Geomorphic impact of the January 2011 flood on Murphys Creek, southeast Queensland

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Key Points

- The relative magnitude and frequency changed dramatically from the top to the bottom of the Lockyer catchment
- The geomorphic setting of lower Murphys Creek exposed the channel to extreme values of stream power
- Scouring of channel banks and benches along the confined channel resulted in a 3-fold increase in channel width and a net export of 476 188sediment from the reach

Abstract

Murphys Creek is one of the main headwaters of the Lockyer Catchment and was subject to the devastating January 2011 floods in southeast Queensland. Rainfall leading to the event had a moderate-high return interval, however, the already wet catchment resulted in very high rainfall-runoff coefficient causing flash flooding. This paper uses gauging station data, pre- and post-flood LiDAR data and modeling to evaluate the flood peak hydraulic characteristics and predict flood peak transport capacity. Major channel change occurred throughout the confined reach with benches stripped and channel banks eroded. Channel width increased up to three times pre-flood width. Peak unit stream powers reached 4700 W m^{-2} at points along the confined channel but do not appear to be high enough to entrain and deposit the exposed boulders (>2m in diameter) evident on the channel bed after the flood. The relatively high degree of channel change in this reach is due to not only to the confined valley setting in which floodwaters remain concentrated, but also to the high energy gradient of the reach and the proximity to source of the rainfall in the headwaters of the catchment.

Keywords

Lockyer Valley, extreme flood, channel change, modeling, sediment dating.

Introduction

It has been postulated that modest changes in climate have lead to large increases in flood magnitudes (Knox, 1993; 2000; Macklin and Lewin, 2003). The possible extent of such increases in magnitude remain largely unknown in Australia with much of our knowledge on extreme floods coming from studies based on slackwater deposits and paleostage indicators associated with large bedrock channels in the northern hemisphere (eg., Baker, 1973; Church, 1978; Costa, 1983; House et al., 2002). A limited number of such studies have been undertaken in Australia, largely confined to the north (Wohl, 1992; Nott and Price, 1999) and central Australia (Pickup et al., 2002; Jansen and Brierly, 2004).

A number of studies have reported significant channel change as a result of moderately large floods (~100 yr ARI) in populated parts of eastern Australia (eg. Nanson, 1986; Erskine, 1993; Eskine and Saynor, 1996). these studies indicated that such catastrophic channel change was based on allogenic factors (external to the catchment) and notably the occurrence of the 3-5 decadal shift between flood-dominated and drought-dominated regimes (Eskine and Warner, 1988; 1998; Warner, 1997) . Others suggest the catastrophism is a result of the effects of historic land use change superimposed on the cyclical hydrological regime (Brooks and Brierley, 1997; Kirkup et al., 1998).

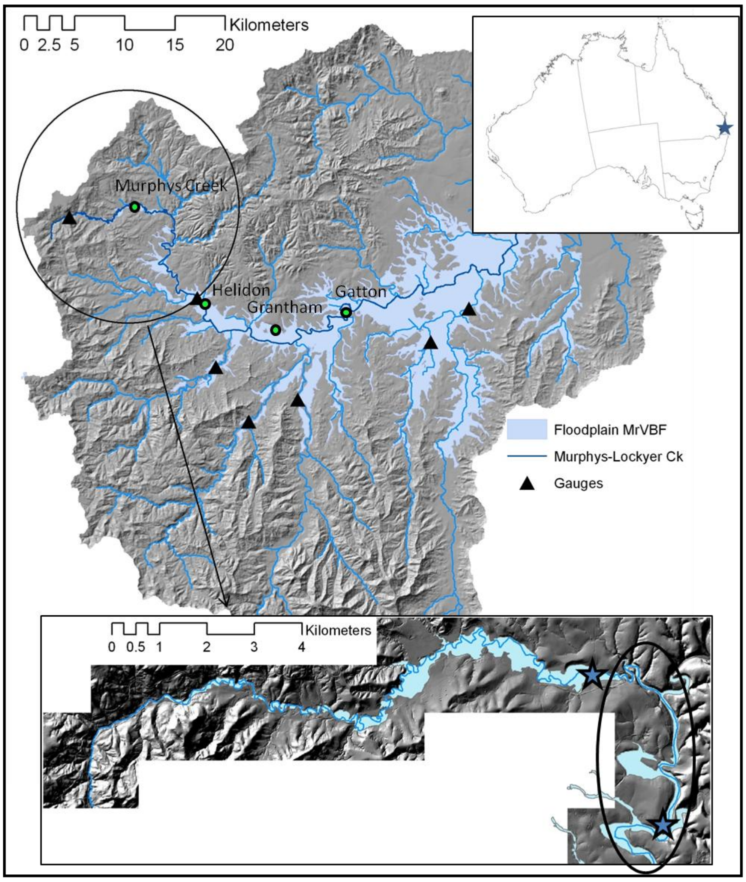

Figure 2. Lockyer valley catchment in southeastern Queensland. The circled area in main figure shows Murphys Creek catchment. The bottom insert shows Murphys Creek with the circled area marking the lower confined segment. The stars indicate the locations of representative reaches A4 (top) and A6 (bottom).

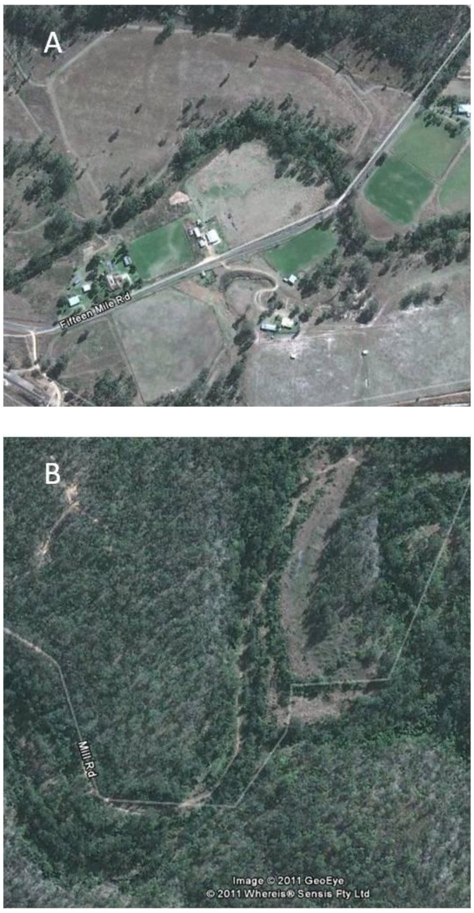

Figure 1. Pre-flood aerial images of sites (A) A4 and (B) A6. Source: Goggle Earth.

This paper reports on a large-to-extreme flood in southeast Queensland and provides a preliminary assessment of the geomorphic impacts of the event along a section of channel that has experienced minimal land use change both relative to the rest of the catchment, and previous research on catastrophic channel change in eastern Australian. The specific aims of the paper are to determine(a) the relative magnitude and frequency of the event, (b) the flood peaks energy for doing work (stream power), and (c) the nature and extent of geomorphic change within the study reach.

Study Area

The Lockyer Valley lies to the west of Brisbane and extends to the Great Dividing Range which marks the catchment divide from the Murray-Darling Basin near the town of Toowoomba . The Lockyer catchment drains nearly 2976 km^{2}of prime agricultural land in southeast Queensland. Murphys Creek forms the headwater tributary (235 km^2, Figure 1) and is characterized by steep and mainly forested terrain relative to the extensive alluvial floodplains of Lockyer Creek downstream.

This paper focuses on a 30 km section of Murphys Creek from the Spring Bluff gauging station down to the Alice Creek tributary junction where it becomes officially known as the Lockyer Creek. This study section is divided into two geomorphologic segments. The first is Upper Murphys Creek (~20 km long) which flows east from the escarpment and contains the community of Murphys Creek. The channel meanders through an expanding valley bottom with increasing floodplain width. The valley bottoms tend to be cleared of trees for cattle grazing (Fig. 2A). geomorphic features in this segment are represented aerially as approximately 60%

floodplain, 26% channel bank (including inner active channel bank and an out macrochannel bank), 10% alluvial benches formed between the inner and out banks, and 4% is active channel bed. The second is a lower confined segment which is forced to flow south due to the resistant sandstones of White Mountain and the steeply undulating area comprising of White Mountain State Forest. The channel is predominantly a confined bedrock channel with a coarse alluvial cover. It flows between hillslopes of native eucalypt woodland/forest and has well intact riparian vegetation (Fig. 2B). The tributary of Fifteen Mile Creek, with a catchment area of 91 km^2 also joins Murphys Creek along the confined segment and the section terminates with the confluence of the 60 km^2 Alice Creek. Morphology type and extent along this segment include ~15% active channel bed, 13% inner channel banks, 23% bench and 22% floodplain. The floodplain areas are mainly derived from two large meanders with expansive deposition areas on the outside of the bend.

The January 2011 event

A detailed synopsis of the events meteorology and hydrology is provided by Jordan (2011). In summary, a strongly La Nina event had lead to a wet summer and in the days leading to the event 20 to 30 mm had fallen across the catchment. On the day of the event, the soils were saturated and a number of massive storm cells converged and moved across the top of the catchment and intensified further due to the orographic effect. Recorded rainfall intensities in Toowoomba had annual exceedance probabilities of 18 years for 10 minutes duration, 200 years for 30 minutes duration and 370 years for 60 minutes duration.

Methods

Field surveys of the study reach were undertaken in May 2011 as part of the Lockyer Valley catchment survey for validation of Light Detection And Ranging (LiDAR) data (see Croke et al., this vol). LiDAR data acquired in 2009. LiDAR imagery was acquired immediately after the flood in January 2011. The two LiDAR datasets enabled computation of elevation differences resulting from erosion or deposition of sediment from the flood.

Modeling of flood peak inundation extent and flood competence was conducted using the 1-dimensional step backwater model HEC-RAS. Data preprocessing was completed using HEC-GeoRAS based on pre-flood LiDAR derived DEM. The HEC-RAS model was set up to cover 100 km length of Murphys-Lockyer Creek extending from Spring Bluff (GS# 143219C) down to near Rifle Range Road (GS# 143210B) which lies approx 22km east of Gatton. This length consisted of 8 reaches along Murphys Creek, 5 reaches along Lockyer Creek and 12 significant tributaries which formed the junction points between mainstem reaches. Channel and overbank Mannings *n* values were based on tables and ranged from 0.04 in the lower catchment to 0.06 on the confined reach. Input discharge values for each reach and tributary modeled are based on a discharge-area function derived from Lockyer catchment gauging stations measures of the peak flood discharge.

To predict whether the flood was competent to mobilize all channel bed material, the 10 largest boulders on the channel bed near site A6 were measured across their b-axis. Given the size of the boulders and their resting angle in the channel, accuracy in the measurement of the b-axis measure will be reduced. Competence was predicted using Costa's (1983) regression equation for predicting critical unit stream power ($\omega_c = 0.03D^{1.686}$, Wm^{-2}) and also using his conservative lower envelop curve ($\omega_c = 0.009D^{1.686}$, Wm^{-2}).

Results and discussion

Magnitude and frequency of January 2011 event

The approximate magnitude of the January 2011 event was captured by the gauging stations along the course of the mainstem until they failed near the flood peak. The Spring Bluff gauge measured 361.5 m^{3}s^{-1} at 13:40 on 10/1/2011, Helidon measured 3642 m^{3}s^{-1} at 15:10 on 10/1/2011 and Rifle Range Road gauge measured

1453.2 m^3s^{-1} at 16:20 on 11/1/2011. The distance between the stations is approximately 36.3 km and 72.8 km respectively which gives average transmission speeds of the flood peak of 24.2 kmh^{-1} between Spring Bluff and Helidon gauges. This reduces to 2.9 kmh^{-1} between Helidon and Rifle Range Road gauges. While there is uncertainty in these absolute values based on upper tributary contributions, the relative differences show a stark difference between the Murphys Creek and upper Lockyer Creek compared with the mid to lower Lockyer Creek flood wave propagation. The slowing flood wave speed and diminishing flood peak also indicates that most of the runoff was derived from the steeper headwaters.

Estimates of the average return interval (ARI) of the January flood based on the Log Pearson type III (LP3) analysis of the annual flood series show a significant increase in return frequency with distance downstream. At Spring Bluff gauge, the ARI is >>1000 years, while at Helidon it's approximately 80 years and at the Rifle Range Road gauge the ARI decreased to approximately 27 years. The estimates of event ARI based on LP3 yield similar values to the statistical metrics calculated by Rustomji et al. (2009) and applied to the annual maximum flood series and the flood peaks-over-threshold data. Rustomji et al. (2009) statistics indicated the event at Helidon to have a slightly higher ARI (~100 years) while at Riffle Range Road the ARI decreased slightly (~20 years). Regardless of the statistical methods used they are based on only two-to-three decades of record. Anecdotal information extends the big flood record back to the 1890s but this still remains a relatively short and climatically stable period of record to judge event average return interval (Kershaw & Nanson, 1993; Nott & Price, 1999).

Longitudinal Trends in Stream Power

The longitudinal profile of Murphys Creek displays a notable knickpoint at ~19 km downstream from the Spring Bluff gauge between the towns of Murphys Creek and Helidon (Fig. 3). HEC-RAS modeling of the flood peak discharge along the mainstem illustrates the rapid increase in magnitude and variability of unit stream power which reaches a peak of 4700 Wm^{-2} coincident with the top of the knickpoint and extending down through the confined section (Fig. 3).

The location of the knickpoint is significant because it lies at a distance downstream that is theoretically described as having relatively high total and unit stream power for a conventional concave longitudinal profile stream (Knighton, 1999; Fonstad, 2003). Hence, the knickpoint, and the associated increase in energy slope, has a multiplicative impact on stream power. The result is a nonlinear downstream unit stream power profile as reported for quite a number of other rivers around the world and in Australia (eg. Lecce, 1997; Reinfelds et al., 2004). Knickpoints occurring along rivers in the 10-100 km downstream distance range can produce extremely high unit streams power during floods which translate to river reaches exposed to potentially high morphological and ecological disturbances (Bendix, 1999; Thompson et al., 2008).

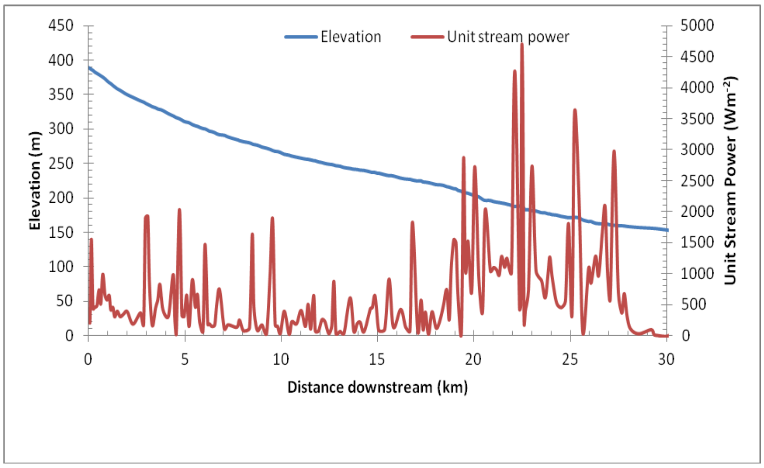

Figure 3. Longitudinal profile of elevation and unit stream power of Murphys Creek.

Channel change in the Study Reach.

Channel change occurred throughout Murphys Creek but, it was particularly significant along the confined section. The observed changes were generally restricted to within the main macrochannel. The overall channel alignment remained unchanged except for the development of some flood chutes across point bars. Figure 4 illustrates post-flood aerial images of sites A4 and A6 for comparison. Site A4 from the upper Murphys Creek segment shows little change (*c.f.* Fig. 2A). Site A6 shows significant change with all of the vegetation removed from within the macrochannel and a clearly visible wider channel bed (*c.f.* Fig. 2B).

Based on the difference in surface elevation between the 2009 and 2011 LiDAR DEMs, the upper Murphys Creek section had a mean elevation loss of 0.06 m which equals 63.3 t/ha of material eroded (Table 1). This primarily came from the marochannel banks and benches. The confined section had a mean decrease in elevation of 0.28m which equaled 595.2 t/ha of eroded material (Table 1). Here, benches were eroded the most in terms of depth and volume, followed by the macrochannel banks. The inner channel was largely infilled.

Figure 5 illustrates the spatial distribution of the erosion and deposition for sites A4 and A6. While similar patterns are evident between the two sites in terms of the pattern of erosion and deposition from each geomorphic feature, a degree of patchiness is evident at site A4 compared to the large-scale stripping of features at site A6. Site A6 also illustrates well the extent of within-channel bench removal, channel widening and point bar growth which occurred. On average, the channel experienced a 3-fold increase in width along the confined section compared to negligible change in the Upper Murphys Creek section.

Figure 4. Post-flood images of site (A) A4 and (B) A6.

The material stripped from the benches, channel banks and bed was sand, gravel, cobbles and boulders. However, the largest boulders lying exposed on the channel bed near site A6 had a mean b-axis of ~2m. These boulders would require a unit stream power in the order of 11370 Wm^{-2}. This estimate could potentially

Table 1. Geomorphic features and there change in depth and mass after the January flood. Positive values indicate deposition and Negative values indicate erosion.

Feature	Upper Murphys Creek			Lower confined section		
	Area (%)	Depth change (m)	Mass (t)	Area (%)	Depth change (m)	Mass (t)
Inner channel	4.2	0.04	4 076	14.8	0.07	15 298
Inner channel banks	8.6	-0.01	2 307	13.0	-0.14	-25 258
Bench	9.8	-0.11	-25 716	22.5	-0.75	-239 826
Macro channel banks	16.9	-0.24	-91 698	28.0	-0.48	-192 122
Floodplain	60.5	-0.01	-9 255	21.7	-0.11	-34 282
mean		*-0.06*			*-0.28*	
sum			*-120 285*			*-476 188*

reduce to 3310 Wm^{-2} if Costa's (1983) lower envelope is selected but this is considered quite conservative and is likely to represent a minimum stream power (Thompson and Croke, 2008). Regardless, these predicted values exceed the modeled maximum values of unit stream power for the site of 3000 Wm^{-2}. This suggests that the largest boulders are more likely to have just been 'uncovered' by the flood rather than transported and deposited. Boulders with b-axes approaching 1 m are likely to have been entrained in the January 2011 event.

Conclusion

This study presents a preliminary assessment of the magnitude and effective energy of the January 2011 flood event in a confined upland reach of Murphys Creek in the Lockyer valley. Estimated recurrence intervals for the event ranged from > >1000 years to 80 years using available, short gauging station records. Unit stream powers peaked at 4600 W m^{-2} along the confined reach and 3000 Wm^{-2} at site A6 but are not considered sufficient to transport the largest boulders found on the channel bed. These appear to be lag deposits from past floods of even larger magnitude. The dominant form of channel adjustment was channel erosion of the macrochannel banks and within-channel benches. No cutoffs occurred along the meandering channel. In addition, negligible change in channel depth occurred along the thalweg. The susceptibility and response of this reach to channel change is a response to the confined valley setting, which concentrated floodwaters, but also to the higher energy gradient near the knick point. Importantly, the sites proximity to the headwaters which were strongly aligned to the source of the storm, resulted in the rapid onset and fast transmission of the flood peak through this upper part of the catchment. Further work is underway to undertake dating of preserved alluvial deposits which can be used to reconstruct past flood magnitudes and frequency.

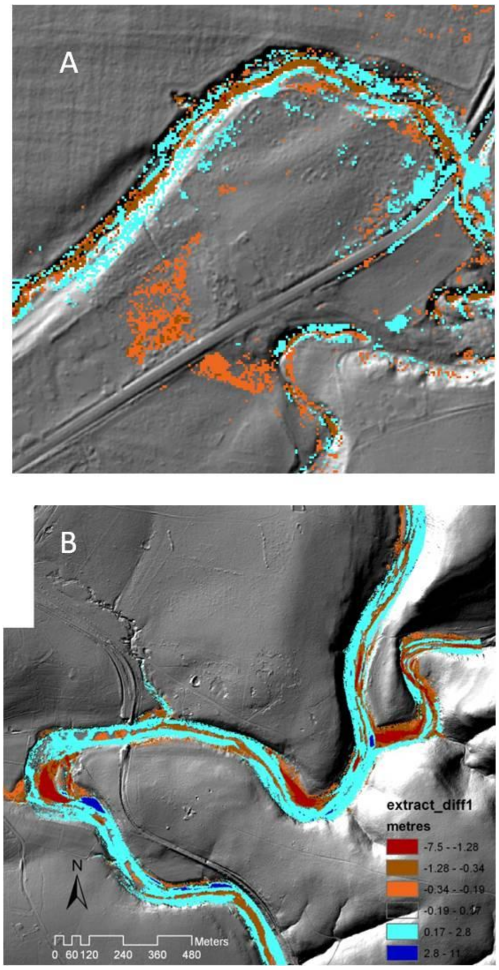

Figure 5. Difference in elevation between 2009 and 2011 LiDAR DEMs. Negative = erosion, Positive = deposition.

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