Low Australian sediment yields - a question of inefficient sediment delivery?

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ABSTRACT. Research has suggested that Australian sediment yields are very low with Walling & Webb (1983) listing Australian yields among global minima. Recent work on soil erosion and plot scale soil loss has however reported high sediment loads. This paper examines the features and characteristics of Australian sediment yields and outlines possible controls particularly with respect to sediment supply and stream flow regimes. It also examines sediment delivery especially in the inland basins and examines its role in the resulting low sediment yields.

INTRODUCTION

Australia has long been noted for its low sediment yields. Much of the continent consists of desert with no real drainage system but even in the wetter areas the reported yields have been low by world standards. Walling & Webb (1983) report Australian yields at less than 100 t km^{-2} yr^{-1} and several Australian results represent global minima. However, in a major review of soil erosion, a Government Soil Conservation Study (Dept. Environment Housing and Community Development 1978) found that approximately half the land used for pastoral and agricultural purposes in Australia, representing about 2 700 000 km^2, suffers from soil erosion and requires conservation treatment of some type at a total estimated cost of $A675 million. Also small scale studies of soil erosion in agricultural areas have found extremely high sediment concentrations and loads. These high loads are not reflected in continental erosion rates. This paper examines Australian sediment yields and attempts to explain the resulting pattern and examines the yields in the context of sediment delivery.

AUSTRALIAN SEDIMENT YIELDS

Studies of sediment yields in Australia have been limited in scope and geographical extent. There is no systematic long term monitoring programme and most early studies were restricted to short term thesis type studies with a restricted monitoring programme over a period of one to two years. These studies were restricted to small basins predominantly in south eastern Australia. Recently, more intensive problem oriented programmes have been established concentrating on basin disturbance due to changing human land use. In particular these have examined the influence of logging operations in native forests, agricultural activities and mining operations. Very little work has been done on major rivers because of their perceived low sediment yields which are not seen to pose any major problems and research in these basins has concentrated on issues thought to be more critical such as salinisation. As a result very little is known of sediment transport of the major Australian drainage basins.

The results of research into sediment yields in Australia have been reviewed by Olive & Walker (1982) and Loughran (1984) and are summarised in Table 1. The locations of the basins concerned are shown in Fig. 1. Care must be taken with this data as the studies are based on variable data bases with a range of techniques in field, laboratory and data analysis being used and as a result direct comparison of results is difficult. The reliability of the data is also variable with the types of problems and errors involved being similar to those outlined by Walling (1978) and Walling & Webb (1981). Most studies have involved the use of rating curves with their inherent problems (Walling 1977) and Australian studies (Geary 1981 and Olive et al.1980) have shown that this technique can result in large scale underestimations of load.

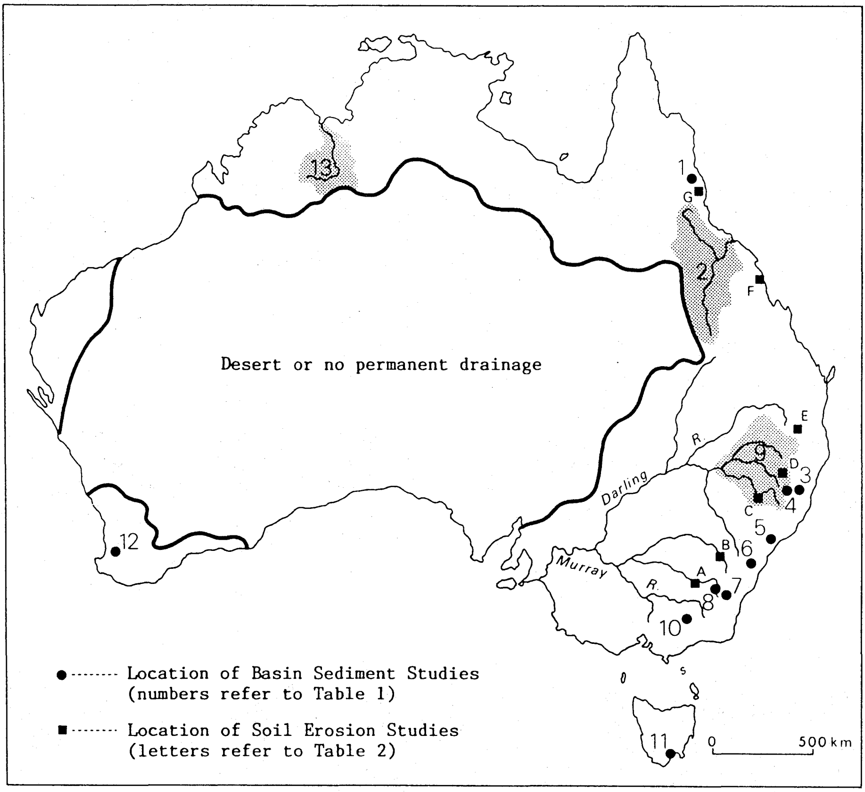

FIG. 1 Location of Australian basin and soil loss studies.

From the table it is obvious that only a small part of Australia has been studied and most studies have concentrated on small basins with only three studies involving larger scale basins namely the

TABLE 1 Australian basin sediment yields

Basin	Map locality (Fig. 1)	Area (km^2)	Mean Ann Rain (mm)	Sediment Yield ($t\ km^{-2} yr^{-1}$)	Source
Queensland					
Tully R	1	44-585	1015-	8-45	Douglas (1973)
Herbert R	1		2235		" "
Babinda	1	15	4320	480	" "
Burdekin R	2	129 500	400-2 900	23.17	Belperio (1979)
New South Wales					
Macleay R	3	7.5-20	1 500-2 000	138-179	Loughran (1969)
Chandler R	3	208	950	6.2-8.4	" (1976)
Macleay R	4	<16	872-1 066	.33-12.52	Field (1985)
Congewai Ck	5	85.5	1084	28	Loughran (1977)
Deep Ck	5	25	764	121-232	Geary (1981)
Macquarie R	6	1-7	1 500	8-17	Douglas (1973)
Queanbeyan R	7	284	475	2.7	" "
Goodradigbee R	8	26-216	400-1 000	1.5-11.7	" "
Barwon R	9	139 000		2.9	Taylor (1976)
Victoria					
East Kiewa R	10	1.4-2.4	1850	9.9-19.5	Leitch (1982)
Tasmania					
Browns R	11	13	680-1 220	12	Olive (1973)
Mountain R	11	40	780	11	" "
Snug Rivulet	11	19	1 140	12	" "
Western Aust					
Wights R	12	0.93	1 150	57	Abawi & Stokes (1982)
Ord R	13	46 100	400-800	634	Kata (1978)

Barwon, Burdekin and Ord Rivers. It must be remembered however that a large part of the Continent is covered by desert with no permanent drainage basins (Fig. 1).

From the data presented and allowing for variability in techniques and their associated errors the majority of loads reported are low by world standards. Most have loads less than 50 t $km^{-2}yr^{-1}$ and many have loads in the range 0-10 t $km^{-2}yr^{-1}$. The only higher loads reported occur in basins which have been disturbed by agriculture where loads of 120-240 t $km^{-2}yr^{-1}$ have been reported and two results from northern Australia where loads of 480 and 634 t km^{-2} yr^{-1} were estimated. The Babinda Basin (480 t km^{-2} yr^{-1}) lies in tropical north Queensland an area of very high annual rainfall and rainfall intensities where rainfall energy is up to an order of magnitude greater than in temperate south eastern Australia (Olive & Walker 1982). The Ord River (634 t km^{-2} yr^{-1}) in north western Australian has an annual rainfall of only 400-800 mm but this occurs as high intensity storms during the monsoonal "wet" and much of the basin has accelerated erosion related to the pastoral industry.

A comparison of these results with the generalised pattern suggested by Walling & Webb (1983) shows a good correlation for most of the results except for the high yields already discussed. Walling & Webb show all Australian yields under 100 t km^{-2} yr^{-1} but it is now apparent that much higher yields occur in northern Australia although the data is at present scanty. Research currently being carried out in this area is likely to further clarify the situation. It is clear however that the major part of Australian has low sediment yields.

WHY ARE YIELDS LOW ?

Australia has a very distinctive environment and any attempt to explain sediment yields or compare them with the world pattern must be made in the context of this environment. The major environmental factors which influence sediment transport and particularly the availability of transportable material have been outlined by Olive and Walker (1982) and are:

(a) rainfall characteristics and associated run-off
(b) soil characteristics
(c) vegetative cover

Australia is the driest continent and its rainfall is both spatially and temporally variable. Olive & Walker (1982) have shown that a wide range of rainstorms energies occur where annual frequency tropical storms in north Queensland can deliver as much energy as 1 in 100 year events in south eastern Australia so there is a wide range of erosive potential. The streamflow regimes of Australian rivers are extremely variable with mean annual runoff ranging from 689 mm in Tasmania to 22 mm in the Murray-Darling system (Munro 1974). Temporal variability is particularly high and MacMahon (1982) found in Australian streams a co-efficient of variation of annual flows three times the world average, while the semiarid streams were five times more variable than the world average. This feature of low annual runoffs and high variability leads to a greater dominance of storm or flood events in the stream regime.

The Australian continent is one of great geological age and generally low gradients which has resulted in deep chemical weathering and size reduction to clay-rich material which provides a store of easily transportable material. Walker & Hutka (1979) have found that the B horizons of podsolic soils have a high proportion of fine clay (< 2 um) providing sources of easily transportable colloids. The distribution of these soils corresponds with the areas of highest population density and large areas of cultivation which tend to increase erosion potential.

The natural vegetation of Australia exhibits less variation than most areas due to the ubiquitous eucalypt. This tends to reduce variations in sediment yield as Moss (1979) has shown that vegetative cover is the major controlling factor. Much of the natural vegetation, however, has been disturbed and replaced over the last 200 years with the advent of European man.

While some of these factors tend to lead to lower sediment yields many parts of Australia have a high potential for stream sediment transport with a large supply of very fine material which requires little energy for transport, abundant incident energy from rainfall even if this energy is temporally variable and in many cases a reduced vegetation cover due to man's activities. Research results have suggested however that Australian sediment yields are very low. To explain this situation a number of factors are important.

The low annual runoff and the variability of runoff are obviously key factors. Australia's largest basin the Murray-Darling system with an area of over 1 million km^2 has an annual runoff of only 22 mm which greatly reduces its ability to transport sediment. The variability of flow is also important as storm or flood events become more dominant in the erosion history of the rivers and as a result infrequent catastrophic events may be responsible for the majority of sediment transported. For example, in the Ord River over a twelve year period annual yields ranged from 36.8 to 2 104 t km^{-2} yr^{-1} (Kata 1978). In a study by the authors of small basins in south east New South Wales over an 8 year period one large storm accounted for 50 to 70% of the measured storm sediment transported. Because of the dominance of these events, any representative long term yield must be based on a longer termed record which includes all the flow regime. Most previous research in Australia was based on short records which would generally not include the largest events and so could underestimate the long term loads. The importance of the extreme events in the long term erosion history needs further research.

As well as the low runoffs exhibited many streams have low gradients further reducing their ability to transport sediment. This is marked in the Murray-Darling system where gradients are particularly low and in some reaches the river has negative bed gradients. Walgett on the Darling River approximately 2 000 km from the river mouth is only 140 m above sea-level.

Sediment concentrations in Australian Rivers are also low by world standards. In areas of native eucalypt forest, where vegetation is relatively undisturbed, concentrations rarely exceed 500 mg l^{-1} and in most cases are much lower (Loughran 1985). This situation is also common in many grassland grazing areas although where overgrazing has occurred concentrations are higher. Only in basins where the ground cover has been disturbed by man's activities are concentrations significantly higher. Concentrations exceeding 10 000 mg l^{-1} have been reported in the Ord River (Kata 1978) and in a vineyard in the Hunter Valley (Geary 1981). In many cases however post disturbance concentrations are low by world standards. In a logging operation in North Queensland where annual rainfall exceeded 4 000 mm Gilmour _et_ al. (1982) reported maximum concentrations of 4 000 mg l^{-1}. Olive & Rieger (1986) reported maximum concentrations of 2 500 mg l^{-1} in a small basin which had been subjected to clear-felling and a very intense wildfire.

In all the studies, suspended sediment has been clearly supply limited. Although there is often a large supply of fine material this may not be readily available for transport. In several studies sediment exhaustion has been reported (Gilmour et al. 1982 and Geary 1981). In the Eden basins in south eastern New South Wales, Olive & Rieger (1985) reported marked sediment exhaustion in multiple-rise storms. This pattern was also observed in a logged and burnt basin when sediment supply was apparently optimised (Fig.2). Sediment exhaustion was still evident when concentrations were examined with respect to quick-flow (Rieger & Olive 1984) which is at variance with the results reported by Walling & Webb (1982) at Exeter. It does appear that while there is an apparent abundant supply of fine material this is difficult to detach particularly as a storm progresses. More research is necessary in determining the sources of sediment in Australian basins and particularly to examine the interaction of sediment source areas with the variable-source areas of runoff generation which appear common in many small Australian basins (O'Loughlin 1981) .

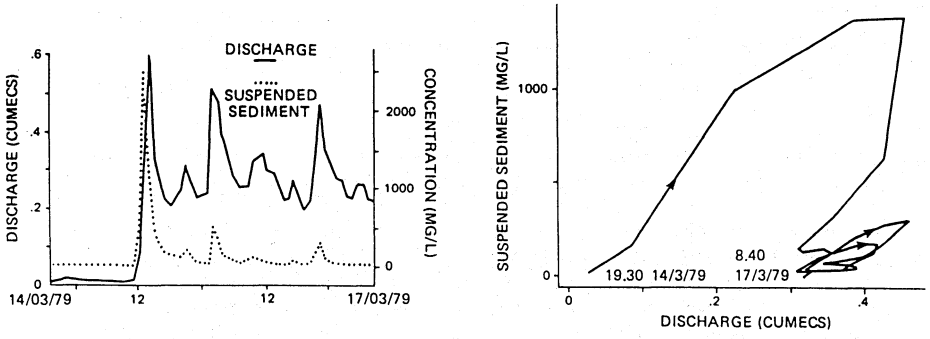

FIG. 2 Sedigraph and hysteresis loop for a storm in Stringybark Creek.

Clearly in Australian streams a number of factors operate resulting in low sediment yields. The supply of transportable material in many cases is limited resulting in low sediment concentrations. Runoff is generally low and extremely variable and in the major inland rivers gradients are low so the energy available for transport is minimal. A key question which arises from the interaction of these factors is that of sediment delivery. Is a major contributing factor to the low sediment yields one of inefficient sediment delivery?

SEDIMENT DELIVERY

While the reported sediment yields of Australian basins are generally low, research into soil erosion and plot scale sediment transport has reported high concentrations and loads which suggests that sediment delivery of basins is inefficient. Insufficient data on soil erosion are available to make a synthesis of the Australian situation but in a review of the available data Olive & Walker (1982) reported losses at rates of up to 38 200 t km^{-2} yr^{-1}. A consolidation of the data is shown in Table 2. A single storm event in the Darling Downs southern Queensland removed soil at the rate of 10 000 t km^{-2} (Kamel 1980).

Again the bulk of soil erosion losses over a long period could be attributed to a few storm events and Adamson (1974) found that 89% of soil loss at Wagga Wagga NSW was attributable to storms in 5 out of 22 years of record. While river sediment loads are low, soil erosion on hillslopes can be very high particularly in cultivated areas.

TABLE 2 Soil erosion losses

Location	Locality (Fig. 1)	Area	Annual Soil Loss (t $km^{-2}yr^{-1}$)	Source
Wagga Wagga	A	40m^2-7ha	3-210	Adamson (1974)
Cowra	B	std runoff plot	23-220	Packer & Aveyard (1981)
Gunnedah	C	40m^2-1ha	3-780	Edwards (1980)
Inverell	D	std runoff plot	6 000-6 600	Armstrong (1981)
Darling Downs	E	up to 1ha	100-5 300	Ciesolka & Freebairn (1982)
Mackay	F	std runoff plot	4 200-22 700	Anonymous (1981)
Innisfail	G	small field	9 000-38 200	"

Very little effort has been made to attempt to explain these major variations where much of the soil eroded from hillslopes is not transported into and through the river systems. Loughran (1975) reported a steady downstream decline in sediment yield in Congewai Creek an 85 km^2 basin in the Hunter Valley. Ciesiolka & Freebairn (1982) examined sediment delivery in the Darling Downs in Queensland, an area of cracking clay basaltic soils. They examined soil loss at three scales; a 0.2 ha rill within a contour bay, a 1 ha contour bay and a 250 ha basin. Peak sediment concentrations decreased from 65 600 mg l^{-1} in the rill to 18 000 in the contour bay and 9 400 in the basin while storm sediment loads decreased by an order of magnitude. The majority of the total transported material was deposited before it reached the trunk streams. In this area much of the soil loss is deposited as large low-angled alluvial fans which fill the valley floors and where re-incision is active.

The results of Ciesolka & Freebairn are significant as their research area is in the upper reaches of the Murray-Darling basin. While the situation on the Darling Downs is probably the extreme, high soil erosion rates have been reported from other headwater areas where cultivation, particularly for grain production, is extensive. While the Darling Downs has reported annual soil losses of up to 5 300 t km^{-2} yr^{-1}, at Gunnedah losses of up to 780 t km^{-2} yr^{-1} have been observed and in a plot experiment there Marschke & Rosewell (1984) reported plot scale losses of up to 34 600 t km^{-2} yr^{-1} and those of a 1 ha contour bay of 26 600 for an individual storm with maximum concentrations of 160 700 mg l^{-1}. Unfortunately there is no data available on intermediate sized basins downstream of these studies but they can be compared with the results of Taylor (1976) for the Barwon River at Walgett. The Gunnedah basins feed directly into the Barwon while the Darling Downs basins enter the Darling system below Walgett. The Barwon with a basin area of 139 000 km^{2} had a sediment load of 2.9 t km^{-2} yr^{-1} some three orders of magnitude less than the erosion rates reported in the headwater areas. Also Walker et al.(1974) reported maximum sediment concentrations of less than 300 mg l^{-1} and that 77-95% of the suspended load was finer than 2 um so the majority of the coarse fraction had already been deposited.

The decrease in load and concentration is not just related to inefficient delivery however, as not all of the basin contributes high sediment concentrations and there is a dilution factor which would reduce the high concentrations from the cultivated areas of the headwaters. The Murray-Darling basin, Australia's largest, appears to provide a very interesting situation in relation to sediment delivery and much further research is necessary to clarify what is at present a very sketchy picture. It does appear in this basin that the low sediment yields are a result of a very inefficient sediment delivery system related to the environmental conditions of rainfall, run-off and low stream gradient.

While this situation exists in many of the low gradient inland streams, inefficient sediment delivery is not the sole explanation of the low sediment yields. In many basins concentrations and loads are low even in the headwaters and sediment supply appears to be the major limiting factor on sediment transport rather than sediment delivery.

CONCLUSIONS

Australia has consistently been regarded as a continent of very low sediment yields. While this is generally the case, recent evidence has suggested that higher yields do occur in Northern Australia where rainfall and runoff are much higher. The low sediment yields can be partially explained in terms of limited sediment supply resulting in low sediment concentrations and in the generally low and variable basin runoff. Some of low yields however, appear to be a result of extremely inefficient sediment delivery. This is particularly marked in the Murray-Darling basin where very high sediment concentrations and loads have been observed in the headwaters while downstream low concentrations of predominantly clay sized sediment result in extremely low yields. The low gradient inland Australian rivers appear to offer a unique opportunity to examine the mechanisms of sediment delivery.

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