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The morphology and hydrology of small spring-dominated channels

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ABSTRACT

Small, low order channels located in wet meadows along the Mogollon Rim of northern Arizona that receive the bulk of their flow from spring discharge exhibit a morphology that differs markedly from channels that receive the bulk of their flow from runoff. These small, spring-dominated channels generally have dense vegetation cover, vertical (or near vertical) banks with flat channel beds that are armored with clasts up to 60 mm. Clasts armoring the spring-dominated channels become mobile at 45 to 85% of the bankfull depth. The lack of fine-grained material in the bed of the spring-dominated channels reflects the small drainage size, lack of fine grain input from the spring, and winnowing affect of the consistent discharge. Minor amounts of large woody debris were present in some of the spring-dominated channels, however, unlike previous studies it does not appear to play a role in the spring-dominated channel morphology. Sinuosity values for spring-dominated channels averaged 1.19, while the average sinuosity values for the runoff-dominated channels, 1.08, were significantly lower. Measured width-to-depth ratios averaged 2.4 in the spring-dominated channels, much lower than the average ratio of 11.6 found for the runoff-dominated channels. The standard deviation of width-to-depth ratios was higher for runoff-dominated channels, reflecting a more variable channel profile. A third channel type, here referred to as hybrid channels, receive significant flow from both springs and runoff. These channels have characteristics that fall between spring-dominated and runoff-dominated channels.

Elevation, gradient, organic matter content, and sediment grain size distribution of the wet meadows in which the channels are formed do not exhibit significant differences between channel types, suggesting that these factors are not responsible for the observed differences in channel morphologies. The major differences in controls on the channel morphology found between the spring-dominated and runoff-dominated channels are the discharge regime and the sediment input. The hydrology unique to the spring-dominated channels and the lack of fine-grained sediment input combine to create the observed differences.

1. Introduction

Stream channels that receive the bulk of their flow from springs, termed spring-dominated channels by Stamm and Whiting (1994), exhibit a unique morphology and, in some environments, provide critical habitat for many species. Stream morphologies have been extensively studied and classified (Shumm, 1963; Church, 1992; Rosgen, 1994); however; little has been done to fit spring-dominated channels into the existing framework or to establish why spring-dominated channels differ from those that receive the bulk of their discharge from rain and/or snowmelt runoff. Recent work comparing the hydrology and geomorphology of spring-dominated channels to runoff-dominated channels in areas of Oregon, Idaho, and Montana (Stamm and Whiting, 1994; Whiting and Stamm, 1995; Whiting and Moog, 2001) has shown significant differences in morphology. The hydrograph of spring-dominated systems shows comparatively little change throughout the year (Manga, 1996; Swanson and Bahr, 2004), resulting in prevalent bankfull or near bankfull conditions. In comparison, runoff-dominated channels have relatively little base flow and exhibit a much more variable character dependent on the magnitude of local precipitation events (Manga, 1996). Whiting and Moog (2001) investigated streams fed by relatively large spring discharges (6.19 to 0.005 m^3/s) in volcanic-dominated areas in Oregon, Idaho, and Montana. They found, among other things, that spring-dominated systems exhibited larger width-to-depth ratios, large Manning roughness coefficients, and a "damped hydrograph" when compared with runoff-dominated systems.

The morphology of streams in wetlands is another area in which little work has been done. Studies by Jurmu and Andrle (1996) and Jurmu (2002) found characteristics unique to streams in wetland environments. To reduce the chance that the different channel morphologies observed in this study were a result of the morphologic

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difference between wetland and normal alluvial channels all of the channels studied were within the same type of environmental setting.

The purpose of this study was to describe the morphology and hydrology of first-order, spring-dominated channels (all with <0.00013 m^3/s measured discharge) and to compare these channels with similar order runoff channels to establish how, or if, the spring-fed flow and sediment input regimes affect the channel morphology. In addition, hybrid channels, or channels that receive significant flow from both springs and runoff, were studied to determine if the intermediate flow and sediment regime could shed light on the unique spring-dominated channel morphology. Finally, these results were compared to previous work done by Whiting and Moog (2001) to determine how the scale of spring-dominated channels plays a role in the channel morphology. Some springs and their dependent channels support a large array of microhabitats, each supporting a different suite of species (Springer et al., 2006). The results of this study are important for assisting with assessment, conservation, and management of the ecosystems associated with springs and spring-dominated channels.

2. Physical setting

During initial field reconnaissance in the winter and summer of 2002, potential study sites were identified along the Mogollon Rim of northern Arizona (Fig. 1; Table 1). The Mogollon Rim is part of an escarpment that diagonally bisects Arizona from the northwestern corner across to the eastern-central part of the state. This escarpment is ~500 km in length, averages an elevation of 2100 m, and has a local relief of up to 600 m (Peirce et al., 1979). The relief of the Mogollon Rim induces a strong orographic effect, yielding some of the highest precipitation in the state with an annual average of over 900 mm (data averaged from 1961 and 1990) (NRCS, 2005). Annual precipitation follows a bimodal distribution with periods of high precipitation during summer and winter (Green and Sellers, 1964). Summer precipitation comes in the form of monsoonal moisture arriving from the south, normally lasting from early July until September. Winter precipitation arrives as snow and rain from frontal systems; the greatest amounts of precipitation occur from late December until March. Many of Arizona's rivers (including the Little Colorado, Salt, and Verde) have headwaters that originate along the Mogollon Rim.

Major geologic formations in the area that pertain to this study consist of Permian limestone (Kaibab Formation) and sandstone (Coconino Sandstone), which dip slightly to the northeast, Tertiary basalts, and valley fill alluvium (Moore et al., 1960). All of the springs in this study originate at the contact between the Coconino Sandstone and the overlying Kaibab Formation. The Kaibab Formation, which is the local aquifer, is fractured and contains locally significant amounts of chert that often weather out to form residual gravel (Weisman, 1984). Most modern workers have differentiated the Kaibab Formation into two separate members, the Harrisburg and Fossil Mountain (Norton, 1990). The Harrisburg member is not present in the study area. The base of the Kaibab Formation consists of gently dipping to horizontal cross-stratified sandstone cosets with calcite filling or partially filling the remaining pore space; the presence of sand decreases upward in most areas (Norton, 1990). In the study area, the Kaibab Formation is ~50 to 100 m thick.

The Coconino Sandstone is a thick, up to 305 m, cross-bedded eolian deposit (Weisman, 1984). Although the Coconino Sandstone locally acts as an aquitard, it is an important regional aquifer. Tertiary basalt flows overlie the Kaibab Formation and are highly fractured. The local valley fill alluvium is Holocene in age; work by Joyal (2004) at Houston Draw recovered a calibrated ^{14}C date of 4030±250 YBP from the valley fill alluvium. This age is consistent with other early to mid-Holocene maximum ages recovered from valley fill alluvium in the area: 5070±40 yr B.P. in Dick Hart Draw (Joyal, 2004), 7000 YBP at Clover Springs (Anderson et al., submitted for publication) and 8000 YBP. in Walnut Canyon (Neff et al., 2003). The valley fill maximum ages suggest that a large-scale erosional event occurred in the area prior to 6000 yr B.P. followed by relatively steady aggradation of massive, predominately silty, alluvium with minor gravel lenses (Joyal, 2004). In some areas, the massive alluvium is capped by a more gravel-rich unit that possibly represents fire-related hillslope erosion (Joyal, 2004).

The study region lies entirely in the Coconino National Forest, a region that is predominately vegetated with ponderosa pine (*Pinus ponderosa*), mixed conifers, and gamble oak (*Quercus gambelii*). The spring-dominated channels examined in this study are located in the valley fill alluvium of low order streams along the Mogollon Rim (Fig. 2). Many of these lower order alluvial valleys are wet meadows, a locally rare environment, that are important for flood control and critical

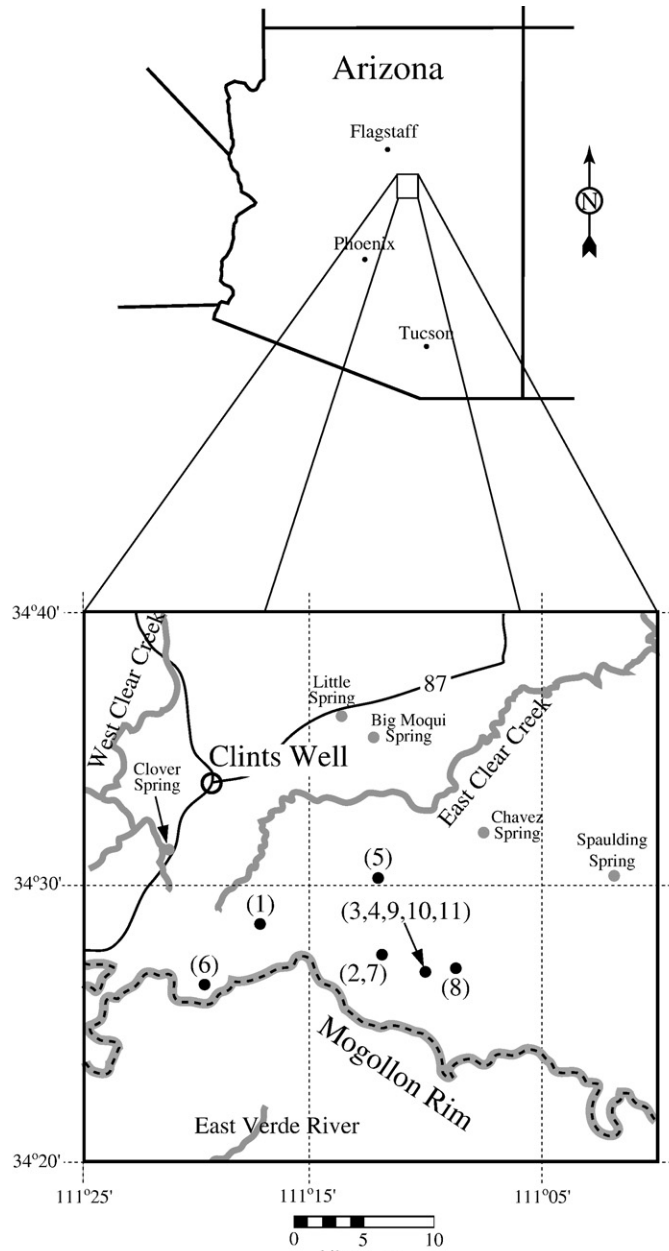

Fig. 1. Location of study sites (see Table 1 for specific site information): (1) Unnamed Spring 1, (2) Whistling Spring, (3) Unnamed Spring 2, (4) Unnamed Spring 3, (5) West Pinchot Spring, (6) Quaking Aspen Canyon, (7) Merritt Draw, (8) Buck Springs Canyon, (9) Bill McClintock Draw 1, (9) Bill McClintock Draw 2, (9) Bill McClintock Draw 3.