Sand-slugs in South East Australian streams: origins, distribution and management

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ABSTRACT: Since European settlement, mining, stream incision (gullying), and catastrophic widening of streams, have released waves of sand that have choked stream channels in SE Australia. These sand-slugs are among the most obvious of human impacts on stream channels. Sand-choked channels are particularly common in streams that drain granite catchments. Sediment yields from mining and gullying are generally declining across SE Australia, reducing sediment supply to the upstream end of the slugs. The focus of management must now shift to the fate of sediment in storage in the stream system. Sand-slugs usually pass through stream channels as discrete, moving waves, with well defined 'snouts'. The rate of migration of the sand typically declines as it moves downstream, with rates declining from kilometres per year to tens of metres.

The return of stream-beds to their former elevations will probably be followed by a new phase of channel erosion. This is because, in some cases, the sand has protected the channel from higher flood peaks from cleared catchments and gully networks; and because the erosion that was halted with the arrival of the slug will resume when the slug is gone. Removing the sand-slug manually is a very real management option that will not cause erosion of the original channel, but it will remove the protection that the sand afforded the channel, so that erosion can recommence.

1. INTRODUCTION

There is no doubt that the rate and magnitude of sediment movement in the Australian landscape was increased by European settlement. Mining, gully erosion, and less commonly, sheet erosion, have increased sediment yields by several orders of magnitude (Neil & Fogarty, 1991) . Much of the finer fraction of the sediment eroded over the last 150 years (eg. the fine sand, silt, and clay) has either passed through the stream system, or is stored on floodplains (Peterson, 1995; Rutherfurd & Smith, 1992). It is the sand fraction of the sediment that we are interested in here, and this is often stored in the stream channel. This sand tends to move through stream systems in discrete slugs.

In the past, most research has focussed on the sources of sediment. However, there is a growing consensus that the rate of anthropogenic sediment yield to streams is declining across much of SE Australia. This means that the focus of research and management should now be turning to the fate of the sediment that is in storage in various parts of stream systems. The purpose of this paper is to briefly review the sources of sand in sand-slugs in S.E. Australia; the distribution of slugs in the region; how the sand moves through stream networks, and how the sand can be managed. I emphasise that large volumes of sediment have been stored on floodplains and other storage sites in catchments, but this paper concentrates on the movement of sand through stream channels.

2. SAND-SLUGS: DISTRIBUTION AND SOURCES OF SAND

Sand enters channels from point or diffuse sources. There are three major sources of sand to streams in SE Australia: mining, gully erosion, and catastrophic widening of streams. Figure 1 shows the distribution of some sand-slugs in S.E. Australian streams for which there are published descriptions.

2.1 Mining

A classic example of a point source of sediment is the Mt Lyle Copper mine in Tasmania (see Locher, this volume). This mine has released nearly 100 million tonnes of sediment directly into the Queen River (probably the largest single artificial source of sediment to an Australian stream). Mining can also produce 'multiple point sources' of sand where there are many mines. This was the case in the Ringarooma River in NE Tasmania where numerous mines introduced a total of 40 million m^3 of sediment into various tributaries, particularly in the period 1900-20 (Knighton, 1987). Numerous streams throughout Victoria were also inundated with sediment from gold mining between the 1850s and 1920s (Peterson, 1995; Sherrard, 1990).

2.2 Gullying

Rapid stream deepening, and drainage network extension, was a ubiquitous response to European settlement of Australia (Woods, 1983). Gullies developed rapidly, but most had reached a stable length by the 1950s (Abernethy & Prosser, this volume; Herron, 1993) Most of the sand released from gullies is stored in 'floodouts' high in the channel network and does not reach the trunk stream (Melville & Erskine, 1986; Rutherfurd & Smith, 1992) (Figure 1). An important exception, where sand from gullying has moved through the entire stream network, is in granite catchments. Granite catchments are dominated by sand-sized sediment, and clay and gravel are usually less abundant. Possibly because a higher proportion of the load is transported as bedload in these catchments, there are many granite catchments around Australia (Figure 1) where sand from channel network extension has reached even the largest streams within decades. Examples include the upper Lachlan and Murrumbidgee Rivers in NSW, and the Glenelg River in Western Victoria.

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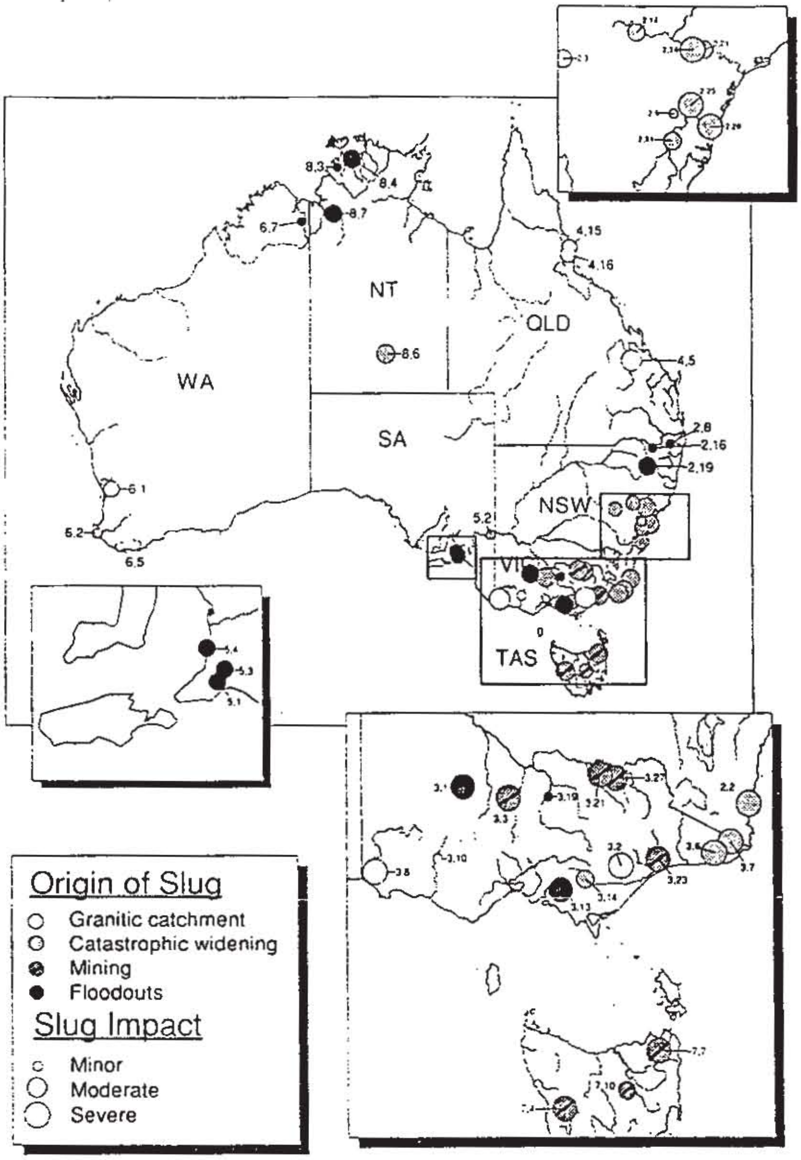

State	No.*	River/Creek	State	No.*	River/Creek
2	2	Bega	3	20	Pykes Creek
2	3	Bell	3	21	Sandy Creek
2	8	Clarence	3	22	Snowy
2	9	Colo	3	23	Tambo
2	16	Dumaresq	3	25	Thomson
2	18	Goulburn	3	27	Yackandandah Creek
2	19	Gwydir	4	5	Don
2	20	Hawkesbury	4	15	South Johnstone
2	21	Hunter	4	16	Tully
2	25	Macdonald	5	1	Hindmarsh
2	31	Nepean	5	2	Murray
2	38	Wollombi Brook	5	3	Nangkita Creek
3	1	Avoca	5	4	Onkaparinga
3	2	Avon	6	1	Avon
3	3	Bendigo Creek	6	2	Blackwood
3	6	Cann	6	5	Frankland
3	7	Genoa	6	7	Ord
3	8	Glenelg	7	4	King
3	13	Lang Lang	7	7	Ringarooma
3	14	Latrobe	8	3	Finniss
3	19	Pranjip Creek	8	4	Mary
			8	7	Victoria

Figure 1: Distribution of some published records of sand-slugs in Australia (incomplete) (Note: this map shows only streams for which there is a published account of sand-slugs. The published reference for each example can be found in Rutherfurd et al. (1995) by cross-referencing the code number for each stream) ("Slug impact" is a qualitative measure of the volume of sand involved in each slug or flood-out)

2.3 Catastrophic widening

Dramatic widening of streams during major floods provides a pulse of sand into streams. This can occur in the absence of human disturbance, but the magnitude of widening may be increased by removal of riparian vegetation. Several examples of such widening have been reported in Eastern Victoria and in the NSW coastal streams (Figure 1). The most prominent example of such widening was in the Hunter River in NSW. A series of floods in the 1940s and 50s, particularly the flood of 1955, transformed reaches of the Hunter River from a sinuous, single-thread channel, to a braided river (Reddoch, 1957). The sand released by this widening is still moving through the Hunter in discrete slugs (C. Thomas, pers. comm., 1995). In the same way, in-channel benches on the Goulburn River in NSW are periodically eroded by large floods. The liberated sand moves down the stream system as a slug, but is gradually redeposited as channel benches (Erskine, 1994). Floods from cyclones cause similar episodic widening of streams in coastal Queensland.

There are other sources of sand to stream channels, but mining, gullying in granite catchments, and catastrophic widening are the major sources. The length of time that the sand is being introduced into the stream varies from over a century in the case of some mines, to days or hours in the case of catastrophic channel widening. Most individual mining and gullying inputs last less than one to two decades. Once the supply of sand into the stream has declined, the most important management question is how does the pulse of sand move through the stream system?

3. FORM AND MOVEMENT OF SAND-SLUGS

G.K. Gilbert in his classic paper on hydraulic mining debris in California, suggested that sediment that is episodically introduced into a channel ..."is analogous to a flood of water in its mode of progression through a river channel. It travels in a wave"... (1917 p.31) . Thus the bed of the river will rise and then fall as the wave passes. Gilbert observed that both the amplitude of sediment waves, and their velocity, decline as the wave moves downstream. This model of sediment movement has been observed in many streams (Madej & Ozaki, in press; Pickup,Higgins, & Grant, 1983). For a single slug of given size, the rate of sediment transport declines downstream because the rate of bedload transport declines with small decreases in slope. The amplitude (depth) of the slug also decreases downstream because the sediment is 'sorted' as it migrates, with finer sediment moving further. This dispersion is described by Pickup (1983). I will describe some Australian examples that show the rate at which sand-slugs can move, and that illustrate that the simple 'wave' model can become more complex in reality.

3.1 Sand-slugs Formed by Catastrophic Widening

Sand-slugs generated by flood-erosion in the Goulburn River (NSW) move through the stream system within 3-4 decades (Erskine, 1994). This is shown by the rise and fall of the channel bed at gauging stations (Figure 2). The rapid rise and fall of the bed in the Goulburn, and in many similar streams, occurs partly because this river has a high bedload transport capacity, but also because not all of the sand slug is removed. That is, the sand fills the stream channel, but it is then incised by a narrow channel, leaving most of the sand as in-channel benches that will be re-eroded in the next major flood.

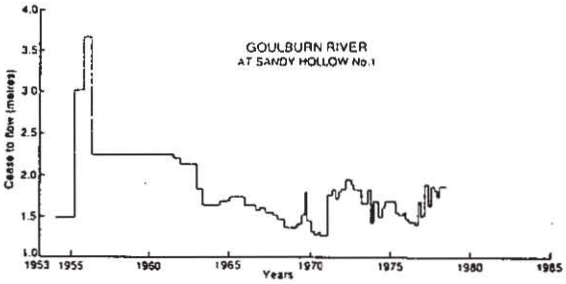

Figure 2: Bed level changes at Sandy Hollow Gauge No. 1, Goulburn River, NSW (from Erskine, 1995, p.147).

3.1 Sand-slugs Derived from Mining

Where sand enters a stream network from the catchment, rather than from erosion of the lower reaches (as in the Goulburn example) the transit time of the sand will be longer, and the interaction of the tributaries will make the process much more complicated. Knighton (1987; 1989; 1991) has described the complex movement of sand through the Ringarooma River stream network following over a century of inputs from some 20 tin mines. A model of bedload transport in the stream shows that the complex changes in bed-level in the upper reaches become progressively more regular with distance downstream. Close to the main source of sediment the bed had returned to its original level within 35 years of the cessation of mining, but the model predicts that it will be at least 50 more years before the sand-wave has moved through the lower reaches.

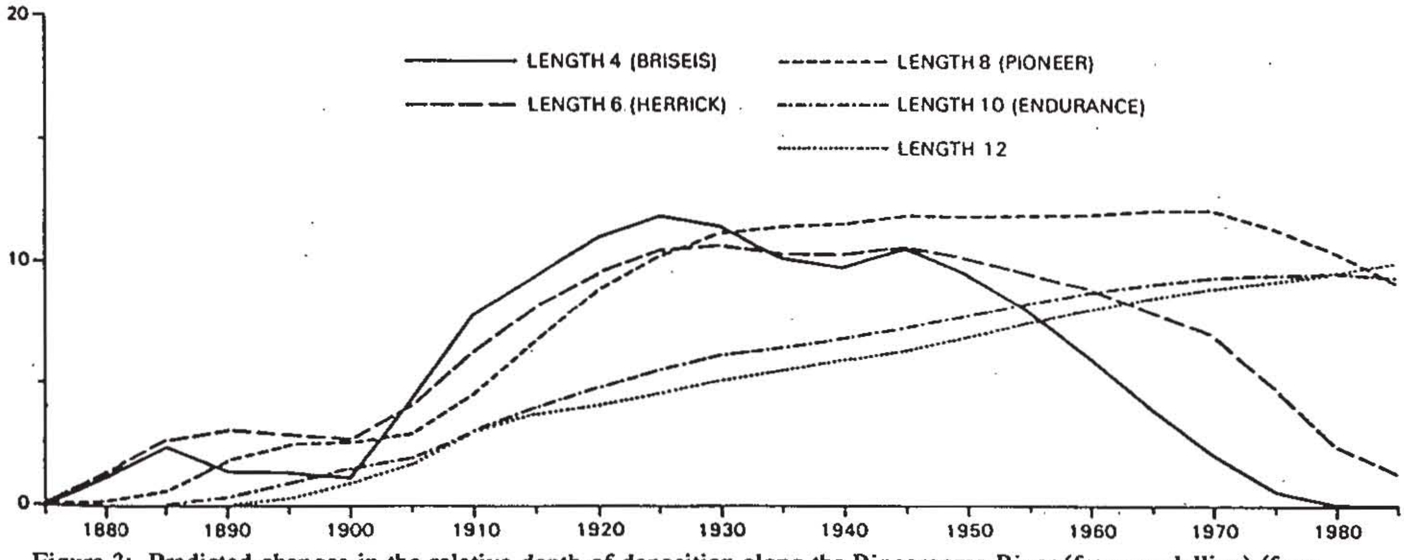

Figure 3: Predicted changes in the relative depth of deposition along the Ringarooma River (from modelling) (from Knighton, 1989). N.B. the reaches are numbered downstream. Thus one can see that the sand-slug has moved through the upstream reach 4, but the slug is still to peak in the downstream reach 12.

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The Ringarooma also shows a complex interaction between tributaries and the trunk stream. Where sediment from tributaries reached the Ringarooma before the main wave of sediment, they deposited a delta into the channel. In other cases, aggradation of the Ringarooma dammed the tributaries. The result is a classic 'complex response' situation (Schumm, 1973). That is, the wave of sediment in the Ringarooma will move downstream, but the tributaries will incise as their base-level falls, producing a continuous source of sediment to the system for many decades.

Another example of a sand slug is provided by the Tambo River in Gippsland (Erskine,Rutherfurd, & Tilleard, 1990). Gold mining in the late 1880s produced a slug of sand that moved through the 50 km long Tambo gorge. Remarkably, the bed-level at the Bruthen gauge (at the downstream end of the gorge) had already begun to rise by 1890, and had aggraded by 4 m within 10 years. Bed-level at Bruthen only began to fall in the 1960s. The front of the sand-slug is now marked by a 4m avalanche-face of sand in the channel. Even in large floods this avalanche face now moves less than 20m per year, in comparison with the 1000s of metres per year at which the slug migrated through the Tambo gorge.

3.3. Sand-slugs from Gully Erosion

The Glenelg River (and its tributary the Wannon) in Western Victoria provides another example of a complex response to sand input. Since the 1850s, gully erosion and, to a lesser extent, sheet erosion of the granite portions of the Dundas Tablelands have produced a reasonably uniform injection of sand into many tributaries of the catchment. The rate of sediment contribution is now declining (Erskine, 1994). There is between 4 and 11 million m^3 of sand stored in the Glenelg catchment, however, the interaction between the tributaries and the trunk stream means that the sand is spread discontinuously through the network (Rutherfurd & Budahazy, 1995). On the Ringarooma River, the tributaries were dammed by the slug in the trunk stream. In the Glenelg catchment, large sand loads from tributaries have fromed dams at the confluence with the trunks streams. As a result, sand movement through the Glenelg system is disjointed because it must first pass through the backwaters produced by these 'tributary junction plugs' (TJPs). Unlike the Ringarooma then, transmission of sand down the trunk streams depends on the decline of sediment yield from the tributaries, rather than on migration of the sand-slug through the trunk stream. This will lead to the removal of the TJPs and a new wave of sand down the trunk streams.

It is also interesting to note that the present distribution of sand in the Glenelg was in place by the 1940s, and has changed little since that time. Between the TJPs, sand is stored in discrete waves 200-1000m in length, but these do not change their position over time. Instead sand moves from wave to wave at a slow rate. It will certainly be centuries before the anthropogenic sand in the Glenelg River system will have moved through the stream network.

3.4 Summary of Case Studies

Some points from these cases studies can be summarized in the following points.

- On both the Tambo and Ringarooma, despite numerous point sources of sediment, the sand-slugs tend to coallesce into a single slug as they move downstream.
- Rates of migration decline exponentially downstream, reducing from 1000s of metres per year to 10s of metres. Sand typically evacuates the upper tributaries within a few decades, but it takes over a century to leave the lower reaches of streams.
- The bed-level will return to its original level more quickly when a large proportion of the sand is stored in lateral deposits such as benches.
- Damming of both the tributaries and the trunk stream can make the movement of sand through a stream network very complex.

4. MANAGEMENT IMPLICATIONS OF SAND-SLUGS

4.1 Impacts as the sand-wave peaks

There are several management implications of a sand-slug passing through a stream system. Sand-slugs influence flooding, erosion rates, stream ecology, and recreation. The primary effect of a sand-slug is to reduce channel depth. On the Glenelg River, sand occupies up to 75% of the cross-section. This reduces the frequency of low flows in the channel because water flows within the sand body. The reduced channel capacity also produces an increased frequency of minor flooding, although it probably has little impact on major floods.

Hydraulic geometry relations and other models of channel response predict that an increase in bedload should lead to an increase in channel width. There is no doubt that the width-depth ratio increases as depth decreases, but the absolute width of the channel does not increase unless the channel is completely filled with sand. I have not seen examples of streams in which a sand-slug has led to bank erosion. This is probably explained by the cohesive character of the banks in many of the lower reaches of streams affected by sand-slugs. A more common geomorphic effect of sand-slugs is channel avulsions because of the increased frequency and depth of flooding over the floodplain. A good example is the avulsion on the Tambo River where the combination of a sand-slug with willow infestation reduced channel capacity and triggered a full channel avulsion for a distance of 7.4 km.

Converting a narrow and deep channel, with regular pools, into a featureless sheet of sand, has disastrous ecological consequences (Alexander & Hanson, 1986). On the Pranjip-Creighton Creek system in Victoria the migration of a slug of sand through the creek has not only destroyed habitat, but it has also led to a change in seasonal diversity (O'Connor & Lake, 1994). Because the sandy substrate is more mobile than the original bed, it is scoured every winter. This produces large declines in macroinvertebrate species richness and poulations. In addition, the water temperature increases in the shallower water over sand-slugs.

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4.2 Impacts as the sand-wave passes

As the sand-slug passes, and the channel deepens again, there are a new suite of management issues. When sand-slugs have moved through catchments, the channel is likely to begin a new phase of erosion. This will occur for two reasons, first, because erosion and channel adjustment that was interrupted by the sand-slug will continue; and second because the channel will be subjected to the new anthropogenic flow regime. For example, the channel may have been in a phase of erosion that was interrupted by the arrival of the sand-slug. This was the case in Bryan Creek, a tributary of the Wannon River in Victoria. Bryan Creek was originally a chain-of-ponds that was drained. This triggered a phase of erosion last century that was interrupted when the sand-slug arrived. The extraction of 415,000 m^3 of sand from the creek from the 1950s removed the bulk of the sand-slug. This was followed by up to 2 metres of incision upstream of the extraction. This incision has been explained by the reduction of sediment yield from the catchment (Erskine, 1994), but it could equally be explained by a simple continuation of the erosion that was already occurring in Bryan Creek before the sand-slug arrived.

Similarly, sand-slugs have also protected channels from erosion caused by a changed flow regime. Since sand-slugs can take several decades to move through a reach, conditions in the catchment may change in the intervening years. When humans transformed catchments from forest to pasture they increased flood peaks and volumes (Burch,Bath,Moore, et al., 1987). In addition, the development of a gully network alone can increase flood peaks by up to 20% (Rutherfurd,Hoang,Prosser, et al., In press).

5. MANAGEMENT OPTIONS FOR SAND-SLUGS

The first task when managing sand-slugs is to estimate the volume of sediment in storage, and the second is to estimate the rate at which the slug is moving. The former is best estimated by probing combined with repeat cross-sections. The latter can be estimated by the migration rate of the front of the sand wave, and sediment transport modelling (Knighton, 1989; Pickup, et al., 1983). Knowing the volume of sand and the rate of migration, there are several management options for sand-slugs. One is to do nothing, and wait until the slug passes. In some cases this option is not viable. The slug could be moving rapidly toward some asset. For example, the Tambo slug is moving into the portion of the river that is one of the prime Bass breeding sections of the Gippsland Lakes. Similarly, the slugs in the Glenelg are moving into the Nelson National Park - a Heritage River under Victorian legislation. However, in both the Tambo and Glenelg, the present rates of migration suggest that it will take several decades for the sand to reach the sensitive reaches. Another example would be where a slug is moving into an urban area where it will increase flooding. If the 'do-nothing' option cannot be tolerated, the sand must be manually removed. Stream sand is often prized by the aggregate industry, and extraction of the sand can be used to raise revenue that can be used to improve the management of the stream (eg. revegetation, or buying environmental flow allocations).

A sand-slug represents a temporary storage of sand in a reach. It is important to appreciate that this sand can be artificially extracted without triggering the type of up and downstream erosion described by Galay (1983). Extraction will certainly lead to erosion of the sand slug, but not of the original channel into which the sand-slug has migrated. However, it is important to appreciate that, as discussed above, once the sand is removed, the stream may well begin to deepen because the stream is no longer protected by the sand. In addition, the increased depth of the channel could lead to increased bank erosion simply because the banks will be relatively higher.

6. CONCLUSIONS

Mining, stream incision (gullying), and catastrophic widening of streams since European settlement, , have released waves of sand that have choked stream channels in SE Australia. These sand-slugs are among the most obvious of human impacts on stream channels. Sand-choked channels are particularly common in streams that drain granite catchments. Sediment yields from mining and gullying are generally declining across SE Australia, reducing sediment supply to the upstream end of the slugs. As a result a major management issue is the dynamics of these sand-slugs.

A single injection of sand into a stream will pass through the stream channel as a discrete wave or slug, often with a well defined 'snout'. In many streams, however, the movement of sand is more complicated. Where the injection of sand to the stream network occurs from many points, over a long period, more complex sediment transport occurs - particularly because of interactions between sand moving down the tributaries and the trunk.

The rate of migration, and the amplitude, of the sand wave in Australian streams typically declines as it move downstream. A typical slug would move at 1000s of metres per year in the headwaters, declining to 10s of metres per year in the lower reaches. Depending on the size of the stream (Lewin & Macklin, 1987), it will typical takes more than a century for bed-levels to return to their former levels throughout the stream system. Large volumes of sand will remain in storage in floodplains and benches for longer periods.

The progressive waning of sand-slugs over coming decades (particularly in headwater streams) will probably be followed by a new phase of channel erosion. This is because, in some cases, the sand has protected the channel from higher flood peaks from cleared catchments and gully networks; and because the erosion that was halted with the arrival of the slug will resume when the slug is gone. Removing the sand-slug manually is a very real management option. Because the sand-slug represents a store of sand in the channel, its artificial removal will not lead to up or downstream erosion of the

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original cross-section, however, removing the sand will remove the protection that the sand provides, thus bringing forward the expected erosion in the channel.

The significance of sand-slugs must be seen in terms of time scales (Meade, 1988). Over the time scale of decades, sand-slugs can be seen as devastating changes in stream morphology, with many secondary effects. However, over longer time-scales of centuries, sand-slugs are transitory features that will pass through stream systems.

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