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Geomorphic signature of a dammed Sandy River: The lower Trinity River downstream of Livingston Dam in Texas, USA

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ABSTRACT

Reservoirs behind dams act as deposition sites for much of the sediment being transported by rivers. As a result, the downstream river flow can be well below the transport capacity for bed-material. This promotes bed erosion and other geomorphic changes over some length of river located immediately downstream from a dam. These adjustments have been characterized for the Trinity River, TX, downstream of Livingston Dam. Field measurements and results from a 1D numerical model define a 50–60 river kilometer segment of river undergoing bed erosion as the transport capacity for bed material is reestablished. Consequences of this erosion include lowering of the channel bed, reduction in the sediment volume of channel bars, coarsening of sediment on bar tops, steepening of channel banks, and reduction in lateral migration rates of river bends. Repeat surveys of the river long profile reveals that 40 yr of dam closure has produced up to seven meters of channel-bottom incision downstream of the dam, transforming an initially linear profile into a convex-up long profile. The model output matches this observed change, providing confidence that calculated estimates for spatial and temporal changes in bed-material sediment flux can be used to explore the long-term signature of dam influence on the geomorphology of a sand-bed channel. Measurements of channel geometry, profile, lateral migration, and grain size of the lower Trinity River with distance downstream define both the trend and expected variability about the trend associated with the disruption to the bed-material load.

1. Introduction

The damming of rivers and the impoundment of sediment behind dams is considered a critical component in reducing sediment to the coast (Syvitski et al., 2005). It is typically assumed that deposition within a reservoir permanently reduces the overall sediment flux downstream of the dam. In this scenario there is no accounting for the possibility that net erosion of material from the bed and banks of a river could re-establish part of or the entire sediment load (Williams and Wolman, 1984; Graf, 2005). The potential for recovering some fraction of the sediment load removed through deposition in reservoirs is particularly important in the case of coastal rivers. Coastal rivers play a critical role in the delivery of sediment to coastlines which counteracts wetland loss associated with relative sea-level rise (Nicholls, 2003) and mitigates coastal erosion (Syvitski et al., 2005). The majority of the world's population resides within 50 km of a coast, with coastal population hubs often located near the mouths of rivers (Crossland et al., 2005). This critical delivery of sediment to the coast requires a delicate balance between water resource demands, ecologic needs, and river and reservoir management practices (Lagasse et al., 2004).

The lower Trinity River of Texas is a prime example of a sand-bed coastal river. The channel banks and substratum are composed primarily of erodible sandy fluvial deposits. In 1968 the river was impounded 180 river kilometers (rkm) upstream of Trinity Bay by closure of Livingston Dam, an earthen structure with a concrete spillway and a full pool depth of 40 m. The dam is primarily operated as a flow-through dam. The associated reservoir, Lake Livingston, supports water resource demands for a large portion of the metro-Houston area (Forrest, 2014), while the river downstream of the dam serves as a habitat for many species of interest, including the American alligator, the alligator gar, and over 400 species of birds, such as the bald eagle and the roseate spoonbill (Norris and Linam, 1999). In this paper we focus on the 120 rkm reach located immediately downstream from the dam in order to study the geomorphic adjustments to a sand-bed river in response to a disrupted bed-material load (Fig. 1). Bed-material trapped at the upstream end of Lake Livingston is building a delta. Delta construction results in water being released from the dam with a sediment load far below the transport capacity for the river (Fan and Morris, 1992; Schmidt and Wilcock, 2008).

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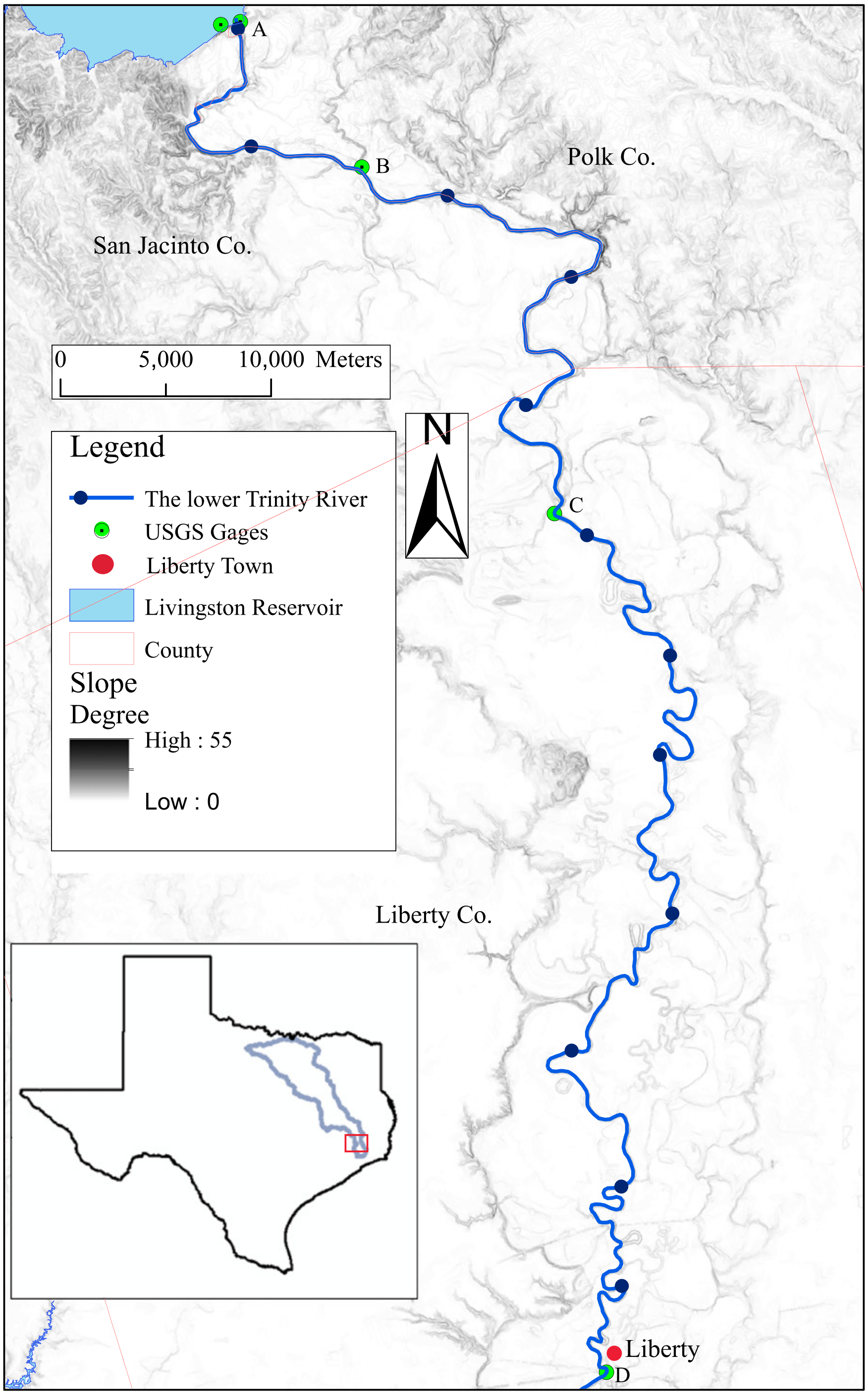

Fig. 1. Map of the lower Trinity study. The Trinity watershed within the state of Texas is outlined, running across the eastern portion of the state. The box at the lower end of the watershed marks the section of the watershed that is the study area. The study area is bounded by Livingston Dam to the north and Liberty, Texas, to the south. On this map the counties are outlined and labeled. The town of Liberty, TX is labeled near gage D. The circles with a dot in the center mark USGS gages at Livingston Dam (A; USGS number 08065350), Goodrich, TX (B; USGS number 08066250), Romayor, TX (C; USGS number 08066500), and Liberty, TX (D; USGS number 08067000). Blue dots are positioned along the centerline every 10 rkm.

Many studies have shown that dam emplacement causes downstream river incision (Mackin, 1948; Williams and Wolman, 1984; Kondolf, 1997) as sediment-starved water exiting a dam drives bed and bank erosion as the flow picks up sediment to reestablish sediment transport at the channel's transport capacity. This bed and bank erosion alters a channel's shape and long profile (Brandt, 2000). In coarse-grained rivers an equilibrium bed slope can be achieved through coarsening or bed armoring (Kondolf, 1997). Over the lifetime of a dam this downstream channel armoring limits the distance and amount of channel scour (Aksoy, 1971; Rzhanitzin et al., 1971; Jain and Park, 1989). However, in cases where armoring does not occur, as in the case of many sandy rivers, slope adjustments can be substantial and can evolve over decades (Williams and Wolman, 1984; Chien, 1985; Petts and Gurnell, 2005). The Trinity River downstream of Livingston