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Original Research

Hydrologic Response of Four Ecological Sites to Natural Rainfall Events Within a Semiarid Watershed☆

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ABSTRACT

Understanding the capture and redistribution of water within ecological sites should improve our understanding of the function of rangeland watersheds. We compare ecological site physical properties, runoff events, and precipitation event characteristics to assess the variability in hydrologic response of four ecological sites to natural rainfall events in a semiarid watershed in southeast Wyoming, United States. Ecological sites were selected on the basis of their extent of areal coverage in the watershed and their perceived importance in watershed scale hydrologic response. At each study site, four 12-m^2 runoff plots were installed with collection troughs to capture and quantify the rate and amount of runoff. A tension infiltrometer was used to measure effective saturated hydraulic conductivity at the point scale, and a data-logging rain gauge was installed at each site to measure rainfall. One-way analysis of variance ($\alpha = 0.05$) was used to compare the hydrologic characteristics of ecological sties. Amounts and intensities of rainfall required to generate runoff, timing of overland flow, and peak runoff rates differed ($P < 0.05$) among sites in their current state. We found differences in effective hydraulic conductivity, 20.30 mm hr^{-1} on shallow loamy site up to 50.40 mm hr^{-1} on the coarse upland, and plot water storage potential, which varied from 101.8 mm on the shallow loamy site to 472.0 mm on the loamy upland site, due to differences in soil depth and porosity among sites. After normalizing runoff according to rainfall depth, we found no statistical difference ($P > 0.05$) in the volumes of runoff produced by different sites. The amount of runoff generated on all sites was very small, indicating high infiltration and limited ponding and overland flow. Ecological sites were shown to have different hydrologic response characteristics (i.e., timing of runoff), suggesting that they can be used to better quantify and understand the variability in hydrology in rangeland watersheds.

Introduction

Rangelands provide a variety of ecosystem services (Havstad et al., 2007; Boyd and Svejcar, 2009). In the western United States and other semiarid regions, increasing human populations (Wilcox and Thurow, 2006) are stressing naturally limited water resources; because of the spatial extent of rangelands, the majority of surface water in these environments falls on and moves through rangeland ecosystems. Management of rangeland watersheds directly impacts soil stability and vegetative cover characteristics (Thurow, 1991; Pierson et al., 2002), which subsequently influence the soil water available to support plant production (Snyman, 2009), loss to evapotranspiration (Nicholson, 1999), and human use (Wilcox and Thurow, 2006). Rangeland systems are relied on to provide water resources under changing stressors: increasing population (Havstad et al., 2007) with 8 of the 11 western states showing to be the fastest growing states between 1980 and 2006 (Albrecht, 2008), increased demand for water resources in response to a growing population (Pimentel et al., 1997), and increased climate variability (Archer and Predick, 2008). It is predicted that with increases in temperature associated with increased concentrations of greenhouse gases, annual precipitation variability will trend toward the extremes (McCabe and Clark, 2006) and the frequency of rainfall events may decrease while the intensity of events may increase (Groisman et al., 2005; Wentz et al., 2007; Fay et al., 2008). Quantifying the relationship between rangeland characteristics and hydrologic processes will improve our ability to predict and understand how changes in climate and management impact critical water supplies (Havstad et al., 2007, see Fig. 2).

Rangeland watersheds are highly heterogeneous systems composed of variable soils and vegetation. Because management of rangelands occurs at landscape scales, a spatially explicit means of partitioning rangeland watersheds may improve management and applicability of rangeland watershed models. Ecological sites are distinct units of land with characteristic soils, topography, and climate that produce a distinct

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type and amount of vegetation. Ecological sites are used as the baseline spatial unit for monitoring and assessment of rangeland systems by major US land management agencies (e.g., Bureau of Land Management, US Forest Service, Natural Resources Conservation Service; Brown, 2010; Caudle et al., 2013). In addition, they effectively capture some of the inherent spatial variability of rangeland systems and allow for improved understanding of rangeland watershed processes (Herrick et al., 2009; Williams et al., 2016). The same physical factors that define an ecological site also drive the near-surface hydrology of rangelands, and it has been suggested that ecological sites within a given state should have a characteristic hydrologic response to precipitation (Stone and Paige, 2003).

Most plot scale runoff and water erosion studies are conducted using rainfall simulation (Laflen et al., 1991; Simanton et al., 1991; Pierson et al., 2002; Paige and Stone, 2003; Wilson et al., 2014; Carey and Paige, 2016). Rainfall simulators provide a convenient tool capable of generating consistent precipitation response data. Such studies are critical in arid and semiarid rangelands where rainfall is limited and highly variable both spatially and temporally. While rainfall simulators allow researchers to study the hydrologic response of ecological sites (Paige et al., 2003; Stone et al., 2008; Carey and Paige, 2016), simulated rainfall intensities and duration are often extreme compared with natural rainfall events. In addition, most rainfall simulator experiments use both dry (no additional inputs of water beyond antecedent soil moisture) and wet runs (soils are at field capacity or higher), increasing the amount of water applied and potentially the runoff generated from experimental plots. Infiltration rates at the plot scale can vary with simulated rainfall intensity and between ecological sites (Paige and Stone, 2003). Here, we examine the relationship between near-surface hydrologic processes and the abiotic and biotic characteristics of ecological sites under natural rainfall conditions. Examining the ecological site hydrologic response during natural rainfall events, we aim to better characterize runoff generation and plot scale infiltration capacities under nonextreme conditions. A key question we investigate is if ecological sites differ in the generation of overland flow.

A long-held hypothesis, stemming from years of rainfall simulator experiments, is that different ecological sites will have a distinct hydrologic response for a given state. This hypothesis has not been fully tested under natural rainfall conditions. In this study, we documented rangeland hydrologic response at the plot scale to better understand the role of near-surface hydrology on ecological sites and quantify the variability within and among ecological sites. The objectives of this study were to quantify the amount and variability of runoff generated by natural rainfall and identify the important hydrologic characteristics (i.e., water holding capacity and infiltration rates) that impact runoff generation of key ecological sites within a semiarid watershed in southeast Wyoming. We explore ecological site characteristics and identify the amounts and timing of runoff as a function of summer rainfall events to test the hypothesis that ecological sites have distinct hydrologic responses. Linkage of ecological sites to surface hydrology is critical to understanding rangeland watersheds and their potential for being impacted by management at varying spatial scales.

Methods

Study Area

This study was conducted within the upper reaches of the Crow Creek watershed in southeastern Wyoming, United States from 2011 to 2013. The watershed covers an area of approximately 120 km^2 ranging in elevation from 2 040 m to 2 760 m above sea level. The watershed contains a variety of vegetation types including xeric uplands, broad riparian habitats, coniferous forests, and large areas of exposed granitic bedrock. The study area is within major land resource area (MLRA) 49A, the southern Rocky Mountain foothills northern part, and is in the 38 − 48 cm precipitation zone. The climate is characterized by wide fluctuations in precipitation; annual average precipitation is 41.7 cm, with the majority of precipitation falling as snow (USDA-NRCS, 2006). Spring precipitation is generated by frontal systems that produce low-intensity rainfall events over several days. Summer and fall precipitation is primarily in the form of convective thunderstorms, capable of producing short bursts of high-intensity rainfall. During our study period (2011 − 2013), 2011 was an above-average precipitation year (52 cm), 2012 was a dry year (35 cm), and 2013 was a “normal” year (46 cm). MLRA 49A is characterized by highly variable temperatures, cold winters and summer temperatures that sometimes exceed 33°C (USDA-NRCS, 2006). Wind, occasionally exceeding 80 km · h^{-1}, plays a significant role in snow redistribution, which consequently affects soil and ecological site development (Winstral and Marks, 2002).

Crow Creek watershed is located in the Medicine Bow − Routt National Forest managed by the US Forest Service (USFS). Before and during the study, all sites were grazed by cattle. Grazing management in the watershed consists of a rotational grazing system, light to moderate stocking rates, spring development, and use of herders to improve livestock distribution and utilization. Other management activities (i.e., timber harvest) that are part of the USFS management did not impact the study sites.

Ecological Sites

Four key ecological sites were selected for the study on the basis of their areal extent across the watershed and hypothesized role in watershed hydrologic response. Selected ecological sites were coarse upland (049XA108WY), loamy upland (049XA122WY), shallow loamy (049XA162WY), and shallow upland sites (049XA160WY) (USDA-NRCS, 2014).

The coarse upland ecological site is characterized by deep, well-drained, coarse textured soils. The A-horizon is approximately 2 cm thick with a sandy loam texture. Lower horizons have a loamy sand texture with > 35% coarse fragments to a depth of > 40 cm. The site is located on an alluvial fan overlaying granitic bedrock. The plant community is dominated by Idaho fescue (*Festuca idahoensis* Elmer) and fringed sagewort (*Artemisia frigida* Willd). More than 20% of the soil surface is covered by a mat of spiny phlox (*Phlox hoodii* Richardson) and lichens. The Ecological Site Description (R049XA108WY, USDA-NRCS, 2014) indicates a big sagebrush (*Artemisia tridentata* Nutt.) component; however, on-site measurements recorded few big sagebrush plants found primarily on disturbed areas (i.e., ground-dwelling mammal holes). Smaller subshrubs *(Artemisia frigida)* dominate the shrub component (Table 1). Site characteristics and the currently published state-and-transition model (STM, USDA-NRCS, 2014) indicate that this site is in a highly resistant state near what could be considered the historic climax plant community.

The loamy upland ecological site is characterized by deep, well-drained loamy soils overlaying granitic bedrock. A well-developed, 20-cm A horizon with a sandy loam surface texture on top of a 50-cm B horizon supports a dense plant community. The plant community is dominated by big sagebrush with bitterbrush (*Purshia tridentata* Pursh) and bear-berry (*Arctostaphylos uva-ursi* L.). The site has > 75% canopy cover due to the addition of a dense understory of bunch grasses, blue bunch wheat grass (*Psuedoroegneria spicata* Pursh.), and Idaho fescue. This specific site is also experiencing conifer encroachment, which may alter the site function in the future (Kormos et al., 2017). The loamy upland study site has transitioned from a bunchgrass-dominated community, likely because of lack of recent fire, to a big sagebrush dominant community with high litter cover (77%). Reintroduction of fire to this site will likely transition the site to a bunch grass − dominated state as the native bunch grasses remain a vigorous component of the study sites plant community (049XA122WY).

The shallow loamy ecological site has a clay loam surface texture. The shallow, approximately 2-cm, A horizon overlays fractured granitic bedrock. Bedrock is usually < 40 cm from the surface, with exposed granitic boulders common. The plant community is dominated by