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Geomorphic and vegetation changes in a meandering dryland river regulated by a large dam, Sauce Grande River, Argentina

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ABSTRACT

This paper investigates post-dam geomorphic and vegetation changes in the Sauce Grande River, a meandering dryland river impounded by a large water-conservation dam. As the dam impounds a river section with scarce influence of tributaries, sources for fresh water and sediment downstream are limited. Changes were inspected based on (i) analysis of historical photographs/imagery spanning pre- (1961) and post-dam (1981, 2004) channel conditions for two river segments located above and below the dam, and (ii) field survey of present channel conditions for a set of eight reference reaches along the river segments. Whilst the unregulated river exhibited active lateral migration with consequent adjustments of the channel shape and size, the river section below the dam was characterized by (i) marked planform stability (93 to 97%), and by (ii) vegetation encroachment leading to alternating yet localized contraction of the channel width (up to 30%). The present river displays a moribund, stable channel where (i) redistribution of sediment along the river course no longer occurs and (ii) channel forms constitute a remnant of a fluvial environment created before closing the dam, under conditions of higher energy. In addition to providing new information on the complex geomorphic response of dryland rivers to impoundment, this paper represents the very first geomorphic assessment of the regulated Sauce Grande and therefore provides an important platform to underpin further research assessing the geomorphic state of this highly regulated dryland river.

1. Introduction

Drylands — which include dry-subhumid, semiarid, arid, and hyperarid regions — cover 40% of the Earth's surface and contain almost 40% of the global population (UNEM, 2011). Population growth and changing living standards force increased water allocation for urban, agricultural and industrial use (Young and Kingsford, 2006; Schmandt et al., 2013). As a result, water resources in drylands tend to be heavily exploited through dams, weirs, canals, and other structures (Davies et al., 1994). Although most dams in drylands are multipurpose dams, with hydropower and flood control as common primary functions, many of them operate as water-conservation structures to support irrigation and/or drinking water supply. Water-conservation dams maintain the reservoir as full as possible and impound the entire runoff volume in periods of reservoir filling (Petts, 1984). Thus, the disparity between natural and regulated flow regimes may be particularly striking in drylands (Walker et al., 1995).

One particular concern is that dryland fluvial processes (and therefore the fluvial response to impoundment) may be very different from those generally accepted in more humid regions (Tooth, 2000b, 2013; Nanson et al., 2002). Dryland rivers are characterized by extreme variability in flow and sediment transport (Davies et al., 1994; Bunn et al., 2006; Young and Kingsford, 2006). Long periods of little or no flow are interspersed with floods of high, sometimes extreme magnitude (Tooth and Nanson, 2000), short duration (Graf, 1988), and low predictability (Poff and Ward, 1989). Floods control erosion, transport, and deposition processes (Bull and Kirkby, 2002) and therefore constitute the major determinant of dryland channel shape and size (Tooth, 2000b). As morphogenetic floods exhibit highly skewed frequency (Tooth, 2000b), complete adjustment of dryland channel form to process is sometimes inhibited (Bull and Kirkby, 2002). Feedback mechanisms between channel form and process are rarely found in drylands (Tooth, 2000a), and therefore researchers have a tendency to presume that dryland rivers are in an unstable, nonequilibrium state (Tooth and Nanson, 2000).

The unstable character of natural dryland rivers challenges assessing the impacts of flow regulation on dryland channel forms. Notable

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advances on the complex response of dryland rivers to impoundment have been made in the United States and Australia, as well as in central Asia, South Africa, and South America in minor extent. For example, Friedman et al. (1998) found that regulated braided rivers in the American Great Plains tend to narrow owing to vegetation encroachment (such as has occurred in the Orange River, South Africa; Blanchon and Bravard, 2007), whereas meandering rivers tend to reduce their migration rates (e.g., the upper Missouri; Shields et al., 2000). In the American Southwest (e.g., Green River; Merritt and Cooper, 2000; Grams and Schmidt, 2002), the most common response to impoundment involved reduced channel capacity by aggradation and vegetation invasion of lateral deposits, such as has occurred in dryland rivers of Australia (e.g., Cudgegong River; Benn and Erskine, 1994), the Mediterranean Basin (e.g., Medjerda River in Tunisia; Zahar et al., 2008), and South America (e.g., Chubut River in Argentina; Kaless et al., 2008). The studies cited above, among many others, have certainly contributed to the understanding of form to process relationships in regulated dryland rivers. Yet most of the previous research has centred on locations where tributaries contribute water and sediment below the dam, and very few studies have investigated geomorphic adjustments in flood-driven, regulated dryland rivers where tributary influence below the dam is scarce.

This paper examines geomorphic and vegetation adjustments in a meandering dryland river where (i) flow regulation is extreme and (ii) sources for flow and sediment below the dam are limited to erratic reservoir discharges and reworked local alluvium because the river flows without influence of tributaries. It aims to address two fundamental questions: (i) how do flood-driven, dryland channels adjust their morphology in highly regulated, low stream power settings with scarce influence of tributaries? and (ii) how does riparian vegetation interact with (and react to) altered river hydrology and morphology in dry, highly regulated fluvial settings? The study centres on the Sauce Grande River below the Paso de las Piedras Dam (central-eastern Argentina), where prior geomorphic assessment is limited to reconstructions of Quaternary fluvial processes at the broad scale of the river basin. Change in channel geometry (planform and cross section) and riparian vegetation structure are quantified simultaneously above and below the dam using a sequence of rectified aerial photographs and high-resolution imagery spanning pre- and post-dam channel conditions. Changes as a function of distance downstream from the dam are also examined.

2. Materials and methods

2.1. Study site

The Sauce Grande River collects its waters on the eastern slope of the Sierra de la Ventana Range and flows down into the Atlantic Ocean draining a basin area of ~4600 km^2 (Fig. 1). The climate in the majority of the river basin is dry-subhumid. Mean annual rainfall decreases from 800 mm in the uplands to 640 mm in the lowlands, and mean annual potential evapotranspiration is 1030 mm (Paoloni et al., 1972). Interannual rainfall variability is marked and linked primarily to alternating phases of ENSO (Scian, 2000), inducing episodes of drier- and wetter-than-normal climate (Campo et al., 2009; Bohn et al., 2011). Recurrence of drought and increasing water demand owing to population growth very seriously impact on local water resources (Andrés et al., 2009).

2.1.1. Hydrological context

The natural river flow regime is perennial flashy (rainfed) and event-driven. Mean daily flow (1910–1947) is 3.4 m^3 s^{-1}, but floods may reach more than 1000 m^3 s^{-1} in a few hours (Schefer, 2004). The Paso de las Piedras Dam (initiated in 1972 and completed in 1978) impounds the middle river section for water supply to the cities of Bahía Blanca and Punta Alta (Fig. 1). Its reservoir has a surface area of 36 km^2 and a maximum storage capacity of 328 m^3 10^{-6} for 25 m depth (Schefer, 2004). Annual yield to meet water demand is 65 m^3 10^{-6}; this is about 60% of the mean annual inflow volume (107.2 m^3 10^{-6}). The remaining volume is conserved within the

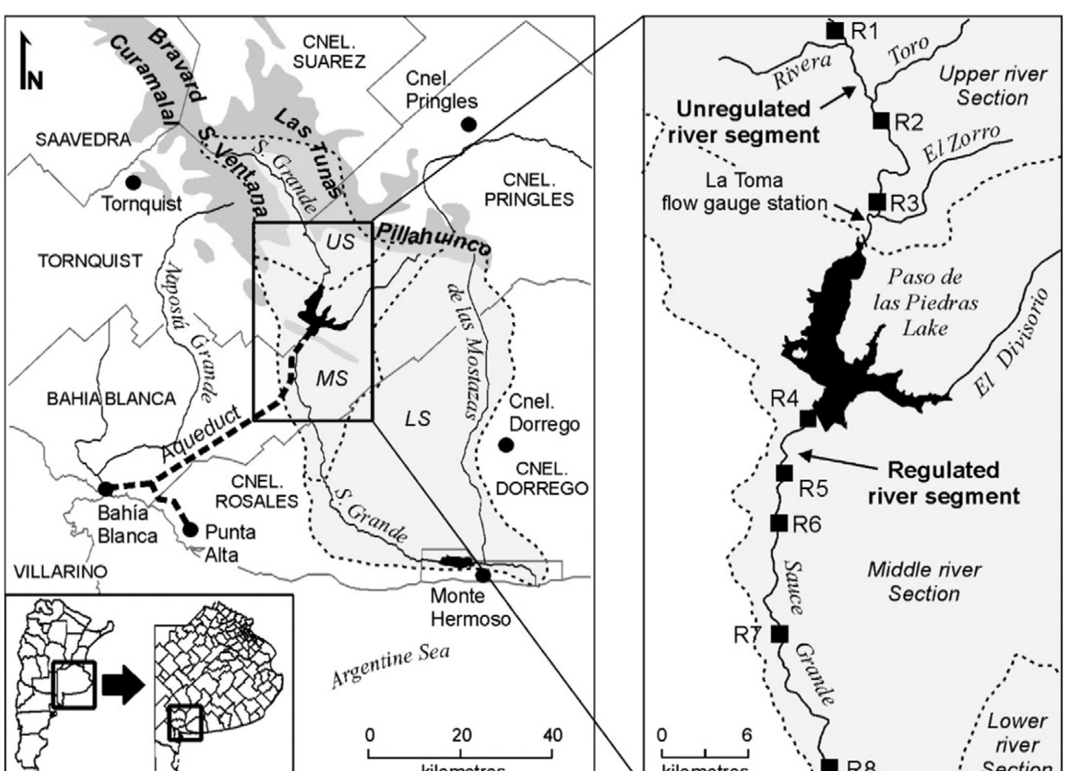

Fig. 1. Map of the Sauce Grande River basin showing main regional features (left) and the river segments selected for analysis (right). The location of reference river reaches (R) along each river segment is also illustrated. US, MS and LS in the left map designate the upper, middle, and lower river sections, respectively.