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Channel adjustments to historical disturbances along the lower Brazos and Sabine Rivers, south-central USA

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ABSTRACT

Historical channel adjustments are documented and discussed in context with anthropogenic disturbances along two meandering, coastal plain rivers — the lower Brazos and Sabine Rivers in the south-central United States. Hard-copy streamflow-measurement notes of the U.S. Geological Survey were utilized to render historical cross sections (1925–2007) at nine gauging stations, which were complemented with repeat photographs and flood-frequency analysis to assess trajectories of channel change and interpret causative mechanisms. Downstream- and upstream-propagating disturbances caused episodes of channel-bed incision and aggradation at different locations for distinct time periods along both rivers. Incision associated with upstream dams is detected, but channels are compensated downstream with sediment inputs from lateral channel migration and tributaries. In one case, temporary aggradation along the Brazos River at Waco was likely caused by a combination of dam construction and regional soil erosion. Channel-bed incision on the lowermost Brazos River is unrelated to dams, but is associated with instream aggregate extraction, possibly in conjunction with downstream channelization. On the Sabine River, extensive aggradation during the 1930s might be associated with logging activities (1880s–1930s), but whether the cause is pervasive regional-scale hillslope erosion or local-scale mill-site activities is indeterminate. Following passage of this sediment, the river generally recovered to pre-disturbance conditions and has exhibited stability despite a mainstem reservoir. Translation of this sediment slug is attenuated by a transition to a flood-prone, distributary-dominated system downstream of the Holocene–Pleistocene terrace onlap position. Additional findings include cross-channel hingepoints separating thalweg incision from simultaneous point-bar or bank accretion at meander bends, which indicates channel adjustment occurs along non-cohesive beds in preference to cohesive or artificially reinforced banks. Also, flood reduction has resulted in bankfull stages that are higher than levels associated with the post-regulation 2-year return period. Finally, vegetation encroachment along banks since the 1970s coupled with reduced flooding along the lower Brazos River has promoted bank accretion deposits that, when fully developed, serve as morphologic indicators of the post-regulation 1- to 2-year return period stage.

1. Introduction

Alluvial river channels are sensitive systems that integrate prevailing environmental conditions from their drainage basins and can gradually or rapidly adjust to variables including tectonics, sea-level fluctuation, discharge, sediment load, and a myriad of constraints imposed by human land use and artificial regulation (Knighton, 1998; Schumm, 2005). The wide-ranging spectrum of river channel controls has led to a vast literature addressing channel adjustment through space and time (Gregory, 1977; Hickin, 1983; Brookes, 1994; Gurnell and Petts, 1995), notably for rivers affected by human activities (Park, 1977; Simon, 1989; Gregory, 2006; James et al., 2009a). The implications of river channel changes to economic development, human health, and ecological condition are substantial, and include increased flood risk (Shankman and Samson, 1991; Poesen and Hooke, 1997; Criss and Shock, 2001; Stover and Montgomery, 2001), aquatic and riparian habitat degradation (Petts, 1987; Brookes, 1994; Annear et al., 2004; Steiger et al., 2005), and minimized nutrient and contaminant sequestration (Bukaveckas, 2007; Hupp et al., 2009), among others. Knowledge about modes of adjustment, rates of change, and the physical mechanisms responsible for change is useful to formulate strategies for channel rehabilitation (Kondolf and Larson, 1995; Tiegs and Pohl, 2005), manage fluvial systems (Brierley and Fryirs, 2005; Gregory et al., 2008), engineer or mitigate problematic reaches (Patrick et al., 1982; Gilvear, 1999), and possibly predict channel form (Hooke and Redmond, 1989).

1.1. Channel change concepts

River channel changes are induced by pulse- or ramp-style disturbances (Brunsden and Thornes, 1979), in which the former are characterized by brief, high magnitude events (e.g., 100-year floods) that are usually followed by a period of recovery (Gupta and Fox, 1974; Pitlick and Thorne, 1987) and the latter constitute an enduring change to

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environmental conditions through space and time (e.g., climate change, urbanization). Ramped disturbances and associated channel changes occur across long-term (10^3–10^4 years), historical (10^1–10^3 years), and short-term (10^{-1}–10^0 years) timeframes (Schumm and Lichty, 1965; Macklin et al., 1998). Traditionally, geomorphologists have investigated climate (e.g., Knox, 1983; Bull, 1991; Starkel, 1995; Blum, 2007), tectonics (e.g., Harbor et al., 1994; Boyd and Schumm, 1995), and sea level (e.g., Blum and Aslan, 2006) for long-term controls of channel change; human impacts for historical change (e.g., Urban and Rhoads, 2003; Surian et al., 2009; James et al., 2009b); and flood or seasonal pulses for short-term investigations (e.g., Knighton, 1977; Gilvear and Harrison, 1991; Goff and Ashmore, 1994; Fuller, 2007, 2008; Bowen and Juracek, 2011). Notably, an abundance of research has documented human-induced channel change during the last few centuries (e.g., Leopold, 1973; Knox, 1977; Van Urt and Smit, 1989; James, 1991; Graf, 2001, 2006), and collectively highlights channel adjustments to forest clearance, agriculture, urbanization, dams, and flow regulation.

1.2. Historical channel changes

Investigations of historical channel adjustments to human impacts have employed various approaches to quantify patterns and rates of change, primarily focusing on planform (Lewin, 1977) and cross-sectional (Park, 1977, 1995) dimensions. Most geomorphic research on river channel change has utilized historical documents, maps, aerial photos, and satellite images to analyze planform adjustments in Europe, North America, and Australia (e.g., Brewer and Lewin, 1998; Warner, 2000; Winterbottom, 2000; Pišút, 2002; Surian and Rinaldi, 2003; Joeckel and Henebry, 2008; Comiti et al., 2011; Michalková et al., 2011). Similar efforts have recently emerged for large rivers in Asia and South America (e.g., Goswami et al., 1999; Amsler et al., 2005; Li et al., 2007; Takagi et al., 2007). In North America, most planform change evaluations consider adjustments downstream from major reservoirs or diversions, which commonly include lateral erosion in humid, temperate zones (Wellmeyer et al., 2005; Draut et al., 2011) and channel narrowing and simplification in semiarid to arid zones (Everitt, 1993; Van Steeter and Pitlick, 1998; Tiegs and Pohl, 2005; Joeckel and Henebry, 2008; Swanson et al., 2011).

Relative to channel pattern assessments, considerably fewer investigations have utilized cross-sectional data to analyze historical river channel changes, although Gregory (2006) noted that channel changes are most evident from the cross-sectional perspective. In part, this is because field investigations of channel morphology have not been designed for long-term monitoring (Sear and Newson, 2003). Some exceptions are noted in the literature that have utilized historical cross-sectional data to detect wholescale (e.g., Rinaldi and Simon, 1998; Gomez et al., 2007; Kiss et al., 2008; Ta et al., 2008), spatially limited (e.g., Musselman, 2011), or complex (e.g., Leopold, 1973; Richards and Greenhalgh, 1984; Phillips et al., 2005; Zawiejska and Wyżga, 2010) adjustments through time. Although survey measurements are preferable and permit accurate computations of channel shape, others have utilized repeat ground-based photography (e.g., Frankl et al., 2011) to document cross-sectional adjustments.

1.3. Streamflow gauging data

Whereas few geomorphic monitoring programs have been established, streamflow monitoring is commonplace and requires data relevant to reconstruct historical cross sections. Measurements of incremental width, depth, and velocity across a channel are made throughout the year and, if measurements span the channel bed and banks along a consistent transect through time and the elevation datum is documented, then historical cross sections can be rendered (Juracek and Fitzpatrick, 2008). The U.S. Geological Survey (USGS) is the primary agency responsible for streamflow monitoring in the United States and has operated thousands of gauging stations since 1889. Discharge measurement summaries (including water-surface width, mean depth, and mean velocity) are publicly accessible on the internet (U.S. Geological Survey, USGS, 2011), but measurements of incremental width, depth, and velocity across the channel are only available on archived, hard-copy field notes present in USGS offices or the Federal Archives.

1.4. Purpose and scope

River restoration and rehabilitation programs benefit from historical channel change assessments because knowledge of previous physical conditions, whether natural or impaired, permits establishment of targets for successful project implementation (Kondolf and Micheli, 1995; Palmer et al., 2005). This article documents and interprets historical, primarily twentieth century, cross-sectional and planform channel adjustments along the lower Brazos and Sabine Rivers in south-central USA, through analyses of USGS streamflow-measurement records, aerial photographs, repeat ground photography, and flood frequency. This work supports the Texas Instream Flow Program, mandated by the Texas Legislature in 2001 to *ensure a sound ecological environment* in priority river segments. To date, this program has embraced an instream flow approach emphasizing restoration of a natural flow regime to mitigate against negative ecological consequences of flow regulation. Therefore, historical data, such as those presented here, will likely be compared to eventual outcomes achieved through implementation of flow schedules.

2. Brazos and Sabine Rivers, south-central USA

The Brazos and Sabine Rivers mostly traverse Texas, and the Sabine River is a boundary between Texas and Louisiana (Fig. 1). The Brazos River drainage basin (118,350 km^2) extends from the semiarid High Plains to the western Gulf Coastal Plain. Small, ephemeral drainage channels (draws) in the High Plains are hydrologically disconnected from the downstream tributary network where baseflow combines with increasingly humid conditions to produce perennial streamflow. Flood-control reservoirs in the upper and middle zones of the basin, including Lake Whitney and Lake Waco, regulate flow downstream of Waco.

The Sabine River drainage basin (25,540 km^2) extends from the Blackland Prairie east of Dallas to the Gulf Coastal Plain. The climate is humid subtropical, with precipitation generally increasing toward the Gulf of Mexico. The Sabine River headwaters are impounded by a series of reservoirs that regulate flows in the upper basin, and the Toledo Bend Reservoir on the mainstem channel regulates flows to the lower river. None of the reservoirs in the Sabine River basin are designed for flood control, and therefore, overbank flows are not completely impeded.

The lower Brazos and Sabine Rivers meander within the gently sloped western Gulf Coastal Plain, which is separated into three geomorphic subdivisions: (i) Texas Blackland Prairies, (ii) Interior Plains, and (iii) Coastal Prairie (Hudson and Heitmuller, 2008). The Blackland Prairies are characterized by outcrops of upper Cretaceous shale, chalk, and marl that deliver fine-grained silt and clay to stream channels. The Interior Plains include southeast-dipping, Tertiary-aged beds of alternating shale and sandstone. Finally, the Coastal Prairie is defined by gently dipping Pliocene, Pleistocene, and Holocene sands and muds of fluvial, deltaic, and marginal marine origins. Late Pleistocene terrace and Holocene floodplain deposits along river channels intersect older sedimentary surfaces.

2.1. Lower Brazos River

The Brazos River enters the Gulf Coastal Plain at Waco and flows ~625 km to the Gulf of Mexico near Freeport. Dimensionless channel slope ranges from 0.00030 near Waco to 0.00015 near Rosharon, and bed composition changes downstream from mixed sand and gravel to