spring	166	5.05E-01	Winter-Spring	37	0.6039
Winter-Summer	1761	4.59E-01	Winter-Summer	377	0.2891
Winter-Fall	183	2.22E-05	Winter-Fall	173	0.2900
Spring-Summer	333	7.61E-01	Spring-Summer	44	1.0000
Spring-Fall	41	4.87E-02	Spring-Fall	18	0.7676
Summer-Fall	412	1.20E-03	Summer-Fall	188	0.7104
25cm			**100cm**		
Kruskal	H	p.value	Kruskal	H	p.value
all seasons	1.60	0.6584	all seasons	4.96	0.1741
Wilcoxon	W	p.value	Wilcoxon	W	p.value
Winter-Spring	188	0.5298	Winter-Spring	25	0.6002
Winter-Summer	1305.5	0.9519	Winter-Summer	191	0.2400
Winter-Fall	511	0.3447	Winter-Fall	63.5	0.0410
Spring-Summer	123	0.5815	Spring-Summer	32	0.8725
Spring-Fall	50	0.3954	Spring-Fall	10	0.3681
Summer-Fall	447	0.3110	Summer-Fall	89	0.1730