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ScienceDirect
Geomorphology 82 (2006) 412–429
GEOMORPHOLOGY
www.elsevier.com/locate/geomorph

Effects of dam operation and land use on stream channel morphology and riparian vegetation

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Received 11 January 2006; received in revised form 6 June 2006; accepted 6 June 2006
Available online 14 July 2006

Abstract

Dams are well known for influencing channel and vegetation dynamics downstream, but little work has focused on distinguishing effects of land use and channel responses to the impoundment. In this paper, we examined interacting effects of a dam and land use on downstream changes in channel morphology and riparian vegetation along an agricultural stream system in northern California. Measurements of planform channel morphology, vegetation area, and land use were mapped along multiple stream segments based on a chronological sequence of historical aerial photographs over a 34-yr period prior to operation of the dam in 1983 and over a 17-yr period after dam operation, and compared to a nearby, undammed reference stream. A two-factor analysis of covariance (ANCOVA) was used to examine the effect of the dam on changes in bankfull area, stream length, and riparian vegetation area while accounting for the effect of land use and distance downstream. The dammed stream's bankfull area contracted 94% after dam operation. Prior to dam operation, bankfull area decreased when land use area increased, but not after operation of the dam. Stream length varied 64% less after dam operation as a consequence of less frequent episodic channel migration and entrenchment. The area of riparian vegetation was decreasing during the pre-dam period, but then increased 72% after operation of the dam. Across time periods, decreases in the area of riparian vegetation were also associated with increases in land use area in both the dammed and reference stream. After operation of the dam, reduced peak discharges and sediment reduction likely lead to channel incision and constrained channel migration, which allowed vegetation to increase 50% on less accessible, abandoned banks. Rating curve and hydraulic exponent analyses based on stream gauge measurements corroborate statistical analyses of the mapped changes. In conclusion, we found that operation of the dam and land use patterns together influenced spatial and temporal changes in channel morphology and riparian vegetation. Use of a nearby undammed reference stream in conjunction with multivariable analysis of spatially and temporally replicated observations provided an effective framework for unraveling interacting effects of dams and land use activities on stream channel and vegetation dynamics.

Keywords: GIS; Channel morphology; Riparian vegetation; Land use; ANCOVA; Hydraulic exponent analysis

1. Introduction

Most river systems in the western United States are currently impounded to provide societal services such as

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doi:10.1016/j.geomorph.2006.06.001

hydropower, irrigation, flood control, and recreation (Graf, 1999, 2001). By regulating natural flow regimes and trapping sediment, an unfortunate trade off of dams is their potential to change historical channel dynamics and vegetation disturbances downstream (Dunne and Leopold, 1978; Simons and Li, 1980; Petts, 1984; Williams and Wolman, 1984; Chien, 1995; Brandt, 2000; Shields et al., 2000). Dams designed to actively control discharge for flood control are particularly effective at reducing peak discharge associated with storm events and increasing discharge during dry periods (Kondolf, 1997). The resultant loss of sediment load impounded behind dams and reduced discharge during storms can cause downstream channel incision and entrenchment, which may also lead to contractions in bankfull width and potential abandonment of floodplains (Cleveland and Kelley, 1977; Gurnell et al., 1994; Rosgen, 1996; Kondolf, 1997; Knighton, 1998; Brandt, 2000; Franklin et al., 2001). Accompanied by these changes, riparian vegetation along channel banks experiences less frequent flood disturbances, which can lead to an encroachment of increased vegetation abundance on the floodplain but with lower species diversity (Pelzman, 1973; Hupp, 1990; Hupp and Osterkamp, 1994; Friedman et al., 1998; Magilligan et al., 2003, Marston et al., 2005). These changes affect ecological processes in both aquatic and terrestrial riparian environments and are becoming an increasing concern in management and restoration of impounded river systems (Stevens et al., 2001; Thoms et al., 2005).

While dams play a critical role in stream channel processes, human land use practices such as agriculture and forest clearing can also impact fluvial geomorphic systems and riparian vegetation (Murgatroyd and Ternan, 1983; Osterkamp and Hupp, 1984; Mossa and McLean, 1997). Elimination of riparian habitat for agriculture can increase runoff, which can destabilize channel banks and vegetation establishment, cause channel aggradation, introduce fine-grained sediments (<1 mm) that inhibit fish spawning habitat (Everest et al., 1987), and increase dissolved organic compounds (Thoms et al., 2005). Changes to historical discharge regimes and a channel's sediment transport capacity can contribute to periods of sediment deficit or surplus. During periods of surplus, aggradation may occur, resulting in increased bed eleation, bank narrowing, and/or bed fining, whereas periods of sediment deficit, with sufficient transport capacities, may lead to bed incision, bank widening, and/or bed coarsening (Carson, 1984; Bledsoe, 1999; Grams and Schmidt, 2005; Richard et al., 2005). Riparian vegetation is also an important factor in channel morphology and its distribution is affected by both discharge regime and land use practices adjacent to the channel (Hupp and Simon, 1991). Riparian vegetation influences channel adjustment processes by increasing bank stability, inhibiting erosion, and enhancing sedimentation for floodplain formation (Friedman et al., 1996). While the potential effect of land use on channel and vegetation dynamics have been increasingly explored (Knox, 1977, Martin and Johnson, 1987; Knox, 2001; Urban and Rhoads, 2003; see also, U.S. Bureau of Reclamation, 2005; U.S. Fish and Wildlife Service, 2005), little is known about interacting effects of land use and dam operation. Empirically based studies are needed to differentiate effects of land use and dam operation on stream channel dynamics (Grams and Schmidt, 2005), but such data are typically difficult to obtain with sufficient spatial and temporal replication for multivariable analyses (Thoms et al., 2005). In addition, few studies have statistically examined the effects of a dam on channel and vegetation dynamics in relation to an undammed reference stream, a control for potential effects of climate change over the study period (but see, Stover and Montgomery, 2001; Grams and Schmidt, 2002, 2005; Thompson, 2006).

In this paper, we examine interacting effects of a northern California dam and land use on downstream changes in channel morphology and riparian vegetation that occurs along the watercourse. Spatial and temporal changes in planform channel morphology, riparian area, and land use adjacent to the channel are measured at multiple sites from a sequence of historical aerial photographs over a 34-yr period prior to operation of Warm Springs Dam in 1983 and over a 17-yr period after dam operation. Changes associated with the dam are also examined in relation to distance downstream of the dam and are statistically compared to a nearby undammed reference stream with similar climatic, geomorphic, and land use features. We corroborate these analyses using gauging station measurements and developed rating curves and performed hydraulic geometry exponent analyses to further examine stream channel dynamics and validate channel and vegetation changes interpreted from the air photos. Based on these data, we examined the following three questions:

(i) Does operation of a dam alter the spatial and temporal variability in channel morphology and the amount of vegetation in the riparian corridor, and to what degree does land use function as a contributing factor?
(ii) Does the rate and direction of changes in channel morphology and riparian vegetation differ after dam operation and does land use influence these changes?