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Geomorphic effects, flood power, and channel competence of a catastrophic flood in confined and unconfined reaches of the upper Lockyer valley, southeast Queensland, Australia

Chris Thompson [a,b,*], Jacky Croke [b]

[a] Centre for Integrated Catchment Assessment and Management (ICAM), The Australian National University, Canberra ACT 0200, Australia
[b] Australian Rivers Institute, Griffith University Nathan Campus, Queensland 4111, Australia

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ABSTRACT

Flooding is a persistent natural hazard, and even modest changes in future climate are believed to lead to large increases in flood magnitude. Previous studies of extreme floods have reported a range of geomorphic responses from negligible change to catastrophic channel change. This paper provides an assessment of the geomorphic effects of a rare, high magnitude event that occurred in the Lockyer valley, southeast Queensland in January 2011. The average return interval of the resulting flood was ~2000 years in the upper catchment and decreased to ~30 years downstream. A multitemporal LiDAR-derived DEM of Difference (DoD) is used to quantify morphological change in two study reaches with contrasting valley settings (confined and unconfined). Differences in geomorphic response between reaches are examined in the context of changes in flood power, channel competence and degree of valley confinement using a combination of one-dimensional (1-D) and two-dimensional (2-D) hydraulic modelling. Flood power peaked at 9800 W m^{-2} along the confined reach and was 2–3 times lower along the unconfined reach. Results from the DoD confirm that the confined reach was net erosional, exporting ~287,000 m^3 of sediment whilst the unconfined reach was net depositional gaining ~209,000 m^3 of sediment, 70% of the amount exported from the upstream, confined reach. The major sources of eroded sediment in the confined reach were within channel benches and macrochannel banks resulting in a significant increase of channel width. In the unconfined reach, the benches and floodplains were the major loci for deposition, whilst the inner channel exhibited minor width increases. The presence of high stream power values, and resultant high erosion rates, within the confined reach is a function of the higher energy gradient of the steeper channel that is associated with knickpoint development. Dramatic differences in geomorphic responses were observed between the two adjacent reaches of contrasting valley configuration. The confined reach experienced large-scale erosion and reorganisation of the channel morphology that resulted in significantly different areal representations of the five geomorphic features classified in this study.

1. Introduction

Flooding is a persistent threat to both human life and infrastructure globally (Baker et al., 1988). Even modest changes in climate are thought to lead to large increases in flood magnitudes (Knox, 1993, 2000; Macklin and Lewin, 2003), the extent of which remains largely unknown in many parts of the world including Australia. Here, evidence of extreme flood magnitudes during the Pleistocene and Holocene has come from limited slackwater and paleostage studies in parts of northern and central Australia (Wohl, 1992; Nott and Price, 1999; Pickup et al., 2002; Jansen and Brierley, 2004). A number of studies have also reported on the magnitude and geomorphic change resulting from rare floods (~100-year average return interval: ARI) in populated parts of eastern Australia (e.g., Nanson, 1986; Erskine, 1993; Erskine and Saynor, 1996) over the last century that describe changes to channel geomorphology ranging from minor to catastrophic. The degree of change has been related to decadal shifts from drought- to flood-dominated regimes (Erskine and Warner, 1988, 1998; Warner, 1997), land use change (Brooks and Brierley, 1997; Kirkup et al., 1998), and a recent flood history that has preadjusted the channel such that subsequent threshold-exceeding events have less impact (Erskine, 2011).

Continuing research has advanced our understanding of the role of key drivers of geomorphic change such as flood power (Kale, 2008), flood competence (Jansen, 2006), sequencing of flood events (Magilligan et al., 1998), and spatial changes in valley floor configuration (Fuller, 2008; Cheetham et al., 2010). A review of these studies also suggests that the spatial scale of investigation may also influence interpretations of the geomorphic effectiveness of specific flood events

* Corresponding author at: Centre for Integrated Catchment Assessment and Management (ICAM), The Australian National University, Canberra ACT 0200, Australia. Tel.: +61 737357963.
E-mail address: Chris.Thompson@griffith.edu.au (C. Thompson).

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with many conclusions derived from reach-scale planform change surveys and limited cross sections. Such approaches can limit detailed understanding of spatial changes in erosion and deposition processes and of the transfer or redistribution of material fluxes between reaches. It remains uncertain, therefore, if river reaches that experience dramatic geomorphic change are representative of the 'overall' geomorphic response or one end of the response spectrum that occurs in localised areas. The factors that may play a role in conditioning the system to a particular response are therefore often difficult to elucidate.

Recent technological advances now make it more tangible to address these issues across larger spatial scales. The increasing availability and use of high resolution topographic data has opened up the possibility of more rapid and spatially extensive assessments of flood-related geomorphic change. For example, Airborne LiDAR (light-induced direction and ranging) data are increasingly used in fluvial geomorphology, including the mapping of gravel-bed rivers (Charlton et al., 2003), defining the boundary layer for hydraulic modelling (French, 2003; Aggett and Wilson, 2009; Kermode et al., 2012), and determining channel heads and stream networks (Sun et al., 2011, 2012). The contribution of this technology over the more traditional at-a-site and planform surveys is unquestionable from a practical flood risk perspective and from improved understanding of spatial variability in geomorphic processes.

This paper presents an assessment of the geomorphic effects of a rare high magnitude event that occurred in the Lockyer valley, southeast Queensland (SEQ) in January 2011 using a combination of one- (1-D) and two-dimensional (2-D) flow hydraulic modelling and morphological budgeting using a multitemporal LiDAR-derived DEM of Difference (DoD). This study tests the hypothesis that differences in geomorphic response between the selected confined and unconfined reaches can be explained in terms of relative differences in flood power, channel competence, and degree of valley confinement.

2. Study area

The Lockyer valley falls to the east of the city of Toowoomba, which lies on the Great Dividing Range and marks the catchment divide from the Murray–Darling basin (Fig. 1). The Lockyer catchment drains nearly 3000 km^{2}of prime agricultural land in southeast Queensland (SEQ). Southeast Queensland is a subtropical region with mean maximum monthly temperatures ranging between 21 and 29 °C. The total annual rainfall ranges between 900 and 1800 mm, with the majority falling during the warm summer season (October to February) (Bureau of Meteorology, BoM, 2012). The region is characterised by seasonally variable patterns of floods and droughts that have been linked to the interannual rainfall variations of the El Niño–Southern Oscillation

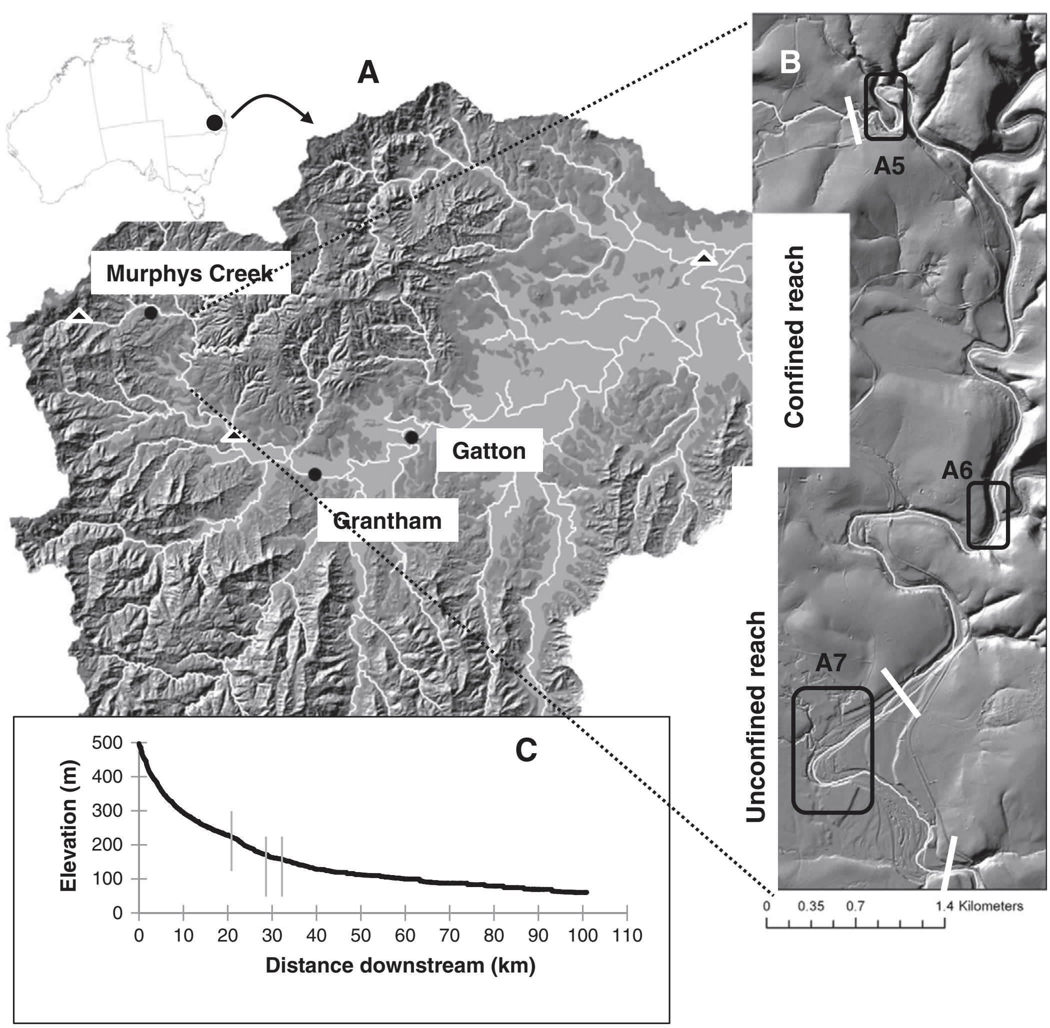

Fig. 1. The Lockyer catchment in eastern Australia showing (A) Gatton, the largest town in the catchment and the communities of Murphys Creek and Grantham that were severely impacted by the flood with numerous lives lost. The three triangles represent locations of gauging stations Spring Bluff (upper), Helidon (mid), and Rifle Range Road (lower catchment). (B) The location of the two adjacent study reaches is displayed on the LiDAR-derived DEM with field survey sites A5, A6, and A7 marked. (C) The longitudinal profile of Murphys and Lockyer Creeks with upper mark showing knickpoint and start of the confined reach, the transition into the unconfined reach, and final mark indicating the end of the study site.