Geomorphology 201 (2013) 183–198

Contents lists available at ScienceDirect

Geomorphology

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

The geomorphic effectiveness of a large flood on the Rio Grande in the Big Bend region: Insights on geomorphic controls and post-flood geomorphic response

David J. Dean [a,*], John C. Schmidt [a,b]

[a] Department of Watershed Sciences, Utah State University, 5210 Old Main Hill, Logan, UT 84322-5210, USA
[b] U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center, 2255 N. Gemini Dr, Flagstaff, AZ 86001, USA

ARTICLE INFO

Article history:
Received 24 October 2012
Received in revised form 12 June 2013
Accepted 14 June 2013
Available online 28 June 2013

Keywords:
Geomorphic effectiveness
Channel widening
Channel narrowing
Sediment supply
Flood
Erosion

ABSTRACT

Since the 1940s, the Rio Grande in the Big Bend region has undergone long periods of channel narrowing, which have been occasionally interrupted by rare, large floods that widen the channel (termed a channel reset). The most recent channel reset occurred in 2008 following a 17-year period of extremely low stream flow and rapid channel narrowing. Flooding was caused by precipitation associated with the remnants of tropical depression Lowell in the Rio Conchos watershed, the largest tributary to the Rio Grande. Floodwaters approached 1500 m^3/s (between a 13 and 15 year recurrence interval) and breached levees, inundated communities, and flooded the alluvial valley of the Rio Grande; the wetted width exceeding 2.5 km in some locations. The 2008 flood had the 7th largest magnitude of record, however, conveyed the largest volume of water than any other flood. Because of the narrow pre-flood channel conditions, record flood stages occurred.

We used pre- and post-flood aerial photographs, channel and floodplain surveys, and 1-dimensional hydraulic models to quantify the magnitude of channel change, investigate the controls of flood-induced geomorphic changes, and measure the post-flood response of the widened channel. These analyses show that geomorphic changes included channel widening, meander migration, avulsions, extensive bar formation, and vertical floodplain accretion. Reach-averaged channel widening between 26 and 52% occurred, but in some localities exceeded 500%. The degree and style of channel response was related, but not limited to, three factors: 1) bed-load supply and transport, 2) pre-flood channel plan form, and 3) rapid declines in specific stream power downstream of constrictions and areas of high channel bed slope. The post-flood channel response has consisted of channel contraction through the aggradation of the channel bed and the formation of fine-grained benches inset within the widened channel margins. The most significant post-flood geomorphic changes have occurred at and downstream from ephemeral tributaries that contribute large volumes of sediment.

1. Introduction

The modern geomorphology of the Rio Grande in the Big Bend region is characterized by episodic disequilibrium (Nanson and Erskine, 1988) wherein the channel narrows on decadal timescales, and rare large floods rewiden the channel. This type of disequilibrium behavior is common in many landscapes (Nanson, 1986; Nanson and Croke, 1992; Erskine and Saynor, 1996) and has been extensively documented on rivers in the arid and semiarid southwestern United States (Schumm and Lichty, 1963; Burkham, 1972; Griffin and Smith, 2004; Vincent et al., 2009). Many studies have focused on aspects of the disequilibrium cycle, such as channel expansion during floods, or channel contraction during years of low peak flow (Miller, 1990; Magilligan et al., 1998; Cenderelli and Wohl, 2003; Hauer and Habersack, 2009); however, only a few studies have comprehensively described how these two processes are linked (Schumm and Lichty, 1963; Burkham, 1972; Costa, 1974; Gupta and Fox, 1974; Pizzuto, 1994).

On the Rio Grande, episodic disequilibrium processes are driven by a large sediment supply and a hydrology composed of two very different flood regimes with different source areas of runoff. Short duration flash floods in Chihuahuan desert tributary watersheds are caused by small-scale convective storms during the North American monsoon season. Infrequent, large, long duration floods are caused by tropical storms and hurricanes that can exceed reservoir storage capacity and flood control infrastructure upstream resulting in large releases/spills to the mainstem river. The large sediment supply allows for rapid narrowing during years of low to moderate peak flows.

We measured each aspect of the disequilibrium cycle of the Rio Grande including channel widening caused by a large flood (termed a channel-reset event), and the initial post-flood geomorphic response of the channel. Dean and Schmidt (2011) described the general trends of channel narrowing and channel reset during the twentieth and early twenty-first century, and Dean et al. (2011) described the rates

---

* Corresponding author. Tel.: +1 435 797 6784; fax: +1 435 797 1871.
E-mail address: david.dean@usu.edu (D.J. Dean).

0169-555X/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.geomorph.2013.06.020

and mechanisms of channel narrowing that occurred during a recent period of low flow. However, those studies did not specifically address the effect of the 2008 flood. This study adds to that body of research by focusing on the channel-resetting flood in 2008 and by describing the spatial variability in the magnitude of channel reset and the different styles of reset that occurred. This study specifically asks: i) what was the geomorphic effectiveness of the 2008 Rio Grande flood in terms of reach average and site-specific geomorphic changes, ii) what are the local physical and hydraulic controls that govern the spatial variability of channel reset and the different magnitudes and styles of geomorphic change, and iv) what is the style and rate of the initial phase of channel contraction in light of a previous model proposed by Dean and Schmidt (2011).

2. Background

Disequilibrium channel behavior is the state of perpetual geomorphic adjustment, such that the size and shape of the channel is never constant. Disequilibrium behavior frequently occurs in cycles or episodes of channel expansion and longer periods of channel contraction (Nanson, 1986; Nanson and Erskine, 1988; Pizzuto, 1994). Typically, studies focus on aspects of the disequilibrium cycle, such as the geomorphic change caused by large floods (Osterkamp and Costa, 1987; Jacobson et al., 1989; Magilligan et al., 1998; Cenderelli and Wohl, 2003; Hauer and Habersack, 2009; Vincent et al., 2009) or processes of post-flood channel recovery (Pizzuto, 1994). In this paper, we describe measurements of both aspects of the disequilibrium cycle.

The geomorphic effectiveness of a reset flood can be defined in a variety of ways. Geomorphic effectiveness has been defined as either the amount of work that occurs during a flood (Wolman and Miller, 1960) or by the degree of landscape modification that was caused by a flood (Thornbury, 1954; Miller, 1987). Wolman and Gerson (1978) refined the latter definition to also include the length of time required for the landscape to be restored to its pre-flood condition. In terms of flood-induced geomorphic change, Wolman and Gerson's (1978) definition is useful because both the direct geomorphic effects of a flood as well as the duration of its geomorphic legacy on the landscape are considered.

On the Rio Grande, however, Dean and Schmidt (2011) showed that the rate of channel recovery processes following a channel-widening flood, consisting of sediment accumulation within the channel and channel narrowing, occur at faster rates today than in the past. Thus, incorporating the time of channel recovery into the definition of effectiveness results in the comparison of processes, and their rates, that are changing in time. For the purposes of this paper, we employ the more traditional definition of geomorphic effectiveness as the amount of geomorphic change exerted on the landscape by a single flood event.

Hydraulic variables typically used to describe the forces exerted by geomorphically effective floods include total shear stress, specific stream power (Baker and Costa, 1987), or the ratio of specific stream power or shear stress of an extreme flood to that of common floods (Schumm, 1977; Cenderelli and Wohl, 2003). A greater ratio represents a greater potential for a flood to be geomorphically effective. Costa and O'Connor (1995) argued that the duration of flow in excess of an erosional threshold might also be important as the peak-specific stream power in causing geomorphic change.

Physical factors that control the geomorphic effectiveness of floods include valley confinement (Wohl, 1992), sediment supply, grain size (Newson, 1980), and the flow resistance provided by floodplain vegetation. The potential for geomorphic effectiveness is generally limited in confined valley settings where valley walls are resistant and alluvium is lacking for the flood to rework (Cenderelli and Wohl, 2003). Significant geomorphic changes may occur, however, in the expansion zones downstream of contrictions or confined reaches because local reductions of the sediment transport capacity can lead to significant deposition of transported sediment. Floods carrying large sediment loads may cause widespread geomorphic changes including bed aggradation, bar construction (Major et al., 2008), meander migration (Harrison et al., 2011), avulsions (Ashworth et al., 2004), and braiding (Desloges and Church, 1992). Floods transporting small sediment loads may cause bed incision. Vegetation density and type partially determine the thresholds and magnitude of bank erosion because plant stems and branches provide flow resistance, and rootsystems provide stability to the banks (Griffin and Smith, 2004; Tal and Paola, 2007; Pollen-Bankhead et al., 2009; Vincent et al., 2009).

Channel recovery following a large flood is dependent upon the rate of sediment delivery to the channel; the frequency, magnitude, and duration of sediment transporting flows; and the rate and density of vegetation establishment along or within the widened channel. Pizzuto (1994) showed that channel narrowing on the Powder River, in the plains of Montana, occurred through bench formation within a widened channel during intermediate flows with recurrence intervals between 1.1 and 2.7 years. Erskine (1994) showed similar processes on the Goulburn River in Australia, and Costa (1974) described this process on Western Run on the Maryland Piedmont following Hurricane Agnes. Friedman et al. (1996) and Osterkamp and Costa (1987) showed that vegetation establishment on surfaces just above the base-flow channel coincided with fine sediment deposition after a widening event on Plum Creek, CO. Dean and Schmidt (2011) showed that vegetation establishment within the widened Rio Grande in the early 1990s stabilized deposits and promoted deposition. Dean et al. (2011) showed that vegetation establishment coincided with extremely low flows, and channel narrowing and floodplain formation occurred at the fastest rates during moderate floods with recurrence intervals between 1 and 6.6 years that deposited fine sediment on benches developing along the channel margins. In all of these cases, as well as others (Schumm and Lichty, 1963; Burkham, 1972; Everitt, 1993), sediment supply was sufficient from which benches could be constructed.

3. Study area

The Rio Grande in the Big Bend region of the Chihuahuan desert extends from the confluence with the Rio Conchos 490 km downstream to Amistad Reservoir (Fig. 1). Here, the river is the international boundary between the United States and Mexico. Today, the Rio Grande in this region is predominantly single-threaded and flows through wide alluvial valleys in structural basins and narrow canyons cut through intervening ranges. Some of the canyons are very narrow, and the channel banks are bedrock. In wider canyons, very fine sand and mud forms the channel banks, and the banks are generally densely vegetated. Channel slope ranges from ~0.0008 in the alluvial valleys to 0.002 in the canyons. The bed of the Rio Grande is sand and gravel. A large amount of mud is supplied from desert watersheds, and thick muddy deposits occur along the channel margins and in low velocity parts of the channel (Dean and Schmidt, 2011; Dean et al., 2011). Much of the riparian vegetation consists of dense stands of tamarisk (*Tamarix* spp.) and giant cane (*Arundo donax*)(Moring, 2002), both of which are nonnative.

Four stream gages exist in the Big Bend region that we refer to in this study (Fig. 1B). Two are operated by the International Boundary and Water Commission (IBWC): (i) Rio Grande below Rio Conchos near Presidio, Texas (08-3742) (BRC gage) and (ii) Rio Grande at Johnson Ranch near Castolon, Texas, and Santa Elena, Chihuahua (08-3750) (JR gage). The BRC gage has been operated since 1900, except between 1914 and 1931; and the Johnson Ranch gage has been operated since 1936. We analyzed the records of both of these gages because tributary flash floods downstream of the BRC gage can cause high flows at Johnson Ranch. Two other gages are operated by the U.S. Geological Survey (USGS): (i) Rio Grande near Castolon, Texas (#08374550) (Castolon gage) and (ii) Rio Grande at Rio Grande Village, Big Bend National Park, Texas (#08375300) (RGV gage). These gages have short records that begin in August 2007.