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Morphological impacts of flow events of varying magnitude on ephemeral channels in a semiarid region

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ABSTRACT

Flows in ephemeral channels in semiarid areas are only occasional, and channel changes are episodic; but the flash floods can be devastating and have major geomorphological impacts. Data on morphological impacts of flows in semiarid areas are needed to increase understanding of the dynamics and variability of geomorphic responses in such channels. For this purpose nine reaches of river channel in three catchments in SE Spain – the Nogalte, Torrealvilla, and Salada – have been sites for measurement of flows and their effects over the period 1997–2012. The sites encompass a range of channel size, channel morphology, substrate, vegetation, and position within the catchments. A major difference is between schist and marl bedrock areas. Peak flow stage has been recorded and topography surveyed at frequent intervals and after major flow events. Over the 16-year period, an average of 0.5 flow events per year has been recorded at the schist sites, and an average of one per year at the marl sites; but occurrence has been highly variable from year to year. Threshold daily rainfall for channel flow is mostly 15–20 mm, but higher rainfalls do not always produce flow. One to two major floods have occurred in each of the catchments in the period, including the extreme flood event of September 2012 in the Nogalte catchment. Measured morphological changes have occurred between 2 and 10 times at the monitored sites. The same size flow can have differing effects depending on the state of the system. Low flow can mobilise sediment without producing much morphological change. The long-term trajectory of the reaches and the sediment substrate has a major influence on response to events. Channel change is governed by threshold values of hydraulic conditions. The measurements provide an indication of the scale of maximum erosion and deposition that occurs within the channels and on the floodplains over a range of flow magnitudes and the flow impacts that need to be considered in management.

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1. Introduction

Many semiarid fluvial systems are highly dynamic and episodic in behaviour. The climatic setting commonly produces flash floods during which most of the morphological change and sediment flux occurs. These floods are also hazardous events that can produce fatalities and damage to infrastructure. Therefore, understanding of the natural functioning and variability of semiarid fluvial systems is important in terms of landscape dynamics and for management purposes. Data are needed on flow impacts, morphological change, and sequences; however, the infrequency of flow events in the semiarid environment makes data collection particularly challenging, resulting in sparsity of such data. A series of sites was established on ephemeral channels in semiarid SE Spain to provide data that could be used to increase understanding of processes and dynamics in such systems and to provide quantitative data that can be used in modelling and management. In this paper the morphological changes and their relation to the occurrence and characteristics of flows of various magnitudes over a period of 16 years are analysed.

Will Graf made major contributions to understanding processes and dynamics of dryland channels, particularly aspects of sediment dynamics (Graf, 1983b, 1987, 1990, 1996), morphological change and channel instability (Graf, 1981, 1982, 1983a, 1984), and vegetation impacts (Graf, 1978), as well as to the conceptualisation of changes and flow impacts (Graf, 1977, 1979, 1988a). He analysed the influences of various factors, including roughness and vegetation, on the dynamics of ephemeral channels and produced methods of modelling and prediction of the dynamics at various timescales. Much of the state of knowledge at the time was synthesised in the text on *Fluvial Processes in Dryland Rivers* (Graf, 1988b). The morphodynamics and key distinctive characteristics of dryland channels have also been discussed by Thornes (1976, 1977, 1980), Tooth (2000), Hooke and Mant (2002), Powell (2009), and Reid and Frostick (2011).

Basic to our understanding of ephemeral channel dynamics is knowledge of the conditions for generation of flows and thresholds of rainfall for runoff and floods (e.g., Beven, 2002). Research on runoff generation, especially in SE Spain, has given new insights into the spatial distribution and characteristics of the major generating areas (e.g., Cammeraat, 2004; Bracken and Kirkby, 2005; Kirkby et al., 2005; Reaney et al., 2007; Smith et al., 2010; Cantón et al., 2011) and on the

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relationship to rainfall and storm properties (e.g., Bracken et al., 2008), showing the importance of bare rock and low infiltration areas for runoff generation and the complex relationship of flow discharge to rainfall amounts and intensity. Short bursts of high intensity rainfall tend to produce the largest flows especially if these occur after a prolonged wet period (Bull et al., 1999).

Frequencies of floods and longer-term occurrence have been analysed for the region using sedimentological and historical records (Conesa-García, 1995; López-Bermudez et al., 2002; Benito et al., 2010; Machado et al., 2011) and indicate an increase in flood frequency since about A.D. 1500 to the mid-twentieth century. Since then the frequency of floods has decreased and the variability of floods has increased. Morphological data on the impact of flood events in semiarid areas are still lacking especially for a series of events over more than a few years. Impacts of some individual flood events have been documented including an event on a channel similar to one analysed here that demonstrated the effects of confinement on channel response (Harvey, 1984). Hooke and Mant (2000) analysed the impacts of a flood event in 1997 on the same channels in SE Spain as those included in this paper, providing a baseline for comparison. Ortega and Garzón Heydt (2009) examined the spatial variability and relation to flow characteristics of deposits from a flash flood in western Spain. Other events in the Mediterranean region for which large morphological impacts have been measured include that of Ouvèze (Arnaud-Fassetta et al., 1993; Wainwright, 1996) in southern France and events in the more arid area of Israel (Schick and Lekach, 1987). Some longer-term sediment flux records do exist, notably for Walnut Gulch in Arizona (Nichols et al., 2008), Nahel Yatir and Nahel Eshtemoa and other channels in Israel (Schick and Lekach, 1993; Reid et al., 1995; Cohen et al., 2010), and for NE Spain (Batalla et al., 2005). Intensive measurements of bedload and suspended sediment at these instrumented sites provide insights into intraevent and interevent dynamics (e.g., Batalla et al., 2005; Alexandrov et al., 2007; Cohen et al., 2010). Rhoads (1990) calculated sediment transport dynamics for a small desert stream in Arizona from a 24-year stream record. Spatial dynamics of runoff and sediment flux have been increasingly examined under the concept of connectivity (Hooke, 2003, 2004; Smith et al., 2010), illuminating channel reach response to floods (Hooke, 2015). The impact and feedback effects of vegetation on channel processes and changes were recognised by Graf (1978), and recent studies have demonstrated their influence on and interaction with flow events in many channels, including those in Spain (Puigdefábregas, 2005; Sandercock and Hooke, 2010, 2011).

Many models exist for runoff and soil erosion in drylands, but few exist for modelling processes and morphological impacts in ephemeral dryland channels. Graf (1996) modelled sediment transfer in dryland channels, and Hooke et al. (2005) produced a model to simulate morphological impact and change, which is one of few models to have incorporated the vegetation and morphological feedbacks.

Conceptualisation of morphological changes and the extent to which channels in semiarid and arid environments are in disequilibrium has been much debated, (e.g., Thornes, 1977; Wolman and Gerson, 1978; Graf, 1988b; Rhoads, 1990; Bull, 1997; Tooth and Nanson, 2000, 2011; Nanson et al., 2002; Dean and Schmidt, 2013), with Rhoads (1990) recognising that equilibrium and disequilibrium elements of the morphology could be present at one time. Patterns of adjustment and rates of recovery to flood events are influenced by sequencing and spacing in time (e.g., Beven, 1981), with some events building on one another to produce ramped or cumulative effects and continued transience (Brunsden and Thornes, 1979). Carling and Beven (1989) considered sequencing of events, together with sediment availability, as important as magnitude in determining flood impact and that the effectiveness of sequences is associated with complexity. Assessment of the relative contribution in the long-term of different events begs the question of how to define the size of an event in relation to its impacts. Kochel (1988) used the definition of large events as >50-y RI (recurrence interval), and Conesa-García (1995) classified events in ephemeral channels of SE Spain into four classes according to flow level and impact. Absolute magnitude may not be the key factor; instead, size in relation to mean annual flow or mean annual flood may be more important (Schumm, 1977; Kochel, 1988; Cenderelli and Wohl, 2003). Alternative measures to peak discharge may have a closer relationship to flood impact, such as peak stream power, total shear stress or unit (specific) stream power (Baker and Costa, 1987; Miller, 1990; Magilligan, 1992), or total discharge and total stream power (Huckleberry, 1994; Costa and O'Connor, 1995). Duration has also been shown to have a large effect (Huckleberry, 1994; Costa and O'Connor, 1995; Dean and Schmidt, 2013). Feedback effects of morphological changes and sequences of events have not generally been used in flood risk modelling applied to management (Neuhold et al., 2009; Hooke, 2015).

Ephemeral semiarid channels pose particular problems of management because of their changeability, episodicity of dynamics, and the dangerous and destructive nature of flash floods. The Mediterranean region is especially vulnerable because of its propensity for high intense rainfalls in certain areas (e.g., Wainwright, 1996), its relatively high population density and degree of development compared with some other drylands, and the long history of settlement and land use which has produced major soil erosion and environmental impacts (Wainwright and Thornes, 2004; Woodward, 2009). Human impacts on fluvial systems and problems of management in the region are well documented (Poesen and Hooke, 1997; Wainwright and Thornes, 2004; Hooke, 2006; and many others). Impacts of specific strategies have been analysed, particularly the effects of check dams on fluvial systems (Boix-Fayos et al., 2007; Castillo et al., 2007). The RECONDES project suggested more sustainable methods of erosion and sediment flux control by use of vegetation (Hooke and Sandercock, 2012).

This paper analyses the morphological changes taking place in a range of channel reaches in SE Spain and their relation to occurrence and characteristics of flows of various magnitude over a period of 16 years. The objectives are to quantify the flow regime and number of flow occurrences of various magnitude in these ephemeral channels; to identify the number of events that produce morphological change and the thresholds for processes of channel erosion and deposition; to quantify the amount, locations, and nature of morphological change, e.g., bed incision, bank erosion, bar deposition; to analyse the within-site, between site, and temporal variability of response to events; to examine the relations of morphological change to the hydraulic characteristics of each event; to consider the effects of sequencing of events and of reach characteristics on response to flow events over the monitoring period and trajectories of channel change; and to assess the overall contribution and effectiveness of events of different magnitude to the morphological changes in these channels.

2. Study area and methods

This paper is based on analysis of data acquired in nine reaches on channels in the Guadalentín basin in SE Spain (Fig. 1) in the period January 1997–January 2013. These monitored sites were established to provide data for parameterising and validating a model being constructed to simulate the morphological effects of flows under various scenarios of climate and land use change as part of the MEDALUS III EU project. The research was motivated by concern about desertification and its likely increase in southern Europe. The model constructed, CHANGISM, involved the interactions of flow processes, sediment flux, and vegetation to produce the spatial patterns and magnitudes of erosion and deposition in channel reaches (Hooke et al., 2005). The Guadalentín catchment is situated mainly in Murcia Province in SE Spain (Fig. 1). Reaches 150–200 m long were established in the upper, middle, and lower parts of three subsystems: the Nogalte (sites Nogalte 1, Nogalte 2, and Nogalte Mon), Torrealvilla (sites Oliva, Aqueduct, and Serrata, then replaced by Pintor), and Salada (sites Salada 1, Salada 2, and Salada 3) (Fig. 1). Consistent methods of measurements were applied to each site (Hooke, 2007). The Nogalte is in schist bedrock, and

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