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Geomorphological analysis and evolution of an altered floodplain drainage system. The case of the Partido Stream (Spain)

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ABSTRACT

The Partido Stream is a small torrential course that flows into the marsh of the Doñana National Park, an area that was declared a World Heritage Site in 1994. Before 1981, floods occurred, and the stream overflowed onto a floodplain. As an old alluvial fan, the floodplain has its singular orography and functionality. From the floodplain, several drainage channels, locally called *caño*, discharged into the marsh. The Partido Stream had the morphology of a caño and covered approximately 8 km from the old fan to the marsh.

The stream was straightened and channelised in 1981 to cultivate the old fan. This resulted in floods that were concentrated between the banks in the following years, which caused the depth of water and the shear stress to increase, thus, scouring the river bed and river banks. In this case, the eroded materials were carried towards the marsh where a new alluvial fan evolved.

Control measures on the old fan were implemented in 2006 to stop the development of the new alluvial fan downstream over the marsh. Thus, the stream would partially recover its original behaviour that it had before channelisation, moving forwards in a new, balanced state. The present study describes the geomorphological evolution that channelisation has caused since 1981 and the later slow process of recovery of the original hydraulic-sedimentation regime since 2006. Additionally, it deepens the understanding of the original hydraulic behaviour of the stream, combining field data and 2D simulations.

1. Introduction

Torrential phenomena often have been underestimated by environmental managers, but the fact is that floods cause severe damage that affects settlements, roads and agricultural lands and causes loss of life, mainly on alluvial fans (Mayer et al., 2010). The morphology and dynamics of an alluvial fan are the result of the transportation of sediments by the water flow and their subsequent deposition. Thus, the processes we see on the alluvial fans are an outcome of the torrential activity of fluvial channels upstream (Gómez-Villar and Garcìa-Ruiz, 2000), which are caused both by strong gradients and a high capacity of sediment yield and transfer (Rachocki and Church, 1990). Alluvial fans generally occur at the base of mountains because of a change to gentle slopes and a reduction in the fluvial energy (Bull, 1979), but this is not the only place where these conditions occur. The Partido Stream shows evidence of torrential processes, and this can be observed in its morphology. The sediment taken from the riverbed and transported in contact with the riverbed is called bed load, and it is the part of the total load that forms the channel morphology. Thus, a precise assessment of the sediment transport is essential to predict changes in the morphology of the channel and to plan any functional interaction with torrential courses. To obtain bed load transport estimation, a calibration from laboratory data or specific measurements from the fluvial courses that are studied is required. The absence of such data reduces the possibility of a reliable application of the equations, which often overestimate sediment transport rates by one or more orders of magnitude. Additionally, sedimentation rates are specified only when sediment availability and supply are unlimited (Gomez, 2006). A direct measure of the bed load transportation requires a large effort, and it is difficult to carry out field work, especially during flooding events. Recently, developments have been achieved to establish advanced field methods for the direct and indirect quantification of bed load transportation (Bunte and Abt, 2005; Laronne et al., 2003; Rickenmann and McArdell, 2007). Moreover, representative parameters of the phenomenon are difficult to obtain because of the spatial and the temporal variability of transportation (Gomez, 1991). An alternative to assess bed load transportation rates from point data over a period of time is the use of a morphological approach. This is conducted by measuring erosion and deposition volumes in a certain period of time (Ham and Church, 2000; Lane et al., 1995; Martin, 2003; McLean and Church, 1999). This approach is also suitable for the application of bed load sediment equations on long spatiotemporal scales (Carson and Griffiths, 1987; Martin, 2003; Nicholas, 2000). Recently, Pelpola and Hickin (2004) estimated the volumetric expansion of a small lacustrine delta using sequential aerial photography, bathymetry and ground penetrating radar over a period

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of 52 years, confirming the effectiveness of the morphological approach.

In this context, the present study exposes the changes that arose when a tributary fluvial course formed a large alluvial fan over the marsh of Doñana National Park (DNP), a protected area that was declared a World Heritage Site in 1994. Previously, an extensive surface of 20 km^2 north of the marsh was modelled as a large alluvial fan that was made by the flooding of the Partido Stream and the Parrilla Stream. As a consequence of the transformation of this area for intensive cultivation in 1981, the Partido Stream was straightened and channelised 8 km upstream from its mouth in the DNP's marsh (see Fig. 1). This caused serious problems, from the destabilisation of the original drainage system with the erosion of the newly channelised bed and banks to the formation of a new alluvial fan over the marsh and next to El Rocío village by the deposition of the eroded sediments from the channelisation.

To solve the sedimentation problems, hydraulic measures on the old alluvial fan were implemented in 2006 within the framework of Intervention 3, which is part of a comprehensive recovery programme project of the hydrologic and hydraulic regime of the DNP marsh, also known as the Doñana 2005 Project (D2005P). Grade controls, such as small check dams, are underscored by studies as effective measures used for mediation in channel evolution (Hawley et al., 2012), making them appropriate for our study site. The aim of the measurements is to partially return the Partido Stream to its original performance and to avoid the advance of the new alluvial fan over the marsh. Within 2006–2010, the Partido Stream again returned in part to its former regime, and the area affected by Intervention 3 has been stabilising and recovering the ecological conditions that were present before the channelisation.

This study deepens in the local morphology from a new perspective and with tools that complement previous works and enrich the research. The effects of geotorrential phenomenon causes are closely related to the local geomorphology. In that line, this work contributes markedly for the knowledge of the landforms and how floods behave on them.

2. Objectives

The objectives of this study are

1) To investigate the natural behaviour that the drainage system of the area had before it was modified with channelisation in 1981 (situation A) and to highlight the importance of the geomorphologic elements.
2) To present the geomorphology and hydraulic evolution that the area has experienced in the periods between civil engineering works; this is once the stream was channelised (situation B) and once the recovery hydraulic measures were implemented in 2006 to control future floods of the Partido Stream (situation C).

3. Study site

The Partido is a 39-km-long stream located in the southwest of Spain (province of Huelva, Andalusia) with a gentle slope of 0.0017 m·m^{-1} (Mintegui et al., 2003, 2006) which flows towards the north of the DNP marsh (see Fig. 2). Both the channel and the floodplain at the

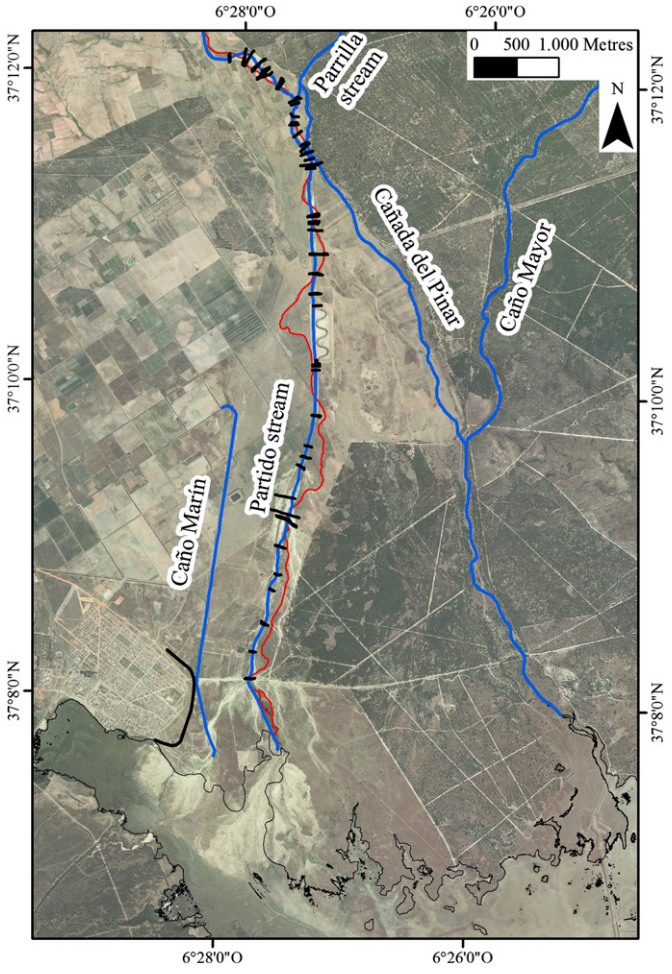

Fig. 1. Main watercourses in the area on a 1998 photograph: the channelised Caño Marín is to the west, the Partido Stream is from northwest, the original stream in red and the channelised in blue, the Parrilla Stream is in the north centre, the Cañada del Pinar extends from the Parrilla Stream to Caño Mayor, and Caño Mayor is from northeast. The artificial recovery meandering course that has been newly built in shown in the centre of the image, the protection wall of the El Rocío village in the southwest is shown in black, the measured cross sections from s100 upstream to s74 downstream are shown, the limit of the marsh before 1981 is shown (black line), and the new alluvial fan that has built up over the marsh is shown (light sands).

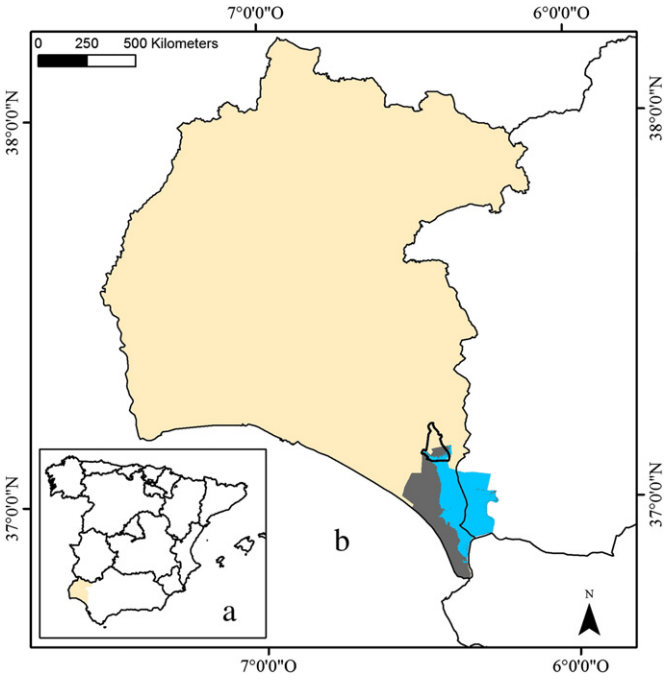

Fig. 2. a; Huelva province in southwestern mainland Spain. b; Study area (black perimeter) in the Huelva province (coloured), Doñana National Park (grey and blue) and the Doñana marsh (blue). Sevilla Province is to the east and Cádiz Province is to the southeast.