Downstream Increasing Flood Frequency On Australian Floodplains

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ABSTRACT: *Unlike most rivers described in the international literature, numerous Australian streams display a downstream decrease in channel dimensions that is matched by an increase in flood frequency. In many of these streams, the phenomenon is explained by human impacts such as channelisation, gullying, and artificially increased sediment loads. However, in many streams, the downstream increase in flood frequency is a natural phenomenon caused by channel avulsion, or, most interestingly, by other processes that we have not yet identified. The recognition of this class of streams has implications for managing floods and for understanding the evolution of floodplains.*

1. INTRODUCTION

One of the corner-stones of fluvial geomorphology is that stream channels maintain an equilibrium between the magnitude and frequency of discharge and channel dimensions. That is, with increasing catchment area, stream discharge increases, and channel size increases so as to maintain a channel that floods, on average, every one to two years. Positive exponents in downstream hydraulic geometry relationships have been found for numerous Northern Hemisphere streams; average exponents are 0.5 for width, 0.3 for depth and 0.2 for velocity (Leopold & Maddock, 1953; Park, 1977; Rhodes, 1987). These same hydraulic geometry relations are often used for defining stable stream dimensions for stream engineering in Australia.

Nanson and Young (1981) described a group of streams flowing from the Illawarra escarpment of NSW that dramatically decrease their channel dimensions, and increase their flood frequency, downstream. This reduction takes place across the lower floodplain tract, after the streams have left their confined bedrock gorges. We have observed that many Australian streams decrease in channel dimensions downstream, and increase in flood frequency. This is true of streams of all sizes, from the large Herbert River in northern Queensland, and the Macalister River in Gippsland, down to small gullies.

This paper describes examples of Australian streams that increase in flood frequency downstream, and considers the various causes of the phenomenon. We should stress that, although we are mostly discussing downstream decreasing channel dimensions, the most important characteristic of these streams is their downstream increase in flood frequency.

The two most common types of stream that decrease in area downstream are 'losing streams' and anabranch systems. 'Losing' streams lose discharge to evaporation and seepage in karst, arid and semi-arid areas. Although their dimensions reduce downstream (eg. Dunkerley, 1992), we suspect that their flood frequency does not. We have found no references that discuss flood frequency in 'losing' streams. Similarly, although anabranching streams decrease their dimensions as they lose water to effluents, the flood frequency in separate channels remains reasonably constant (Rutherfurd, 1992). In the streams we consider here, the channel dimensions decrease downstream but the discharge either increases or remains constant, producing a downstream increase in flood frequency. We have called these 'DIFF' (downstream increasing flood frequency) streams.

2. DISTRIBUTION OF DOWNSTREAM INCREASING FLOOD FREQUENCY (DIFF) STREAMS

This study has concentrated on Victorian streams, but we are able to report some DIFF streams in other states. Table 1 lists the names of major streams we have identified that decrease in dimensions and increase in flood frequency downstream. The table is not the product of an exhaustive search, so there are likely to be many more DIFF streams than shown here. These streams were identified from published cross-sections, from gauging records, or from descriptions in the published literature. Most of the examples discussed in this paper are drawn from streams in Gippsland, Victoria.

It is noteworthy that many of these streams occur in the coastal strip, extending from Melbourne, around the SE coast to Wollongong. The downstream increase in flood frequency (downstream decrease in bankfull capacity) can be caused by several processes. These are listed in Table 1 and discussed in the following section.

3. DESCRIPTIONS AND CAUSES OF DOWNSTREAM INCREASING FLOOD FREQUENCY

DIFF is most commonly the product of erosion (deepening and widening) in one reach of the river, coupled with deposition downstream. This occurs in discontinuous gullies, incised streams, channel avulsions, or with catastrophic widening. We will describe examples of DIFF that are obviously caused by humans, and then move to examples that predate human impact.

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Table 1. Some streams with downstream decreasing channel dimensions in Australia

State	**Name of Stream**	**Source of information**	**Possible cause of DIFF**
Victoria	Latrobe	Gauge data and cross-sections	Mostly channelisation
	Macalister	Gauge data and cross-sections	Channel avulsion
	Avon	Gauge data and cross-sections	?
	Snowy	Gauge data and cross-sections	?
	Tarwin	Gauge data and cross-sections	?
	Avoca	Rutherfurd & Smith, 1992	?
	Rainbow Ck	Brizga & Fabel, 1993	Channel avulsion
	Piccaninny Ck	Gauge data	Aggradation by mining sediment (Peterson, 1995)
	Bendigo Ck	Gauge data	Aggradation by mining sediment (Peterson, 1995)
South Australia	Gawler	Paul Harvey, Co-ord. Mt. Lofty Ranges Catchment Program, pers. comm.	?
	Inman	" "	Channelisation
	Bremer	" "	?
Queensland	Herbert	I.D. Drummond & Assoc., 1994	?
	Barron	Kapitzke *et al.* (this volume)	?
	Mulgrave	Kapitzke *et al.* (this volume)	?
	Burdekin	Kapitzke *et al.* (this volume)	?
	Proserpine	Kapitzke *et al.* (this volume)	?
	O'Connell	Kapitzke *et al.* (this volume)	?
	Mossman	Kapitzke *et al.* (this volume)	?
NSW	Bega	Brooks, 1994	Channel aggradation
	Illawarra escarpment streams	Nanson & Young, 1981	?
	Tantawangalo	Gauge data	Channel aggradation
	Brogo	Gauging data, confirmed by Martin Thoms, pers. comm.	Aggradation downstream of dam?

3.1 Stream Aggradation

European landuse has increased the sediment yield to many streams in SE Australia. Mining, gullying and general catchment erosion (especially in granite catchments) have led to the storage of sand in the downstream reaches of streams. The sand is typically moving through the stream system; the rate of movement decreases downstream, so that the lower reaches of many streams are now choked with sand (see Rutherfurd, this volume). This increases the flood frequency. For example, sand-slugs in the Glenelg River in western Victoria have reduced channel capacity by between one third and one half for over 100 km of river. Other examples include the Tantawangalo River in southern NSW, which has aggraded with sand in the downstream reaches since clearing for agriculture and forestry occurred in the upper catchment (Brooks, 1994), and the Brogo River which shows a notable decrease in downstream channel capacity. According to M. Thoms (pers. comm.), channel capacity has decreased by 30% since a dam was constructed on the river. Mining is another activity that has reduced channel capacity. Huge quantities of sludge, more than 1.7 million m^3 annually, were deposited on floodplains in the Bendigo region, Victoria, as a consequence of gold mining in the 1850s (Peterson, 1995). The decrease in channel dimensions of Piccaninny and Bendigo Creeks in the area is attributed to the deposition of this sludge.

3.2 Incised Streams

"Incised Streams" exhibit the most dramatic decrease in channel dimensions. These are streams that have catastrophically deepened, often since European settlement, and include gullies and larger valley-floor incised streams. It is not uncommon to find incised streams that, within one to two kilometres, decrease from 10m deep and 30m wide to a broad 'floodout' with poorly defined channels. The large upstream channel is never filled by floodwaters, whilst the downstream channel is filled every time the channel flows. The numerous examples of such streams in SE Australia (Bird, 1985; Rutherfurd, 1995) include Eaglehawk Creek in Gippsland and Fernances Creek in NSW (Melville & Erskine, 1986).

3.3 Channelisation

Attempts to increase flow conveyance by desnagging, and cutting drains and bends, have led to many examples of downstream increasing flood frequency. A good example is the Latrobe River in Gippsland (Reinfelds *et al.*, 1995). The floodplain tract of the Latrobe has been straightened by nearly 70 artificial cutoffs, and the channel desnagged up to five times. Even though the channelisation was fairly uniform along the channel, the river response was not. The channelisation produced up to a doubling in width in the upstream reaches of the river, but almost no erosion in the lower reaches. The result is that the river channel now has twice the bankfull capacity at Thoms Bridge (20,000 Ml/d) at the upstream end of the floodplain, than at Rosedale, 70 river kilometres downstream (9,000 Ml/d). The 1937 (pre-channelisation) widths show that the Latrobe did have a natural downstream decrease in channel dimensions (from 34 m wide at Thoms Bridge, to 27 m wide below Rosedale), but this tendency has been greatly increased by channelisation (Figure 1).

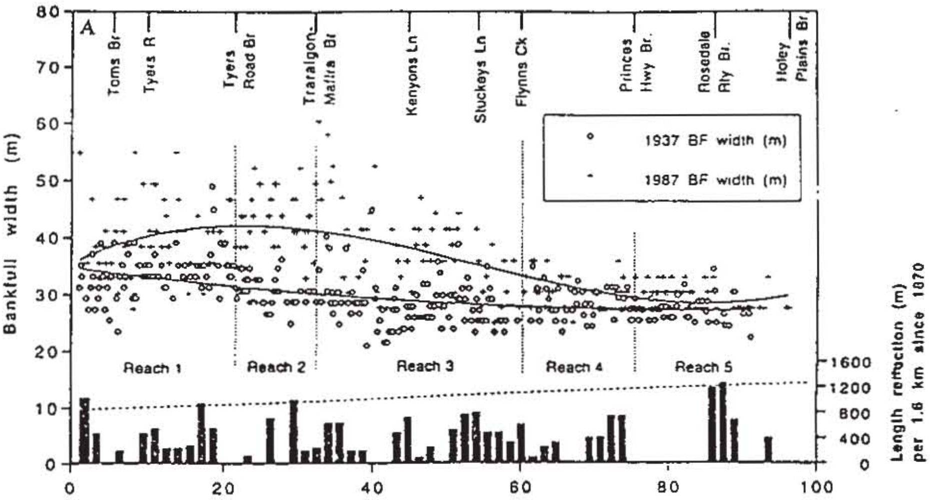

Figure 1. Downstream trends in the effect of channelisation on bankfull width in the Latrobe River. Channel length reductions due to artificial cutoffs for each 1.6 km of river channel are illustrated in the histogram (Reinfelds *et al.*, 1995 p 63).

3.4 Channel Avulsions

Channel avulsions, the sudden abandonment of one channel for another, produce a pronounced downstream increase in flood frequency. During a large flood in 1952 the Thomson River in Gippsland cut a new channel: Rainbow Creek across its floodplain. The new course is 15 km long. Its dimensions decrease downstream from a bankfull width and depth, respectively, of 60 m and 6.7 m at Rice's Bridge, below the off-take from the Thomson, to a bankfull width of 46 m and a depth of 4 m, two kilometres above its junction with the Thomson River.

Channel avulsion may also explain the Macalister River, another DIFF in Gippsland. The Macalister is a large river (catchment area 2,330 km^2) that has a flood frequency of 1 in 20 years (60,000 Ml/d) close to the mountain front. This decreases to a 1 in 1 or 2 year flood (7,500 Ml/d) downstream near Maffra. Whilst channel dimensions decrease downstream, channel sinuosity and wavelength increase. An 1831 map (No. 8198, RWC) shows that the Macalister had its present planform, and probably its present width, before the construction of Glenmaggie Weir. Thus the dimensions of the river are not a product of erosion below the dam.

Note also that the Macalister cannot be interpreted simply as an anabranching stream or as a bifurcating branch around an island. Flood waters do leave the Macalister at defined points, but the effluent points are just slight depressions in the bank, not true anabranches. Most importantly, the channel dimensions of the Macalister do not increase again when the effluents return to the trunk stream. Thus, we interpret the modern Macalister as a pre-historic channel avulsion not unlike Rainbow Creek.

The original Macalister probably occupied Newry Creek, which is still preserved to the North of the modern Macalister (Figure 2). The present Macalister abandons Newry Creek at the mountain front (ie. the apex of the alluvial fan) and rejoins Newry Creek at Bellbird Corner, some 30 river km downstream. Newry creek above Bellbird corner, and the Macalister just below Bellbird Corner share very similar cross sectional areas and channel sinuosities. This suggests that, like Rainbow Creek, the channel avulsion was the cause of the increase in channel capacity upstream of Bellbird Corner.

3.5 DIFF Streams With no Simple Explanation

Of most interest to us are the group of streams that have DIFF, but do not fall into any of the above categories. That is, the DIFF is not caused by stream aggradation, or any other obvious human induced erosion and sedimentation, or by channel avulsions. The streams originally described by Nanson and Young (1981) fall into this category as does the Tarwin River.

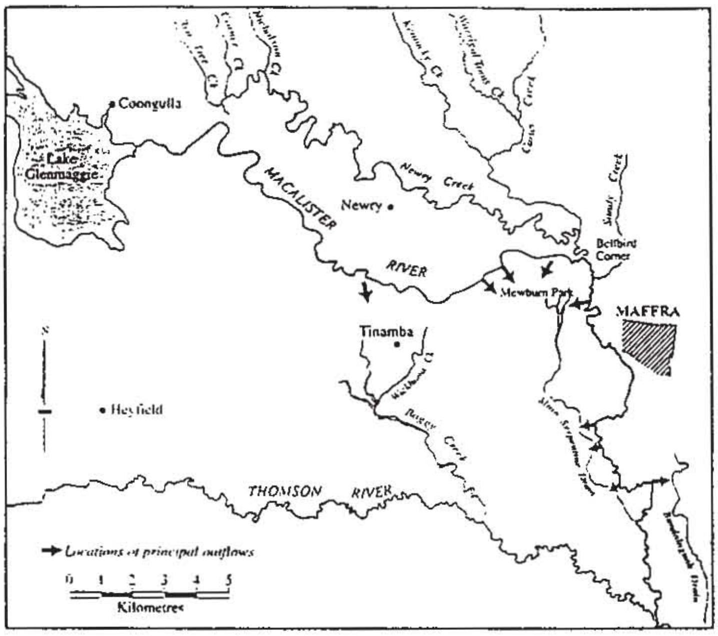

Figure 2. Map of the Macalister River area below Lake Glenmaggie (adapted from I. Drummond and Assoc., 1992, p. 22 & 31).

In their study of five small streams, Nanson and Young (1981) found that downstream flood frequency increased as channel capacity decreased. Anecdotal estimates of flood frequency suggested that overbank flows in the lower reaches occurred approximately 1 - 2 times per year, compared with once every 3 - 8 years at the upstream edge of the floodplain.

The Tarwin River in Southern Gippsland is another example of DIFF. In its upper reaches, the Tarwin's cross-sectional area initially increases until it reaches a maximum at about 15 river kmfrom its headwater (Figure 3). Over the next 20 km, the channel capacity decreases from a bankfull area of 75 m^2 to only 25 m^2, an average decrease of 2.5 m^2/km.). There are no obvious benches within the channel that could be defined as some surrogate bankfull level as is found in many NSW streams (Woodyer, 1968). The reduction in channel capacity is the result of decrease at a similar rate of both width and depth (Figure 4).

What is the explanation for these examples of DIFF? Nanson and Young (1981) explained the downstream decrease in channel size in the Illawarra streams by 'a sudden decline in slope and associated stream power, the cohesive nature of the downstream alluvium, its retention on the channel banks by a dense cover of pasture grasses and the availability of an extensive floodplain to carry displaced water' (Nanson and Young, 1981, p. 239). The problem with this explanation is that these characteristics are shared by most streams as they leave the confined, bedrock portion of their courses and enter the floodplain: slope and stream power decrease, bank cohesion increases, and there is a broad floodplain. Yet the vast majority of streams maintain their channel dimensions, and maintain a reasonably consistent flood frequency downstream. This is shown by the consistency of downstream hydraulic geometry exponents world-wide (Park, 1977; Rhodes, 1987).

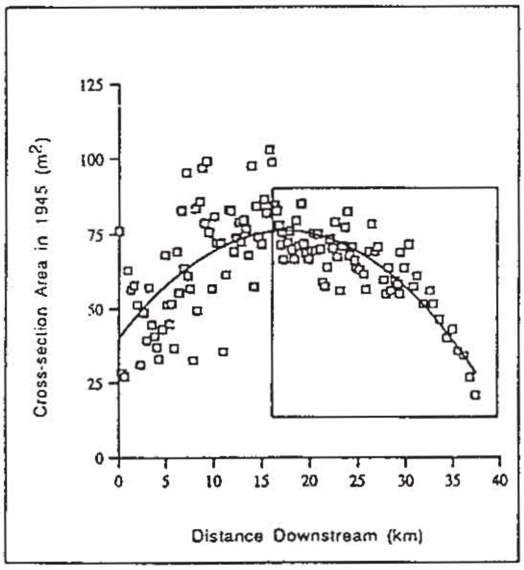

Figure 3. Changes in cross-section area along the Tarwin River, Gippsland. Boxed region highlights where the decrease in dimensions occurs.

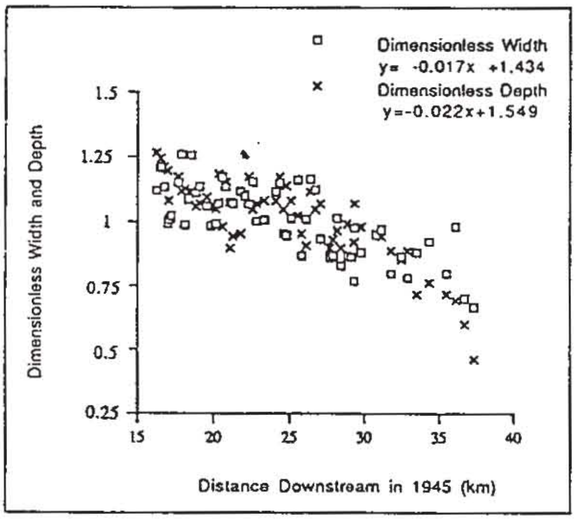

Figure 4. Downstream rates of decrease in width and depth on the Tarwin River for the length of river highlighted in Figure 3. (N.B. width and depth have been non-dimensionalised by dividing each value by the mean value).

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It is true that all of the coastal DIFF streams that we have identified in Victoria (excluding anabranching streams) build their floodplains mainly by vertical accretion, rather than by lateral meander migration. The downstream decrease in channel area could be explained by differential overbank deposition. That is, more material is deposited at the upstream end of a reach where a flood first goes overbank, so that levees are deposited first at the upstream end and are progressively built downstream. Although this effect may contribute to DIFF, it is not the whole explanation. First, levee deposition cannot account for the downstream changes in width. Overbank deposition should, if anything, narrow the channel in the upstream reach, as well as deepen it, as material is deposited on the banks. Second, in the streams that we have considered, the downstream difference in the height of levees is not enough to account for the change in channel capacity. For example, on the Tarwin, the difference in levee height is less than a metre, whilst channel depth decreases by 3 m downstream. There may be some streams in coastal NSW (eg. the Macdonald) that have such well developed levees (up to 10m high) that the levees could explain DIFF, but it is not a universal explanation.

Another possible explanation for these DIFF streams could be 'inherited' low valley slopes. Floodplain slopes are often considered to be a product of the erosion and deposition of the modern stream. Yet, in many cases, the slope of the modern floodplain is a product of the underlying depositional surfaces. This surface is likely to be Pleistocene in origin. Deposition from a low energy stream is more likely to be plastered over the former surface than to modify that surface by erosion. Although we have not yet investigated this hypothesis, we may find that DIFF streams are associated with a lower inherited floodplain slope than other streams of similar size that maintain constant downstream flood frequency.

4. DISCUSSION

4.1 Downstream Rates of Change in DIFF Streams

We have discussed the distribution of DIFF streams, and their possible causes. It is interesting now to note two characteristics of DIFF streams: flood frequency and downstream hydraulic geometry.

The flood frequency of the DIFF streams suggests that the upstream reaches are over-large, rather than that the downstream reaches are too small. The downstream reaches of all of the rivers considered above have a 1 in 2 year bankfull flow, whereas in the upstream reaches bankfull flows are much more rare. If we accept a 1 to 2 year bankfull flood frequency as being 'normal' (Dury, 1976; Wolman & Leopold, 1957), then downstream reaches of these streams are 'normal' and the upstream reaches over-large.

It is important to note that we cannot strictly apply hydraulic geometry relationships to these DIFF streams because the basic presumption of hydraulic geometry, that bankfull flood frequency is constant downstream (Leopold & Maddock, 1953), is not true. However, it is noteworthy that the down-stream change in channel dimensions occurs at the same rate in the Macalister River as it would in a normal stream but in the opposite direction. Thus, although the **discharge** in the Macalister increases downstream, the **size** of the channel decreases downstream at the same rate that other streams would be expected to increase, from hydraulic geometry relationships. This is shown by a comparison of exponents. A review of exponents from numerous rivers around the world (Park, 1977) found that, on average, width tends to increase as the square-root of discharge downstream, whilst depth increased to the 0.3 power. On the Macalister, by comparison, the width **decreases** downstream with an exponent of 0.52, and depth decreases with an exponent of 0.36. This result could be just a coincidence on the Macalister so we are investigating other DIFF streams to see if the same relationships holds.

4.2 Importance of DIFF Streams

What is the significance of DIFF streams? Leaving aside incised streams and smaller streams, DIFF streams are important for three reasons. First, the simple fact that these streams have higher flood frequencies in their downstream reaches helps to explain flooding patterns on many floodplains. The lower flood frequency of the upstream end of these streams means that flooding is less frequent along these channels than one would normally expect. Second, DIFF streams are also important for our understanding of floodplain deposition and destruction. For example, the changing downstream flood frequency leads to differential levee deposition and anabranch development. Down-stream anabranches are likely to develop at a faster rate with more frequent flow. Third, it requires us to consider what is happening to bedload transport. Assuming that there is a balance between supply and transport of bedload in the lower reaches, that is, supply and transport are in 'equilibrium', then the discharge in the upper reaches is able to transport in excess of its supply of bedload. If this is so, where is the sediment deposited? This question is also under investigation as part of this study.

5. CONCLUSIONS

There is a class of streams in Australia in which channel dimensions decrease, and flood frequency and discharge increase downstream.. Even in large rivers, the downstream decrease in channel dimensions can be dramatic, with up to a four times decrease in channel area. The purpose of this paper has been to describe the various types of these streams, and offer some preliminary explanations for this phenomenon. Streams of all sizes display DIFF, but from our preliminary work it appears that large DIFF streams are most common along the coast, particularly between Melbourne and Wollongong, and in Far

North Queensland. The identification of such streams is important for three reasons. First, they differ from the well-accepted model of consistent downstream flood frequency. Second, erosion and sedimentation processes in these types of streams can contribute to our understanding of floodplain evolution. Third, an appreciation of this type of stream explains flooding patterns.

Many of the DIFF streams are a product of erosion of one portion of a stream, often with deposition downstream. The result is that the upstream portion of the channel is usually over-large (ie. low flood frequency) rather than the lower reaches being too small. In most of the examples described, much of the erosion is a result of human interference, usually by channelisation, or by accelerated runoff and erosion from catchments. In other cases, a natural DIFF can be increased by human intervention, for example by channelisation. Other examples of DIFF are explained by natural channel avulsions. Finally, there is a group of DIFF streams that cannot be explained either by human intervention or channel avulsion. We have no satisfactory explanation for these streams' decrease in channel capacity downstream, but it may be related to both levee development and inherited floodplain slope. Finally, we should acknowledge that the 'explanations' we have suggested for DIFF streams are, to some extent, descriptions rather than explanations. For example, we state that channel avulsions tend to be much larger at the upstream end of the avulsion, but why is this so? DIFF streams still require more research.

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