Geomorphology 205 (2014) 51–64

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Beaver dams and channel sediment dynamics on Odell Creek, Centennial Valley, Montana, USA

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ARTICLE INFO

Article history:
Received 12 July 2011
Received in revised form 14 April 2013
Accepted 17 April 2013
Available online 7 May 2013

Keywords:
Channel morphology
Sediment storage
Beaver dams
Aggradation
Dam breach

ABSTRACT

Beaver dams in streams are generally considered to increase bed elevation through in-channel sediment storage, thus, reintroductions of beaver are increasingly employed as a restoration tool to repair incised stream channels. Here we consider hydrologic and geomorphic characteristics of the study stream in relation to in-channel sediment storage promoted by beaver dams. We also document the persistence of sediment in the channel following breaching of dams. Nine reaches, containing 46 cross-sections, were investigated on Odell Creek at Red Rock Lakes National Wildlife Refuge, Centennial Valley, Montana. Odell Creek has a snowmelt-dominated hydrograph and peak flows between 2 and 10 $m^3 s^{-1}$. Odell Creek flows down a fluvial fan with a decreasing gradient (0.018–0.004), but is confined between terraces along most of its length, and displays a mostly single-thread, variably sinuous channel. The study reaches represent the overall downstream decrease in gradient and sediment size, and include three stages of beaver damming: (1) active; (2) built and breached in the last decade; and (3) undammed. In-channel sediment characteristics and storage were investigated using pebble counts, fine-sediment depth measurements, sediment mapping and surveys of dam breaches. Upstream of dams, deposition of fine (≤2 mm) sediment is promoted by reduced water surface slope, shear stress and velocity, with volumes ranging from 48 to 182 m^3. High flows, however, can readily transport suspended sediment over active dams. Variations in bed-sediment texture and channel morphology associated with active dams create substantial discontinuities in downstream trends and add to overall channel heterogeneity. Observations of abandoned dam sites and dam breaches revealed that most sediment stored above beaver dams is quickly evacuated following a breach. Nonetheless, dam remnants trap some sediment, promote meandering and facilitate floodplain development. Persistence of beaver dam sediment within the main channel on Odell Creek is limited by frequent breaching (<1–5 years), so in-channel sediment storage because of damming has not caused measurable channel aggradation over the study period. Enhanced overbank flow by dams, however, likely increases fine-grained floodplain sedimentation and riparian habitat. Contrasts between beaver-damming impacts on Odell Creek and other stream systems of different scales suggest a high sensitivity to hydrologic, geomorphic, and environmental controls, complicating predictions of the longer-term effects of beaver restoration.

1. Introduction

Fluvial and riparian habitats are hubs of biodiversity and essential habitat at the land–water interface in the semi-arid western United States. Riverine and associated habitats are subject to disturbance by changing river flows (Beever et al., 2005) and because of relatively small area but high ecological significance, are areas of primary concern for land managers. Thus, the interaction between physical and biological components of river systems is an active area of research (e.g., Petts, 2009). Beaver damming is thought to be an effective mechanism for reconnecting incised streams to historic floodplains because of the propensity for sediment to be trapped upstream of dams in the beaver ponds (Beechie et al., 2008). Research on the in-channel dynamics of beaver dams and the effects on sediment transport, however, is limited, and few studies have attempted to quantify the persistence of sediment within the channel, the location of maximum storage, and the caliber of the sediment stored.

Historical accounts indicate that North American beaver (*Castor canadensis*) dams had much greater importance in fluvial systems prior to European colonization and extensive beaver trapping (Pollock et al., 2003; Wohl, 2006). Pre-colonization beaver populations are estimated at between 60 and 400 million (Seton, 1929; Naiman et al., 1988), compared with estimates today of 6–12 million (Naiman et al., 1988). Beaver damming has been shown to increase riparian vegetation, raise water levels, attenuate flood peaks and alter sediment transport and storage patterns (e.g., McCullough et al., 2005). Thus, the boggy, flooded landscapes and extensive riparian zones associated with beaver damming are likely reduced at present and represent one of the major human alterations to fluvial landscapes.

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0169-555X/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.geomorph.2013.04.035

Like large woody debris (LWD), beaver dams form low-velocity areas, add cover for fish, and increase habitat suitability for certain emergent aquatic insects (Gurnell, 1998; Marcus et al., 2002), linking streams and their adjacent riparian ecosystems (Nakano and Murakami, 2001). LWD and beaver dams are increasingly being looked at as natural alternatives in river restoration projects (e.g., Pollock et al., 2007), and beaver dams tend to more effectively and consistently increase water and sediment storage. Whereas beaver dams interact with the fluvial system to alter rates of geomorphic change (Viles et al., 2008), how much of an effect the dams will have on the system is likely dependent on the unique conditions of a specific river or stream (Lane and Richards, 1997; Persico and Meyer, 2009).

It has been suggested that the cumulative effect of sediment stored upstream of beaver dams increases the elevation of the channel bed (e.g., Pollock et al., 2007). Thus, the large reductions in beaver throughout the United States have been implicated for increased rates of stream incision with the loss of in-channel sediment storage (e.g., Butler and Malanson, 1995; Pollock et al., 2007). In mountain regions of the western United States and elsewhere, fluvial incision from loss of beaver damming has been hypothesized as a major cause of the loss of wet meadow habitat and a decline in the areal extent of riparian zones (Marston, 1994). Along with extirpation of beaver, incision in the mountain West has also been attributed to grazing and agricultural land use (e.g., Wohl, 2006), as well as shifts in climate and forest fire impacts (e.g., Meyer et al., 1995; Miller et al., 2004). Near our study site, in northern Yellowstone National Park, Wyoming, riparian habitat degradation has been specifically associated with the loss of beaver (Wolf et al., 2007), although reductions in streamflow from severe droughts are also a major factor in reductions to beaver and riparian areas (Persico and Meyer, 2012).

With beaver loss being one of the suggested reasons for the incision of stream systems, a potential solution is re-introducing beaver and promoting building of beaver dams at sites where the health and extent of riparian zones are limited by stream incision. Beaver have been used in some river and riparian rehabilitation projects that led to successful re-colonization of beaver, local increase in water table elevation and reinvigoration of riparian vegetation (Apple et al., 1984; Albert and Trimble, 2000; Demmer and Beschta, 2008). The success of these projects has been attributed, in part, to accumulation of sediment and a rise in bed level upstream of dams where fine sediment accumulation has been well documented (Pollock et al., 2007). Quantitative observations that clearly demonstrate that beaver dams promote a persistent, long-term change in stream bed level, however, are limited.

Sediment accumulation above dams has been directly measured at a variety of locations throughout North America (e.g., Butler and Malanson, 1995; Pollock et al., 2003; McCullough et al., 2005; Pollock et al., 2007; Green and Westbrook, 2009) revealing a wide range (9–6500 m^3) of total volume of sediment stored behind individual dams. Sediment stored upstream of an individual dam may be most strongly related to the persistence of the dam itself (Butler and Malanson, 1995). The longevity of a dam in a given fluvial system may be dependent on hydrologic and geomorphic controls, such as discharge, channel slope and valley width. The physical attributes of the fluvial systems where beaver dams are found and sediment is stored, however, are rarely reported in the literature, and specific reasons for variations in effective sediment storage have not been investigated in much detail. An additional limitation in the current data is the lack of quantitative assessments of sediment volumes that remain following a breach of a beaver dam. Observations of sediment volumes remaining in the channel following a dam breach have primarily been qualitative (Butler and Malanson, 2005), so assessing the longevity and effectiveness of beaver-induced channel sedimentation is difficult given existing data.

To facilitate beaver restoration as a means for restoring riparian habitat, a more diverse and quantitative body of information needs to be obtained that is specifically related to river scale and attributes. The major focus of our study of beaver dams on Odell Creek in southwestern Montana, is to understand some of the basic fluvial hydraulic changes created by beaver damming through comparison of beaver dammed reaches with undammed reaches within the same system. We seek to understand sedimentation patterns related to beaver dams by creating detailed maps of the sizes of bed sediments in the study reaches, and quantifying the sediment stored in the vicinity of beaver dams. An additional question is whether changes in channel morphology and upstream sediment storage persist following the breaching of beaver dams. Dams breached naturally during our study and in the decade preceding our study provide a way to investigate the persistence of change. If beaver damming does generate an increase in bed elevation that persists following a dam breach, then the increase in channel–floodplain connectivity may be a longer-term adjustment and not just related to the base-level and backwater effects of an active beaver dam. An alternate hypothesis, however, is that on larger streams, in particular, sediment storage does not persist once a dam has breached, and that an increase in floodplain connectivity is mainly improved while the dam is present. Although our study primarily focuses on sediment dynamics within the stream channel, additional observations of overbank processes and longer-term geomorphic change caused by beaver dams are also considered. We interpret our findings on Odell Creek in relation to previously studied streams affected by beaver dams.

2. Study area

Odell Creek is located in the Centennial Valley in southwestern Montana, about 50 miles west of Yellowstone National Park (Fig. 1). The Centennial Valley is an east–west trending, normal-faulted basin that holds the large, shallow lakes of the Red Rock Lakes National Wildlife Refuge (RRLNWR). The active normal fault creates dramatic relief, with the Centennial Mountains rising about 1000 m above the valley floor. The headwaters of Odell Creek lie in these mountains, which are composed of diverse rock types, including Miocene volcanic rocks, and thick limestone units within the Cambrian to Cretaceous sedimentary rock sequence. The springs and streams of the upper basin join to form the main trunk of Odell Creek in Odell Canyon. The reaches within the canyon can primarily be classified as plane-bed reaches (Montgomery and Buffington, 1997) and no beaver activity was noted in this area of the basin during our study. At the mouth of the canyon, where Odell Creek flows out onto the valley floor at ~2060 m elevation above sea level, the drainage basin area is ~45 km^2. The valley bottom section of the creek flows over a low-gradient fluvial fan of late Pleistocene–Holocene age (K.L. Pierce, personal communication, 2009). The channel does not have a distributary pattern at present. It is mostly incised within the fan surface and is confined by terraces up to several meters above the channel, with a well-developed inset modern floodplain of about 30 to 400 m width. Channel gradients range from ~0.018 at the fan head, to ~0.007 in the middle reaches and ~0.004 on the lowest reaches above where the creek flows into Lower Red Rock Lake. Thus, the main effect of the fan environment and downstream base-level control is the rapidly decreasing gradient downstream, which allows a variety of fluvial environments to be investigated with relatively constant discharge. Odell Creek displays pool-riffle morphology with a sinuosity of 1.2 in the uppermost study reaches; 2.6 through the middle reaches, where most beaver activity was observed; and 2.3 in lower reaches, declining to a nearly straight channel in the kilometer upstream of the lake. Despite the fan environment, the confined valley created by Holocene incision and moderate to low channel gradients make the site comparable to other streams where the geomorphic effects of beaver have been studied (Table 1).

Centennial Valley experiences the majority of its precipitation in winter and spring, with May and June producing the highest precipitation amounts (Western Regional Climate Center, http://www.wrcc.