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Morphology of small, discontinuous montane meadow streams in the Sierra Nevada

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ABSTRACT

Various fluvial geomorphic models have been developed to characterize the relationships between planform and bedform features of large alluvial channels; however, little information exists for meadow channel morphology. Field investigation of seven narrow, low-energy meadow stream reaches in the northern Sierra Nevada range of California revealed similarities and differences to larger alluvial channels. The average radius of curvature to channel width ratio (5.54) of the meadow streams was almost double that of larger alluvial streams (3.1), with a standard deviation of 4.66. Average meander wavelength to channel width ratio (22.43) was almost triple that of typical alluvial streams (8.5), with a standard deviation of 16.80. Bedform features occurred at an average of 6.72 channel widths, similar to typical pool–riffle spacing of 5-7 channel widths. Grass sod connected a series of scour pools, providing the same energy drop function as riffles or steps. Results suggest that bedform regularity is similar to typical pool–riffle systems, especially as we move to larger watersheds and higher precipitation and runoff, but planform features are less developed and highly influenced by vegetation. Restoration efforts can benefit from considering how planform and bedform channel patterns develop in these meadows.

1. Introduction

Montane meadows in the Sierra Nevada of California are unique riparian wetland ecosystems where seasonal fluctuations in water saturation provide rich environments for biota at elevations between 600 and 3500 m (Rundel et al., 1977). Meadows attenuate peak flood flows, filter sediment, and increase water storage capacity, allowing plant and wildlife populations to thrive (Ratliff, 1982). In the Sierra Nevada, wet meadows are inextricably linked to a shallow groundwater table, which drives productive and diverse ecosystems despite the characteristically dry summer season (Loheide et al., 2008). These meadows represent < 1% of the Sierra Nevada landscape, but nevertheless support more biodiversity than any other habitat type (Kattelmann and Embury, 1996).

The interconnections between hydrology, vegetation, and stream geomorphology create unique ecological conditions that make meadows, and especially wet meadows, habitats for indicator species such as Sierra yellow-legged frog (*Rana sierra*; Viers et al., 2013) and subspecies of the Southwestern willow flycatcher (*Empidonax traillii*; Finch and Stoleson, 2000). Of direct importance to humans, Sierra meadow streams play a vital role in ensuring the quality and availability of freshwater to the populous central valley and San Francisco Bay area (Pupacko, 1993). Meadow environments regulate the snowmelt-driven hydrologic regime and help filter sediment. With millions of people directly dependent on freshwater from this mountain range, understanding the geomorphology of meadow streams should be a priority for land managers. Despite the highly valuable role of meadow streams, little information exists regarding their status and geomorphology.

Stream geomorphology includes planform features, such as meander curves, and bedform features, such as pools and riffles. Changes in planform morphology can have significant effects on habitat quality, and the effects extend not only across the riparian corridor but also longitudinally. Bedform features are part of the channel bottom and help dissipate energy (Leopold et al., 1964; Langbein and Leopold, 1966; Yang, 1971) while providing stable spawning and rearing habitat for fish and other aquatic organisms (Gregory et al., 1994; Gurnell and Sweet, 1998). The majority of stream geomorphology principles refer to larger alluvial channels, while limited research is available to characterize small, discontinuous meadow channels (Hagberg, 1995; Jurmu and Andrle, 1997; Jurmu, 2002; Purdy and Moyle, 2006).

Recent work has shown that wetland stream morphology tends to diverge from typical alluvial stream characteristics. For example, wetland streams in the midwest and east coast of the United States contained tighter bends, larger wavelength-to-width ratios, lengthier straight reaches, and a greater channel width at riffles (Jurmu and Andrle, 1997). Pool–riffle locations were more inconsistent because of the low-energy gradient in wetland environments (Jurmu, 2002). Watters and Stanley (2007) found that peatland channels had lower

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width-to-depth ratios and longer straight reaches than streams in typical alluvial settings.

As the value of meadow habitats are better understood, interest in restoration projects is becoming increasingly common in the Sierra Nevada (Purdy and Moyle, 2006). However, minimal information for meadow stream morphology is incorporated into restoration and monitoring plans, reflecting the assumption that meadow streams are similar to alluvial streams (Jurmu and Andrle, 1997; Jurmu, 2002; Purdy and Moyle, 2006).

The purpose of this research is to identify and characterize planform and bedform morphological features of small, discontinuous montane meadow stream channels in the northern Sierra Nevada. These features were compared to morphological models of alluvial channels as found in the literature. Analysis of channel planform characteristics included radius of curvature, meander wavelength, and length of straight reaches. Channel bedform analysis included pool–riffle spacing and pool-formation mechanisms together with an examination of discontinuous channel morphology. This comparison of morphological features provides evidence for how Sierra Nevada meadow streams compare to larger alluvial channels. Results from this study will provide land managers with better information to develop custom restoration and monitoring plans for meadow streams, taking into account the unique environmental factors acting on these channels.

1.1. Physical setting

The Sierra Nevada in northern California is composed of steep valleys interspersed with shallow alluvial basins extinct lakes. Today, many Sierra alluvial valleys include meadows, whether developed from lake succession or groundwater, constituting the most biologically active plant communities in the mountain range (Ratliff, 1982). This region typically receives the majority of its precipitation during the winter months, with annual rainfall averages varying from 500 to 2000 mm (PRISM, 2004), depending on topography and its effects on uplift and rainshadow. Most of this precipitation falls as snow during the winter, with peak flows corresponding to peak snowmelt in April and May. Summer months are characteristically dry in the Mediterranean climate. During the snowmelt season in the meadows studied, overland flow dominates the entire meadow surface while subsurface drainage takes over during the dry summer months. Meadow sod tends to be erosion-resistant owing to the dominance of hydric and mesic herbaceous vegetation with dense root masses. Xeric vegetation communities, including sagebrush (*Artemisia tridentata*), are present in areas where the groundwater table is low.

Many northern Sierra Nevada meadows are characterized by the presence of shallow, heavily vegetated stream channels that are almost indistinct, particularly when vegetation is thick during the summer months (Hagberg, 1995). In place of the classic gravel-bed entrenched channels typical of the American West, a key distinguishing feature of these meadow channels is the presence of a series of scour pools connected by grass sod. The resistant grass sod serves a similar energy-drop function as riffles or steps in typical alluvial systems (Fig. 1).

Meadows in the Sierra Nevada have been highly impacted by grazing, logging, and other anthropogenic activities, many of which are still widely felt. From the mid-1800s to the early 1900s, Sierra meadows were severely affected because of the arrival of European settlers and their associated land use practices (Ratliff, 1985; Allen-Diaz et al., 1999). Stream incision and the resulting transition from hydric to xeric vegetation eliminated wide swathes of riparian habitat (Ratliff, 1985).

The Carman Creek system provides an example of a wet meadow that underwent restoration to restore hydrologic function and biotic habitat. As early as the 1950s, the area was designated as a severely impaired ecosystem largely because of railroad logging and livestock grazing that began in the mid-1800s (SVRCD, 2004). Carman Creek became incised into a gully running parallel to the railroad tracks, and the

Fig. 1. Instead of riffles composed of coarse sediment, the meadow channels exhibit ‘grass riffles’, or stretches of grass sod connecting two scour holes, as seen in this photograph of Carman Creek in Three Corner Meadow. Gray arrow indicates direction of water flow during the wet season.

meadow subsequently dried out, with vegetation succession from wet meadow species, such as sedges and rushes, to dry meadow species such as sagebrush (SVRCD, 2004). The gully cut off hydrologic connectivity to the floodplain causing significant lowering of the water table and loss of water storage capability (SVRCD, 2004). Restoration efforts in the early 2000s helped reestablish floodplain connectivity and wildlife habitat. As the environmental benefits of meadows are increasingly recognized, similar restoration projects are becoming more common in this region (Purdy and Moyle, 2006).

1.2. Study site descriptions

Stream reaches in the Feather River basin were selected on the basis of the presence of grass sod energy drops acting similarly to riffles. Four stream reaches were selected along Carman Creek, with two reaches in Three Corner Meadow and two reaches in Knuthson Meadow, and one reach each was identified along Willow Creek, Haskell Creek, and Rowland Creek (Fig. 2).

Five of seven reaches were located in meadows restored using ‘pond-and-plug’ methods, which redirect surface flows from the paths of the incised channel, where the ponds and plugs are built, onto adjacent meadow surfaces where in some cases preexisting smaller channels are reoccupied (Lindquist and Wilcox, 2000). Study sites were selected to document a range of conditions under which the grass sod riffle energy-drop phenomenon occurs. All sites (Table 1) were chosen based on recommendations from restoration geomorphologists with the Feather River Coordinated Resource Management Group (Plumas Corporation, Quincy, CA) and Tahoe National Forest (U.S. Forest Service). Site selection was further refined based on the following criteria:

- location in a montane meadow (600–3500 m elevation);
- small drainage area (<50 km^2); and
- narrow, discontinuous stream channel comprising a series of scour holes connected by grass and sod.

2. Materials and methods

2.1. Field methods

We used laser level and GPS technologies to identify and measure planform and bedform features. Our method emphasized obtaining a sufficient number of points to accurately capture the spatial resolution