Confluence of ephemeral tributaries with the mid-Rio Grande

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Abstract

Almost without exception river confluence geometry, dynamics and sedimentology have been studied from the confluence downstream. We concentrate on the topography, morphologic changes and sedimentary character of the ephemeral tributary channel upstream of the confluence. We first identified the meager literature on confluences and ephemeral streams. The confluence of three ephemeral tributaries to the mid-Rio Grande were studied during two monsoon seasons. We determined their morphologic characteristics, topographic changes and the sedimentary character of their resultant deposits, finding evidence of recirculatory deposition in the confluence mouth when flow is exclusively from the larger confluent, and coarse bar deposition when flow is dominated by the smaller, ephemeral confluent.

Introduction

River confluences have been studied for the past half century, concentrating on confluence hydrodynamics such as momentum ratios, turbulent and coherent flow structures (Bradbrooket al., 2000; Rhoads and Sukhodolov, 2004; Boyer et al., 2006; Schindfessel et al, 2015; Sukhodolov et al., 2017; Duguay et al., 2022; Sabrina et al., 2022), confluence channel size and shape (Ashmore, 1982), spatial mobility (Dixon et al., 2018), sediment characteristics (Best, 1988; Biron et al, 1993) and their dependence on confluence angle, symmetry, sediment texture (Mosley, 1976; Best and Reid, 1984; Rhodes et al. 2009; Leite Ribeiro, M., 2012) as well as the relative water/sediment discharges of tributary and trunk (Mosley, 1976; Liu et al., 2015; Bombar & Cardoso; 2020). Few have viewed river confluences in a broader geologic setting (Benda et al., 2004). Recent studies have also directed attention at engineering methods to decrease depth of confluence scour holes (Hydar et al., 2019), and increase tributary width, thereby intensifying habitat heterogeneity (Rice et al., 2008; Milner et al., 2019).

Few studies have concentrated on the tributary channels upstream of, but sufficiently near to be affected by a confluence, with exceptions concerning (i) situations where the scour hole progresses upstream into the tributary, (ii) the non-coincidence of flows in trunk and tributary streams giving rise to temporally varying confluence deposits (Reid and Frostick, 2011), and (iii) the dating of slackwater deposits located in tributaries (Benito et al., 2003; Unde et al., 2009).

Our objective is to further shed light on river confluences by studying confluences that often involve considerable water and sediment transport in either the trunk or in the ephemeral confluent stream, previously referred to as non-coincident flows (Reid and Frostick, 1989) or asynchronous tributary activities (Bourke & Pickup, 1999). We focus on characterizing the upstream confluence area of smaller confluents, determining how their planform, junction angle and discharge ratio contribute to the confluence morphology and sedimentology at three ephemeral tributaries of the mid-Rio Grande.

Study sites

The three study arroyos differ with regards to basin size, geology, channel bed grain size and anthropogenic influences. Therefore, processes that dominate the sediment dynamics at one site may not be influential at others. The three arroyos have been anthropogenically modified to either alleviate lateral migration of the Rio Grande (Arroyo de las Cañas), support ecological restoration (Arroyo de la Parida), or for research purposes (Arroyo de los Pinos). Different morphological responses at each confluence are caused by the variability of sediment supply and the localized runoff events that generate unique flow histories in each watershed.

The Arroyo de los Pinos is located south of the Arroyo de la Parida and north of the Arroyo de las Cañas (Figure 1). The climate is semiarid, with a ~250 mm average annual rainfall. The majority of the rain typically falls during the summer monsoon season. These watersheds are at the northern edge of the Chihuahuan Desert, and are host to desert shrubs and cacti such as creosote, mesquite, cholla, tarbrush, prickly pear, and ocotillo. Cottonwood and juniper trees are sparsely scattered along tributaries and main channel banks.

The Arroyo de los Pinos outlet joins the Rio Grande at a 90° junction angle, with a local channel slope of 1.25 %. The Arroyo de la Parida planform has a junction angle of < 90° with the Rio Grande. The Parida tributary mouth has been modified by the United States Bureau of Reclamation, with the banks lowered and graded to be gently sloping in order to improve habitat for the endangered silvery minnow. Two branches of the Arroyo de las Cañas split near the confluence with the Rio Grande, the northern branch joining at > 90° and the southern branch at < 90°.

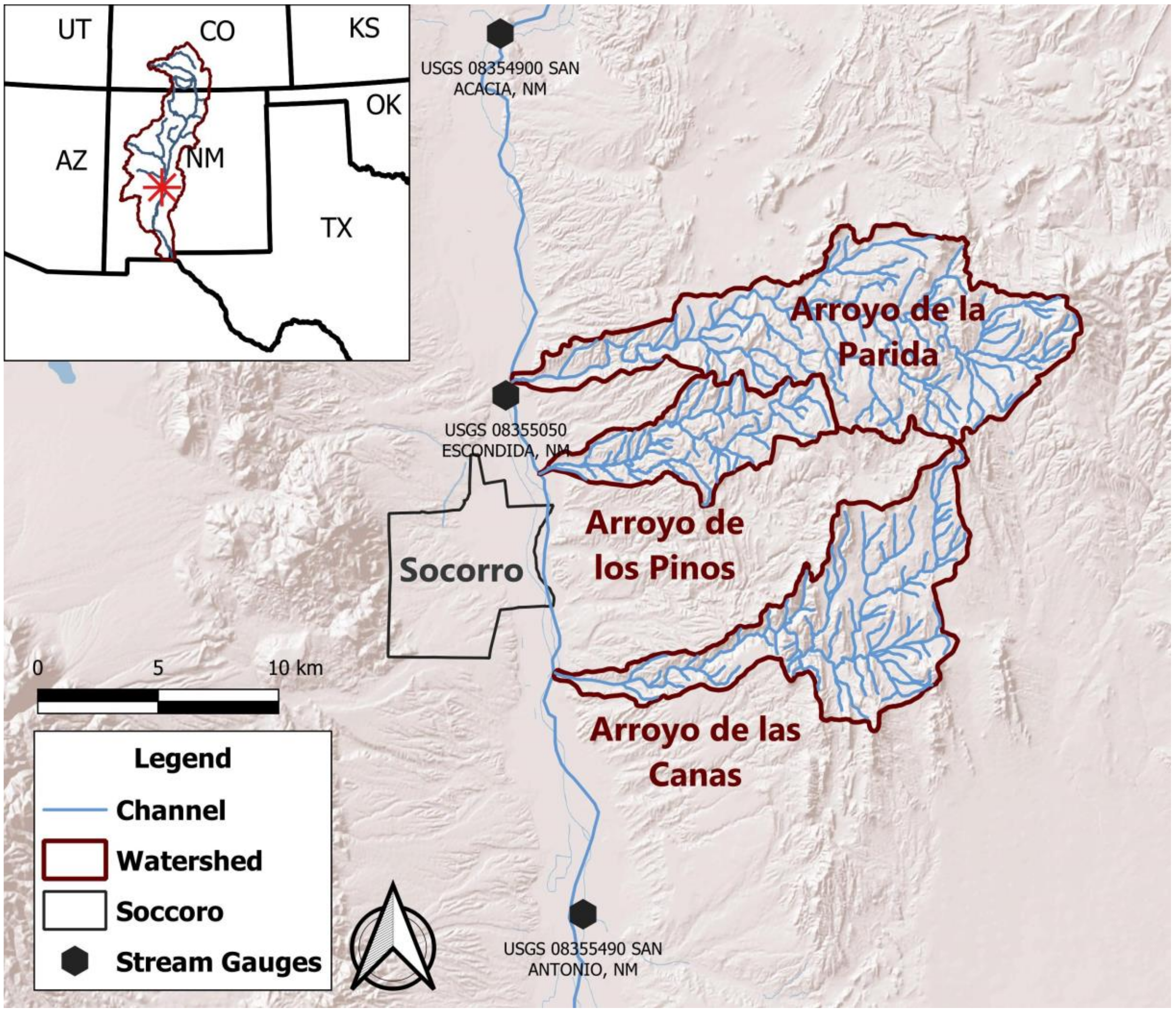

Figure 1: The watersheds of the three arroyos and their confluence with the Rio Grande near Socorro, NM. The USGS local stream gauges are also shown.

Methods

We studied the sedimentary characteristics and the temporally varying morphology of three ephemeral confluents of the mid-Rio Grande close to Socorro, NM: Arroyo de la Parida, Arroyo de los Pinos, and Arroyo de las Cañas, focusing on these tributaries *upstream of the confluence*. Trenching the confluent deposits, we identified bedding type and thickness. Using repeat drone flights and applying Structure from Motion (SfM), we generated orthophotographs and Digital Elevation Models (DEMs), from which we determined the temporally varying tributary morphology and estimated volumes of sediment storage from DEMs of Difference (Wheaton et al., 2010). A sensitivity study compared the three methods of change detection, choosing the optimal 95% confidence interval threshold for a Fuzzy Inference System.

Select Results

<u>Confluence of ephemeral tributaries</u>: The starting point for the study was to identify the confluence angles of an ephemeral tributary confluence with a major river. Field observations

and studies of air photos indicated that small ephemeral tributaries consistently enter the main streams at angles between 80 and 90 degrees (Miller, 1958). Later, Schumm (1961) described the confluence of various ephemeral channels, including that of the smaller Arroyo Frijoles into the Arroyo Calabasas near Santa Fe, NM. While the ephemeral Frijoles tributary remained dry, the larger Calabasas scoured a bar previously deposited by the Arroyo de los Frijoles, leaving the Frijoles high and dry above the Calabasas. This identified the non-contemporaneity of flow and sediment transport in the tributaries and the main stem, also identified in Australia (Bourke and Pickup, 1999) and Africa (Reid and Frostick; 2011). The distribution of fine materials at a tributary mouth suggested that there had been instances in the past where the mainstream flow dominated the confluence and led to slack water deposits on the tributary mouth (Wertz, 1966; Unde and Dakal, 2009;). Ephemeral tributaries to the Rio Chama, also in the mid-Rio Grande Basin, have a considerable sedimentary effect downstream (Swanson and Meyer 2014). That study, as essentially almost all studies on confluences, concentrated on the larger confluent. The few studies on ephemeral dryland channels have not considered the characteristics of the local channel confluences (Vyverberg, 2010).

Topographic changes took place in these tributaries depending on their width, confluence angle and upstream stable section. The Arroyo de la Parida was widened at its confluence by the Bureau of Reclamation. No topographic change was detected when only small events occurred, but several 2020 flash floods deposited sediment wedges up to 1 m thick, particularly in the southern, downstream edge. The Arroyo de las Cañas confluence comprises two outlets separated by a vegetated bar. Considerable (ca 1 m) deposition occurred in the northern, upstream outlet, whereas half as much deposition took place in the southern, downstream outlet, the latter having a smaller confluence angle with the Rio Grande, thereby facilitating the transfer of tributary sediment to the trunk. The Arroyo de los Pinos experienced a large flood on July 2018, generating extensive, 1 m scour throughout the lower 200 m reach and depositing large bars in the center of the Rio Grande. In subsequent flow events, the eroded channel slowly aggraded in its upstream reach, with local erosion in the downstream corner of the confluence.

The sedimentary deposits in the Arroyo de los Pinos confluence comprise lower clay overlain by fine sands and medium cross laminated sands, the latter overlain by slackwater and bank collapse clays. This succession is an indication that the Rio Grande's overbank deposition in the tributary mouth was generated by recirculatory flow (Picard and High, 1973). A similar succession was laid in the Parida confluence, with sandy-gravel at the bottom of the sequence and as much as seven intercalations of clay laminae overlain by cross-bedded sands. These may represent sequential deposition by slight changes in generally increasing Rio Grande water levels.

Conclusions

The available, sparse information on the confluence of ephemeral channels has been summarized. The outlet of ephemeral channels upstream of the main stem confluence is affected by main stem deposition of high concentrations of sediments, mainly sand bars. The tributaries transport large masses of sediment, inclusive of coarse gravel, thereby affecting the confluence of the main stem in times depositing large bars. The tributary area above the confluence is at times scoured by flash floods.

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