Flow variability and channel forms in southeast Queensland

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Key Points

- Compound channel forms are widespread in southeast Queensland and include both natural and anthropogenic forms.
- Alluvial channels in the middle reaches of the rivers systems in southeast Queensland fall into four main categories. These comprise (1) simple channels with low-energy floodplains, (2) simple channels with high-energy floodplains, (3) compound channels with low-energy floodplains, and (4) compound channels with high-energy floodplains.
- In Queensland, the legal definition of the channel boundary fails to include much of the channel bank perimeter in both simple and compound channel types.
- Large basins are associated with very high flow variability, and are most likely to have large compound channels. Channels within larger basins are also most sensitive to channel erosion associated with recent, European land use changes.

Abstract

The management and governance of rivers relies on the ability to accurately identify the channel boundaries and the extent of the active floodplain. In some parts of Australia, identification is made difficult by long bankfull return periods, dense vegetation, and multiple bench deposits. In SE Queensland, channel forms are often compound, leading to a legal recognition of channel banks as those corresponding to the low-flow channel. Typically, this is inset within a “macrochannel” that is flooded with a frequency of ~30 yr. Here, we explore the relationship between regional patterns of precipitation, streamflow variability, and the formation of compound channels in representative channel types of SE Queensland, focusing on the Brisbane, Bremer and Logan River Basins. We identify four main channel types, namely (1) simple channels with low-energy floodplains, (2) simple channels with high-energy floodplains, (3) compound channels with low-energy floodplains, and (4) compound channels with high-energy floodplains. Flow variability peaks on small (<100 km^2) headwater basins and is very high on large (1000-3000 km^2) basins with extensive inland catchments. Compound channels are most likely to be associated with large basins with large flood ranges, but are also more sensitive to channel erosion associated with European land use changes.

Keywords

bankfull discharge; alluvial rivers; channel pattern; hydraulic geometry; hydrology; macrochannels

Introduction

In alluvial channels, the geomorphic definitions of channel rely on identification of the bankfull stage, which separates channel flow from overbank flow across an active floodplain (Wolman and Leopold, 1957). These authors also equated bankfull flow with the channel-forming discharge on the basis that sediment comprising the channel perimeter was on the threshold of movement at bankfull velocity and shear stresses. Wolman and Miller (1960) discovered an approximate correspondence between bankfull frequency and the most effective discharge, which they defined as the flow that transports the greatest amount of sediment. Channel cross-sectional area, therefore, reflected the flow generated by the catchment which was stable in channels that regularly reworked their floodplains. Hydrologically, the active floodplain is often defined by a flow event with a common return period.

In Australia, the identification of bankfull stage is often problematic as it depends on the identification of an active floodplain that may have an irregular surface. Bankfull stage is often obscured by woody vegetation, natural levees, and in-channel benches at various heights above the bed (Riley, 1972). A hydrological definition of bankfull is confounded by the range of bankfull recurrence intervals that have been recorded. Some Australian streams appear to conform to the average bankfull recurrence interval (Woodyer 1968, Page et al., 2005; Kemp, 2010), while others have reported recurrence intervals that are significantly greater, especially streams with vertically accreting floodplains (Nanson and Young, 1981) or variable streamflow (Rutherfurd, 1994; Kemp, 2004).

In Queensland, the definition of channel banks is complicated by the common appearance of compound channels, or 'macrochannels' with both 'high' and 'low' banks (Croke et al., 2014). Measurements of bankfull recurrence intervals in Queensland are sparse, but at one location on the Brisbane River the high bank is reached or overtopped by flows with a return period of 30 yr (Kemp et al., 2015). Despite this long return period, the floodplain contains large flood effects including high, sandy levees and capacious back channels that form part of an active floodplain. Documentary evidence from the first European explorers suggest that a compound channel existed on the Brisbane River prior to the introduction of European agriculture and grazing to the catchment (Kemp et al., 2015). Elsewhere, compound channels may be the result of incision following land use changes, confining the active floodplain to cut and fill episodes within an over-deepened channel (Olley et al., 2009; 2010a; Thompson et al., 2016).

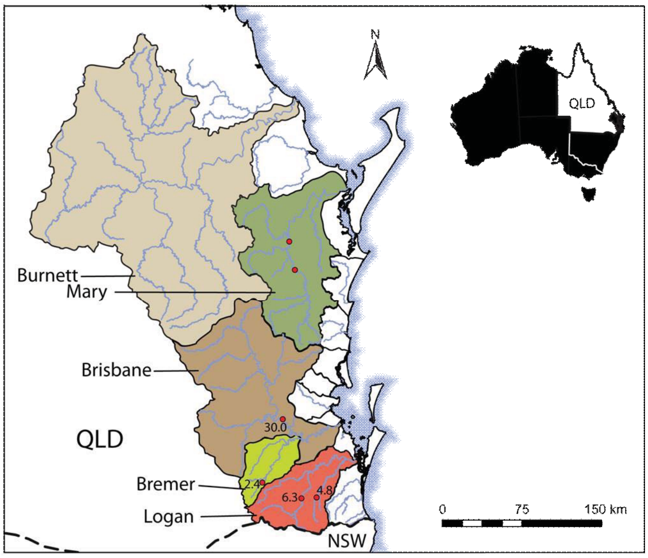

Figure 1. Location of study sites in SE Queensland, showing bankfull frequencies for selected stations.

To date, there have been few published geomorphological investigations upon which to base definitions of channel boundaries, or to assess the frequency of flooding in compound channels in subtropical eastern Australia. The issue has also been complicated by land-use changes which may have altered the channel form in some catchments. In 2004 and 2007, decisions in the Queensland Planning and Environment Court changed the definition of the channel boundary from a watercourse "… in which water flows permanently or intermittently, regardless of the frequency of flow events" to one defined hydrologically by the $Q_{0.25}$, i.e., by the stage at which flow recurs every three months (Nott, 2010). On most rivers around the world, this would more closely approximate the mean flow, filling about one-quarter of the channel (Wolman and Leopold, 1957). This definition effectively transferred ownership of the channel banks to the adjacent landholder, and the riparian zone resources, including aggregrate resources, without payment of State royalties (Nott, 2010). As a result, there is considerable confusion about the physical extent of the fluvial domain and the practical limits to resource use. Here, we analyse streamflow and survey data from gauged streamflow records, and explore the relationship between channel form and runoff regime in the Brisbane, Bremer and Logan catchments. This will allow a better understanding of the spectrum of channel types to inform management strategies and risks to development on these floodplains.

Study Area

The study area is bounded in the west by the Great Dividing Range, which reaches elevations of 1200 m above sea level (Fig. 1). Much of the drainage aligns north-south, with regional tectonic movements producing steep gradients and bedrock rivers on the northern tributaries, and gentler gradients and deeply alluviated valleys on southern tributaries. Wivenhoe Dam (1984) and Somerset Dam (1958) regulate the Stanley and much of the upper Brisbane Rivers. Moogerah Dam (1961) impounds ~11% of the Bremer headwaters. Together, Wyaralong Dam (2011) and Maroon Dam (1974) regulate 21% of the Logan River Basin.

Southeast Queensland experiences a subtropical climate with warm, wet summers and cold, dry winters (Bureau of Meteorology, 2013). A strong precipitation gradient reduces rainfall inland from the coast, except in the higher ranges where annual rainfall can exceed 2000 mm y^{-1}. Average annual precipitation at Ipswich is 882 mm (1870-1994), falling to 829 mm at Lowood (1888-2012) and 772 mm at Gatton (1888-2012). Rainfall is modestly seasonal with 70% falling between October and March. In summer, intense storms and occasionally prolonged rainfall are generated by tropical depressions or the SE trade winds. Daily rainfall intensities of 907 mm have been measured in the Brisbane River catchment at Crohamhurst on 3 February, 1893, officially the 24 hr rainfall record for Australia. This high rainfall variability translates to extreme flow variability in the Brisbane River, including the period before and after the introduction of European-style agriculture (Kemp et al., 2015). Regionally, highly variable streamflow tends to be a feature of the marginal tropics in eastern Australia owing to the occurrence of intense but infrequent tropical cyclones at subtropical latitudes (Rustomji et al., 2009).

Southeast Queensland contains some of the earliest farmed land in the State. Land outside the Moreton Bay penal colony was settled rapidly after its closure in 1842 (Kemp et al., 2015). Evidence suggests that by the time Europeans arrived in the region the valley flats were already open grazing country that had been maintained by aboriginal societies. By 1860, Europeans had introduced 400,000 sheep to the Brisbane River Basin alone, and over two decades, native kangaroo and blue grass became locally extinct (Kemp et al., 2015). Soils were compacted and were no longer able to store the wet season rains. Instead, runoff increased and became seasonal so that rivers that had been perennial dried out during the winter months. Smaller channels changed from shallow, reedy waterways to deeply incised culverts, with larger rivers like the Brisbane suffering extensive bank erosion during successive large floods in the 1890s.

Prized timber species were logged from the 1850s (Powell, 1998), but systematic clearing of the lower hillslopes was delayed until the late C19th and early C20th. In the upper Logan Basin, extensive clearing produced incision and gullying of the drainage lines such that the main channel is now overtopped by floods with a recurrence interval >100 yr (Olley et al., 2009). In the Bremer Basin, clearing of native forest was limited to the lower catchment, now dominated by grazing or arable agriculture. Incision and channel widening was associated with sediment deposition in the lower tributary streams (Olley et al., 2010a). Estimates suggest gullying in the upper Bremer may have commenced around ~1840, with most gullying occurring regionally between 1920 and 1960 (Saxton et al., 2012). In upstream reaches of the Lockyer Basin, one tributary widened by a factor of four during the 1950s-70s, transforming a well vegetated 10 m wide stream with a clean sand and gravel bed to a sparsely vegetated 40 m wide channel infilled with silt and clay. This event coincided with rapid forest clearance in the headwaters (Olley et al., 2010b).

Methods

Daily rainfall data are available from the 1840s with continuous records beginning after 1860. Gauged streamflow records in the Brisbane, Logan and Mary catchments begin in the early 1900s with records of 2-75 yr. Flood frequency analysis was performed on longer records from alluvial channels in the middle to upper reaches of the rivers with catchment areas of 100-3000 km^2. Most records are post-1945, but are sufficiently long to cover secular changes in rainfall variability that have affected SE Queensland (Saxton et al., 2012). Flow modelling of the annual series used a log Pearson III distribution (LPIII) and a water year beginning in September (Pearson and Doran, 1987). River cross-sections were derived from recent surveys of streamflow gauges (DNRM, 2016). Descriptions of the floodplain are based on geomorphic mapping using aerial photographs, Google Earth satellite imagery, and field survey of selected reaches along the Brisbane, Bremer and Logan Rivers.

Results

Figure 2 shows flood growth curves for a range of gauging stations, allowing flood variability and skew to be compared between catchments of different sizes. Growth curves are LPIII flood discharges normalised as the flood magnitude divided by the mean annual flood (MAF) ($Q_{2.33}$), plotted against flood return period. An appraisal of the flood growth curves shows that stations in SE Queensland fit into roughly three groups. In the first group, rivers with small, headwater catchments <100 km^2 have steep flood growth curves and a 100 yr flood approximately 50 times the size of the MAF (e.g. Tenthill Creek). The second group includes the medium reaches of larger rivers with catchments of 1000-3000 km^2 (e.g. Burnett, the Mary, and the Brisbane at Mt Crosby). These rivers have moderately steep flood growth curves with 100 yr floods that are 10-13 times the MAF. The third group includes the Albert and Bremer Rivers with areas of 100-1000 km^2. This group is characterised by 100 yr flood magnitudes that are 2-4 times the MAF.

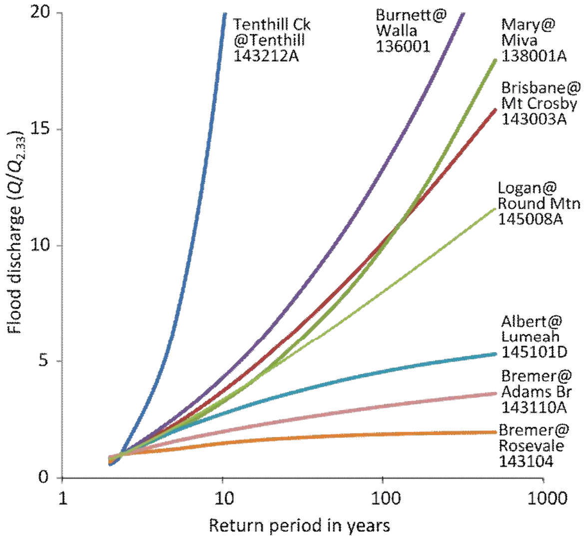

Figure 2. Flood growth curves for selected gauging stations in SE Queensland.

Bankfull frequency is difficult to measure in compound channels owing to high downstream variability of channel width. Frequencies of bankfull discharge were calculated for a number of stations based on the stage of incipient floodplain inundation where this could be identified (Fig. 1). In leveed channels such as the Albert at Bromflet (Fig. 3), bankfull stage was defined by the mean floodplain elevation. Bankfull return period in the region ranged from 2.3 yr in the Mary at Moy Pocket to 20-38 yr in the Brisbane at Savages Crossing. All channels investigated had longer than the average bankfull return interval of 1.5 yr. There is no apparent correspondence between catchment area, flood variability, and the frequency of bankfull discharge, except that the largest compound channels have return periods for bankfull stage that exceed 20 yr.

Alluvial channels in the middle reaches of the rivers systems in southeast Queensland fall into four main categories. These are (1) simple channels with low-energy floodplains, (2) simple channels with high-energy floodplains, (3) compound channels with low-energy floodplains, and (4) compound channels with high-energy floodplains.

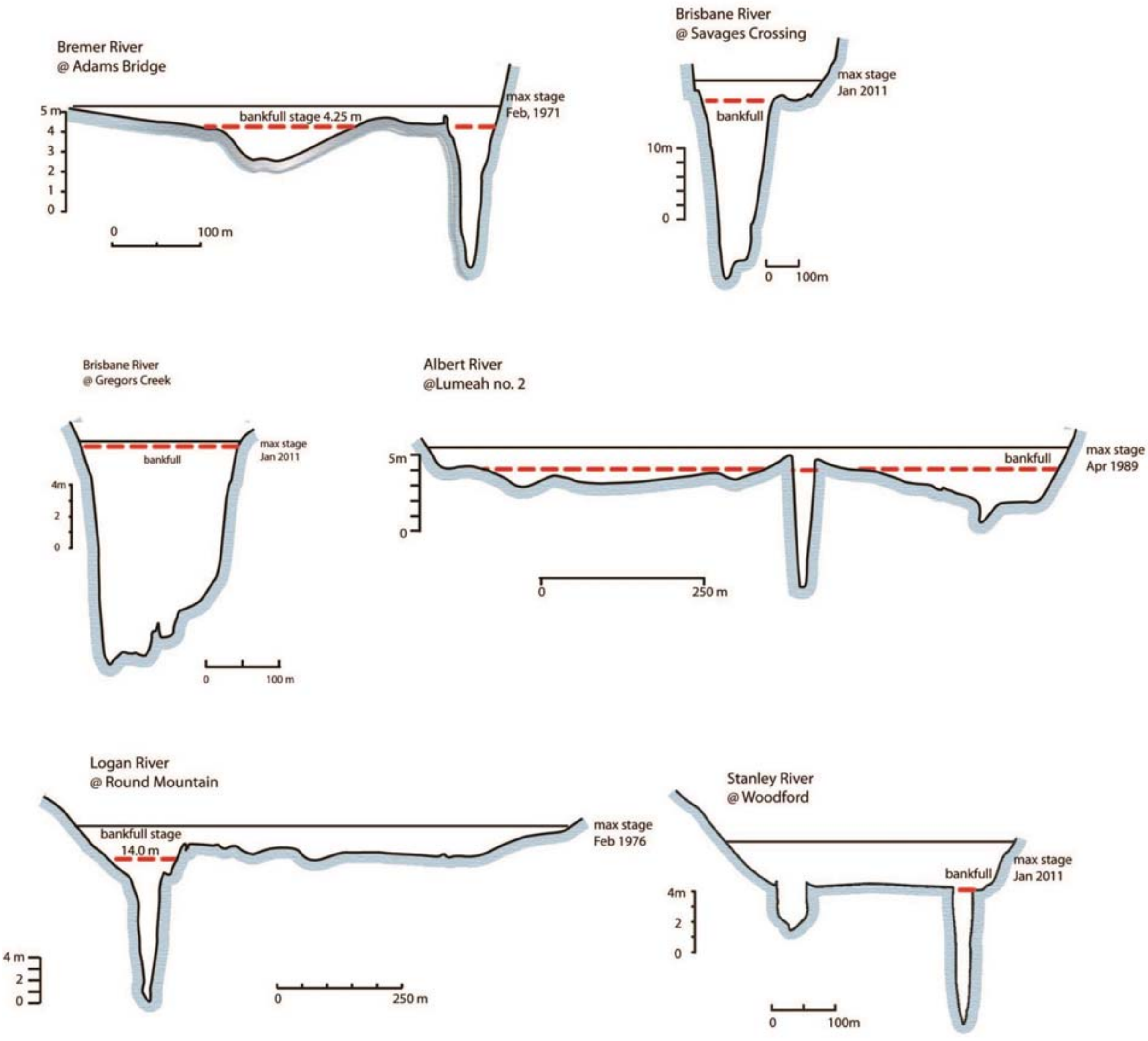

Figure 3. Selected cross-sections of channels and floodplains in the Brisbane and Logan catchments, showing bankfull and maximum recorded flood stages.

Type 1. Simple channels with low-energy floodplains. This channel type was not investigated in this paper, but examples can be found in the middle and upper reaches of smaller catchments, such as Oxley Creek south of Brisbane (Kemp and Ellison, 2013). The channel cross-sectional area may be small relative to the catchment area. On Oxley Creek, the undisturbed riparian zone is well vegetated with open forest and the floodplain supports open forest dominated by Queensland blue gum. These channels are particularly common in broad valley settings, such as those south of the Brisbane River.

Type 2. Simple channels with high-energy floodplains. These are simple channels, but with significant geomorphic activity occurring outside the channel boundaries. Examples include the Stanley River and some reaches of the middle Brisbane River that lack inset channel features. Large back channels are common and the floodplain may have an irregular topography that includes features similar to terraces. Nearer the main channel but above the level of the low banks, the floodplain may feature erosional forms such as elliptical scour scars and flood runners. Depositional forms may include coarse-textured levees, sand and gravel deposits in scour scars, back channels, flood runners and thin overbank deposits on benches and intermediate in-channel surfaces.

Type 3. Compound channels with low-energy floodplains. Examples include some reaches of the Lockyer and Mary Rivers which have overdeepened channels relative to their catchment areas (Thompson et al., 2016). These are incised channels in which most of the geomorphic activity is confined to the channel owing to enlargement of the channel and the associated increase in flow capacity. In many cases, floods have not overtopped the banks onto the floodplain within the gauged streamflow record. These may be anthropogenic features that have evolved from Type 1: simple channels with low-energy floodplains, to compound channels, probably through incision of the bed. Channel enlargement is partially dependent upon the density of the riparian forest (Olley et al., in prep.), but long-term stability of channel form is assisted by rapid infilling of bank failure scours during subsequent floods (Fryirs et al., 2015).

Figure 4 A. The Logan River nearTamrookum, 18 km south of Beaudesert, c. 1903. John Oxley Library. Open forest is established down to the low banks. B. Relatively undisturbed channel in the upper Brisbane near Toogoolawah c. 1892. John Oxley Library. C. Mixed rainforest-sclerophyll forest on the banks of the Brisbane River near Lowood. D. Brisbane River near Lowood looking downstream at sands and gravels along an active back channel.

Type 4. Compound channels with high-energy floodplains. Examples include some reaches of the Brisbane River. The channel has a compound form with a large main channel relative to its catchment area and contains an inset low-flow channel forming a compound channel. The channel banks are topped by intermittent high, coarse-textured levees, punctuated by return gullies and minor tributaries that meet the main channel through deep alluvial gorges. The bed consists of armoured medium and small gravel above a substrate of gravel and coarse sand. Banks and islands within the channel are moderately well forested with mixed rainforest and sclerophyll trees, shrubs, herbs and grass (Fig. 4B and 4C). The low-flow channel and channel bars are stabilized by shrubs and small trees, and are particularly well developed at tributary junctions. The inset floodplain includes pool-riffles, benches, drapes, and flood runners (Fig. 4D).

Flow frequency analysis of the streamflow record of the Brisbane River at Savage's Crossing shows that the high banks are reached by flows with return periods of 20 and 38 yr on the pre- and post-regulation series, respectively (Kemp et al., 2015). Higher benches are inundated every 7.5 and 8.0 yr, and lower benches at stages between 2.9 – 4.8 m every 1.1 and 1.7 yr, respectively. On the Logan River at Round Mountain, the broad floodplain features highly irregular topography (Fig. 3). Over-deepening of the channel is suggested by an unusually low width-depth ratio of 5 (maximum channel depth of 15 m), and bank erosion of the lower banks is suggested by the absence of large riparian trees below the inset bank line. Early C19th photographs show Queensland blue gum growing down to the low flow channel (Fig. 4A). Above the bed, sandy point bars appear disjunct, their rear edges separated from the upper floodplain by approximately half of the channel depth. This channel type appears to include pre-European and anthropogenically altered channels that have incised as a result of European land use. The Brisbane River at Gregors Creek (Fig. 3C) is an example of a channel isolated from its floodplain as a result of post-European incision, in this case following gravel extraction from the channel bed (Shellberg and Brooks, 2007).

Discussion

The predominance of high-energy and compound channels in the region suggests that the natural floodplain geomorphology of SE Queensland is distinctive and reflects the highly variable flow regime, which is extreme compared to other regions around the world. Generally, flow variability and flood power peaks in small catchments of 20-50 km^2, where steep slopes and thin soils combined to produce a flashy runoff response (Baker and Costa, 1987). In SE Queensland, significant flood ranges are recorded in the middle and lower reaches of large catchments with areas of 1000-3000 km^2. Here, the compound channel configuration may be a response to extreme floods that recur on decadal frequencies. In-channel features may be ephemeral, and their rates of reworking are presently being investigated (Stout et al., in prep.). Similar high-energy floodplains containing low energy channels have been described elsewhere in eastern Australia in catchments with highly variable streamflow (Rutherfurd, 1994; Kemp, 2004). These stable floodplains contrast with non-equilibrium channels in which irregular catastrophic flooding produces dramatic channel widening followed by a period of vegetation recovery and narrowing (Stevens et al., 1975). Regionally, channels that exhibit this type of flood response appear to be confined to smaller rivers such as Blackfellows and Tenthill Creeks with headwater catchments along the Great Dividing Range (Olley et al., 2010b).

Catchments with large flood ranges appear to be more sensitive to incision and other channel changes, and to more frequently support compound channel forms. It is worth noting that all flow records post-date significant land use changes, and therefore reflect runoff that may have been accelerated by soil compaction and clearing (Kemp et al., 2015). The degree of correspondence between high flood variability shown by the flood growth curves in Figure 2, and the sensitivity of channels to European land use change is presently being tested by regional mapping of compound channel types.

Conclusion

While legal definitions of waterways in Queensland hinge on the frequency of low flow events, it is important for many reasons to be able to recognise the channel boundary and the nature of geomorphic activity on the adjacent floodplain. In SE Queensland, both the channel and floodplain are potentially zones of vigorous geomorphic activity owing to the extreme range of natural flood flows that regularly produces compound channel forms. These are most pronounced in catchments with large, inland basins. Elsewhere in the region, compound channels may be a result of post-European bed incision. The vertical and lateral extent of floodplain activity depends both upon the flow variability and on the channel sensitivity to changes in catchment dynamics that have occurred as a result of European land use practices. While we are in the preliminary stages of categorising channel types in SE Queensland the present study serves as a conceptual framework for more detailed geomorphic and subsurface investigations.

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