Erosion and Sediment Yield: Global and Regional Perspectives (Proceedings of the Exeter Symposium, July 1996). IAHS Publ. no. 236, 1996.

Rates of erosion and sediment transport in Australia

R. J. WASSON
Division of Water Resources, CSIRO, PO Box 1666, ACT 2601, Australia

L. J. OLIVE
School of Geography and Oceanography, University College, UNSW, Australian Defence Force Academy, Canberra, ACT 2600, Australia

C. J. ROSEWELL
Department of Land and Water Conservation, Soil Conservation Research Centre, Gunnedah, NSW 2380, Australia

Abstract Soil erosion is a serious issue in Australia and this paper attempts a continental synthesis of erosion, fluvial sediment transport and sediment delivery to the coast. Continental soil erosion is estimated to be 28×10^9 t year^{-1} of which about 50% is from sheet and rill erosion and the remainder from gully and river channel erosion. The rill and sheet erosion is 19% of Pimentel's global estimate from 5% of the world land area. Modern rates of erosion have increased by a factor of up to 145 compared to the natural rates before human disturbance. River transport rates are relatively low due to inefficient sediment delivery in keeping with the arid and low lying nature of the continent. Much of the river sediment is derived from gully sources and while sheet and rill erosion are high, little of this material is delivered to rivers. The modern flux to the oceans is about 302×10^6 t year^{-1} or 2% of the estimated global flux (Milliman & Syvitski, 1992) which appears approximately double that pre-human disturbance. The continental sediment delivery ratio is 3%.

INTRODUCTION

It is a curiosity that in a country where soil erosion is said to be a serious issue for agriculture, water resources, and the coastal environment (Commonwealth SoE Report, in press; State of the Marine Environment Report, 1995) there have been few attempts to provide a quantitative national summary of the phenomenon. There have been several earlier reviews of erosion data (Olive & Walker, 1983; Loughran, 1984 and Rieger & Olive, 1988) but these are now dated and have not really attempted a continental scale synthesis. In this brief paper, we note the nature of available data, present partial syntheses, draw conclusions arising from some of these syntheses, and at the continental scale make comparisons with global summaries. Many of the approximations in this paper should be considered only as starting points for further refinements.

AUSTRALIA-WIDE EROSION AND SEDIMENT YIELD

Small-scale sheet and rill erosion

Measured rates of soil loss from small plots on low gradient hillslopes provide the traditional means of estimating erosion at small scale. Numerous plot studies have been carried out in Australia, and a version of the RUSLE (Renard *et al.*, in press) (called SOILOSS) has been created for local use (Rosewell, 1993a). SOILOSS has been applied nationally (Rosewell, in press). The R factor was calculated using the algorithm of Rosewell (1993b); the K factor was estimated from the *Digital Soils Atlas of Australia*; L and S were estimated from the landform attributes attached to map units in the *Digital Soils Atlas*, rather than from the currently available low resolution DEM; the C factor was estimated from the digital form of the *Atlas of Australian Resources-Vegetation* using the data in the SOILOSS Handbook; and P was assumed to be 1, that is, there are no erosion support practices. It is suspected that the C and S factors are overestimated, and that the maximum calculated rates of sheet and rill erosion are too high.

The drainage basins of Australia can be divided into those that drain to the sea and those that drain to the interior (endorheic). Fully 47% of the surface of Australia is endorheic, of which 74% produces no measurable runoff (the Western Plateau) (Warner, 1986). Based on Rosewell's calculations the total sheet and rill erosion for an "average' year is 13.94×10^9 t, of which 9.62×10^9 t (69%) occurs in the area of external drainage. The total rate is about 19% of the global estimate (Pimentel *et al.*, 1995) even though Australia is only about 5% of the world's land area. It is surprising that Australia should have an above average erosion rate, given the continent's low gradients and arid climate. But the highest modelled rates of sheet and rill erosion occur in the rangelands of northern Australia where on-the-ground estimates are as high as 7000 t km^{-2} year^{-1} (Wasson *et al.*, 1994), along the eastern uplands where rates as high as 15 000 t km^{-2} year^{-1} occur in areas of tropical cropping (Prove, 1984), and in parts of the arid zone where rates up to 20 900 t km^{-2} year^{-1} (Fanning, 1994) have been measured. It is also possible that the global estimate is incorrect.

The sheet and rill erosion represents an average continental lowering rate of 2.5 m 1000 year^{-1} (density = 1.4 g cm^{-3}). Pre-disturbance by humans, and long-term, lowering rates have been estimated for rock surfaces by Stone *et al.* (1994) and by Bierman & Turner (1995) using ^{36}Cl, and ^{10}Be and ^{26}Al respectively. Stone *et al.* estimate rates for nearly flat-lying limestone across Australia of 0.003 to 0.021 m 1000 year^{-1} over a period of ~500 000 years. Bierman & Turner (1995) estimate a rate of 0.0007 m 1000 year^{-1} for the tops of granite domes in South Australia. Van de Graaf (1981) estimated a vertical lowering rate, for the Precambrian Yilgarn Plateau of southern Western Australia, of about 0.005 m 1000 year^{-1} since the Cretaceous.

Other lowering rates have been estimated using geomorphic techniques (see Stone *et al.*, 1994, for a partial summary) and are of similar magnitude to those listed above, reflecting both soil and rock lowering. Although insufficient data exist for a continent-wide estimate of lowering rates before the modern era of agriculture, it seems that the modern rate of 2.5 m 1000 year^{-1} is about 145 times higher than the average currently estimated long-term rate, even though the modern rate is probably exaggerated. This is consistent with the conclusion of Edwards (1991) that modern erosion rates are much higher than soil formation rates, considering that where rock is exposed naturally the rock lowering rate is lower than either the soil formation or loss rate, and over long periods the residual soil mantle is lowered at a rate on average the same as the bedrock beneath it.

Caesium-137 and ^{210}Pb have been used in a number of places in Australia to estimate erosion rates at small scale, and Loughran & Elliott (1996) report in this volume the results of the largest survey using ^{137}Cs yet completed.

Gully and river channel erosion

Wasson (1994) summarized then existing knowledge on gully erosion rates in Australia, and since then the only addition to our knowledge has been the production of a gully density map for NSW, ACT, Victoria and Tasmania. An Australia-wide approximation is offered, in the speculative mode of this paper, by assuming that where gullied lands exist they increase the sediment yield of basins < 10 km^2 in area by 10, as is the case on the Southern Tablelands of NSW and the ACT. About 10% of Australia is significantly gullied, and if we assume that in these areas the spatial frequency of sheet and rill erosion rates is the same as over the continent as a whole, then gullies add a further 14×10^9 t year^{-1} to the continental erosion rate. The estimated total sheet, rill and gully erosion is therefore 28×10^9 t year^{-1}.

There is currently no similar estimates for river channel erosion rates. Numerous cases have been investigated and recently summarized by Rutherfurd (in press). The only broadscale estimate is by Rutherfurd for the state of Victoria, where river channel and gully erosion amounts to $>50\%$ of the total post-European erosion. This estimate is consistent with that derived for the relative significance of sheet and rill and gully erosion across the continent.

Sediment yields from 1000 km^2 catchments

A convenient basin area for summarizeng Australian sediment yield data is 1000 km^2, for the following reasons: there are sufficient data to provide a reasonable summary; the between-basin coefficient of variation of the mean annual yield is about the same for basin areas between 100 and 10 000 km^2, at least in the southeast (Wasson, 1994), showing that 1000 km^2 areas are not peculiar; and such basins are not so large as to straddle major climatic boundaries, thereby complicating the interpretation of changes of yield with catchment area. Figure 1 depicts the 1000 km^2 yields for the same regions discussed by Wasson (1994).

Each of these yields is the result of transport of the products of sheet, rill, gully, and river channel erosion, modulated by storage. Insufficient data currently exist to estimate all of these components for each region of Fig. 1, but the tracers ^{137}Cs and ^{210}Pb can be used to estimate the amount of surface soil in transport. Current estimates from various parts of the continent indicate that in catchments >10 km^2 most of the sediment in transport is from subsoils, liberated by gully and river channel erosion (Wallbrink *et al.*, 1996). But these results do not necessarily apply to the entire continent.

At this stage, there is no general explanation of the pattern of 1000 km^2 yields that would allow interpolation between the regions on Fig. 1.

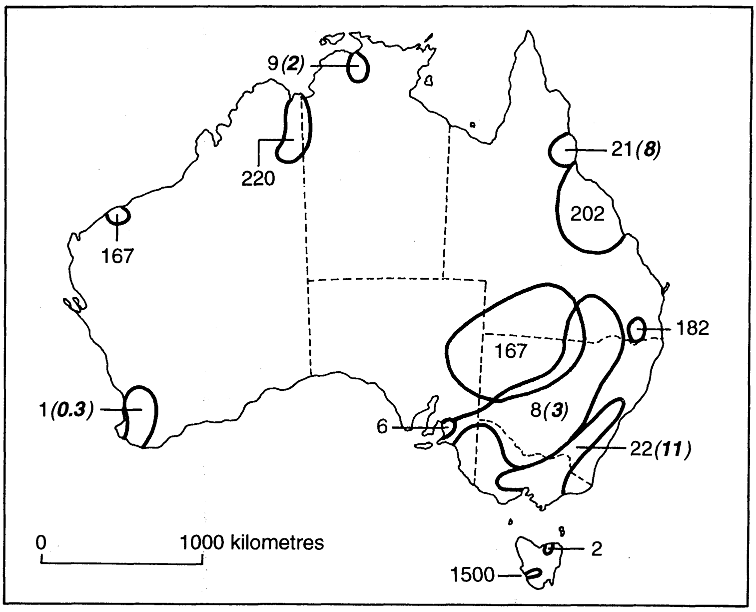

Fig. 1 Mean annual sediment yield for 1000 km^2 rural basins (10^3 t year^{-1}) for disturbed basins; and undisturbed in brackets. The southwest Tasmania estimate is for the King River, coming from a mine. Based on Wasson (1994).

The pre-European settlement rates are also shown on Fig. 1. They are between two and five times lower than the modern (post-settlement) rates, and are based on yields from undisturbed catchments.

SEDIMENT YIELD TO THE COASTAL ZONE

Harris (1995 and personal communication) has estimated the pre-European mean annual flux of sediment to the coastal zone by assembling all measured yields and then adopting usually the lowest yield to reflect the undisturbed' state. By using the same approach, but judging which modern yields from "disturbed" catchments are representative of each Drainage Division, a post-European flux has been calculated (Table 1). Harris' yield for the Murray-Darling basin of 30 × 10^6 t year^{-1}, which appears to be based on figures commonly quoted whose origin is unclear (see Milliman & Syvitski, 1992), is too high based on current information. The yield figure would give a current mean sediment concentration of over 6000 mg l^{-1} much higher than the actual average of less than 200 mg l^{-1}. The only loads determined for the Murray-Darling are for the Barwon River at Walgett 400 × 10^3 t year^{-1} (Taylor, 1976), the Murray River at Tocumwal about 270 × 10^3 t year^{-1} (Thoms & Walker, 1992) and the Murrumbidgee River at Balranald 80 × 10^3 t year^{-1} (Olive *et al.*, 1994). While there are additional tributary contributions downstream of these locations their additional load is unlikely to be greater than the decrease in load due to deposition in these inefficient systems. A figure of 1 × 10^6 t year^{-1} has been used as a more realistic figure but this needs refinement and has a large error term associated with it.

Table 1 Estimates of pre- and post-European sediment flux to the Australian coastal zone.

Drainage division	Area (10^3 km^2)	Adopted pre-European specific yield (t km^{-2} year^{-1})	Pre-European total yield (10^6 t year^{-1})	Adopted post-European specific yield (t km^{-2} year^{-1})	Post-European total yield (10^6 t year^{-1})
I. Northeast coast	430	69	29.5	200	86
II. Southeast coast	274	3.9	0.8	50	14
III. Tasmania	68	12	0.82	25	1.7
IV. Murray-Darling	1060	15.9	0.5	28	1
V. South Australian Gulf	82	2.4	0.2	5	0.4
VI. Southwest coast	315	9.5	3	20	6.3
VII. Indian Ocean	519	9.5	5	20	10.4
VIII. Timor Sea	547	65	33.9	100	54.7
IX. Gulf of Carpentaria	641	86	55.1	200	128
			129		302

Based on Harris (1995, and personal communication).

The post-European flux is estimated to be about twice the pre-European flux, a factor consistent with estimates based on dated sediment cores from Lake Alexandrina at the mouth of the 1.6 × 10^6 km^2 Murray-Darling River basin (Barnett, 1994). The estimated 302 × 10^6 t year^{-}1 modern flux is about 2% of the estimated global flux (Milliman & Syvitski, 1992), and so on an area-weighted basis the Australian flux is below the average. Even though the sheet and rill erosion rate is higher than the global average, and the total erosion rate would be higher still if the gully and river channel contribution could be more accurately estimated, the discharge of sediment to the oceans is below average globally.

These results are consistent with Olive & Rieger's (1986) conclusion that sediment delivery from Australia is inefficient. They are also supported by the more recent results of Olive *et al.* (1994) in the Murrumbidgee River where soil erosion rates from small scale plots reach 6300 t km^{-2} year^{-1} (Olive & Walker, 1983) and rates in small gullied basins 10 000 t km^{-2} year^{-1} (Wasson, 1994). With increasing basin scale these are reduced to 20 t km^{-2} year^{-1} at Wagga Wagga with basin area 26 400 km^2 and 1 t km^{-2} year^{-1} downstream at Balranald (81 000 km^2). It would be expected that the sediment delivery ratio (SDR) would continue to decrease in the low gradient Murray reach to the ocean.

The SDR for the sheet and rill erosion for the external drainage basins and coastal flux is 3%, compared with 27% for the globe where the estimate of 75 × 10^9 t year^{-1} of total soil erosion (Pimentel *et al.*, 1995), is related to the 20 × 10^9 t year^{-1} of sediment discharge to the oceans (Milliman & Syvitski, 1992). The below average SDR for Australia is consistent with the continent being arid, low lying, and flat.

SCALE DEPENDENCE OF POST-EUROPEAN YIELD INCREASE

The total modern sediment yield to the coast is estimated to be about twice the pre-European settlement yield, a value confirmed at the mouth of the largest external drainage basin. It is expected in Australian basins that the increase of yield following disturbance is smallest in large catchments, due to the inefficient delivery of sediment which is more marked with increasing basin size (Olive & Rieger, 1986; Olive *et al.*, 1995). Also, the larger basins are restricted to inland locations associated with drier environments and lower relief. The results are also consistent with the global trends presented by Dedkov & Mozzherin (1984). Therefore, the agreement between the increase estimated for the continent as a whole and for the mouth of the Murray-Darling River is also to be expected.

Twelve estimates (Table 2) of the increase of yield following disturbance are available from southeast Australia, based on comparisons of plot and basin yield for near-natural woodland or grassland and cultivated, grazed, salt-scalded and gullied areas (based on Edwards, 1991; Neil & Fogarty, 1991). These data are shown in Fig. 2, where A-B depicts ungullied areas, B-C mildly gullied areas, and D-E-C severely gullied (one salt scalded) areas. Point F is Lake Alexandrina, at the mouth of the Murray-Darling basin. A-B-C-F is consistent with the conclusion of Dedkov & Mozzherin (1984), and D-E-C shows the importance of gullying as a sediment source in the uplands of southeastern Australia.

Table 2 Estimates of the increase of sediment yield following disturbance in Australia.

Location (and land use change)	Basin area (km^2)	Factor of increase	Reference
Southeast Uplands:			
– native grassland/woodland to cropping	0.0001	48	Edwards (1991)
– native grassland/woodland to salt scald	0.045	98	Neil & Fogarty (1991)
– native grassland/woodland to gullied	0.1	300	Wasson (1994)
– native grassland/woodland to gullied	1.0	375	Wasson (1994)
– native grassland/woodland to gullied	4.0	267	Wasson (1994)
– native grassland to degraded pasture	1.0	9.	Wasson (1994)
– incised basin	130	4	Wasson (unpublished)
Murray-Darling basin	1.6×10^6	2	Barnett (1994)
Lake Curlip (Victoria)	44.2	2	Boon & Dodson (1991)
Lake Bondi (NSW)	2.4	10	Dodson *et al.* (1993)
Killalea Lagoon (NSW)	4.9	8	Dodson *et al.* (1993)
Wet tropics	1000	2.6	Wasson (1994)
Southwest Western Australia	1000	3.3	Wasson (1994)
Alligator Rivers region	1000	4.5	Wasson (1994)

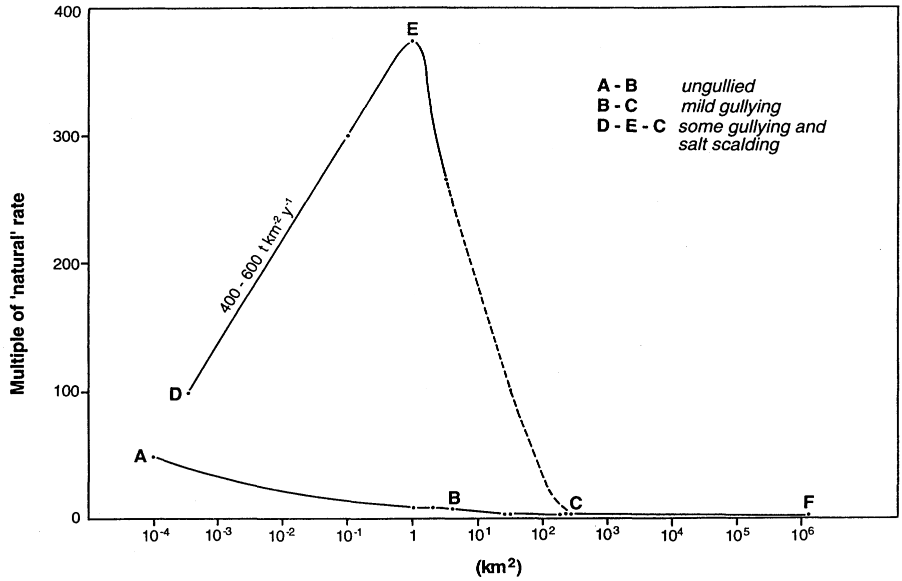

Fig. 2 Relationship between basin area and the multiple of increase of the "natural" erosion rate due to human disturbance for Australian basins.

DISCUSSION

In Australia there is considerable erosion at the small-scale with high rates of rill and sheet erosion with reported rates up to 20 900 t km^{-2} $year^{-1}$. Australia contributes 19% of the global estimate of Pimentel *et al.* (1995) while representing only 5% of the surface area. There is also a significant contribution from gully erosion especially in areas heavily impacted by agriculture. Human occupation, especially that by Europeans in the last 200 years, appears to have increased the current rate which is approximately 145 times the "natural" lowering rates before human occupation and is considerably higher than the rates of soil formation (Edwards, 1991).

While there are insufficient data to enable a continental synthesis (Fig. 1), river and stream sediment yields appear relatively low by world standards. Milliman & Syvitski (1992) in their global summary include only three Australian rivers, the Ord, Burdekin and Murray, and conclude that they "compare favourably with other rivers of similar size" (p. 539). The Ord and Burdekin are streams in higher energy tropical locations which have been heavily impacted by agriculture and are recognized as having high rates for Australia. The 30×10^6 t $year^{-1}$ they quote for the Murray, Australia's largest basin, appears to be at least an order of magnitude too high. The low river yields are due to inefficient sediment delivery (Olive & Rieger, 1986) resulting from the low and variable rainfall and the generally low elevations. As is common elsewhere, the SDR decreases with increasing basin size. Evidence from various parts of the continent using the tracers ^{137}Cs and ^{210}Pb, especially in the Murray-Darling basin, indicates that most of the sediment in transport in rivers is subsurface in origin from gullies (e.g. Wallbrink *et al.*, this volume) and that there is only a small contribution from sheet and rill erosion.

While the sheet and rill erosion rates are high, this sediment is only transported short distances and is not delivered in significant quantities to the rivers.

The delivery of sediment to the oceans is low with a SDR of 3%, considerably below the global figure of 27% derived from the results of both Pimentel *et al.* (1995) and Milliman & Syvitski (1992). The continental average yield is around 40 t km^{-2} year^{-1}. In Australia, 47% of the surface area has internal drainage and does not contribute sediment to the oceans. The majority of the sediment is derived from the tropical drainage basins of the NE coast, Timor Sea and Gulf of Carpentaria (Table 1) which produce about 90% of the sediment from 20% of the land area. The remainder of the sediment is derived from the 30% of the area which has external drainage and has an average sediment yield of 14 t km^{-2} year^{-1}. The magnitude of aeolian losses to the oceans has been given little consideration in the literature and data are limited. Knight *et al.* (1995) have estimated that the annual losses due to wind from a 100 000 to 200 000 km^2 area around Birdsville were of the order of 107-122 t km^{-2} year^{-1} with a total loss to the oceans of 3.8-6.8 $\times$ 10^6 t year^{-1}. It is not possible to extrapolate this figure to the continental scale, but it is probable that aeolian losses in the non-tropical areas are at least as great as those related to fluvial process.

The sediment supplied to the oceans following disturbance since human occupation has approximately doubled, a small increase relative to the magnitude of change at the local scale outlined in Table 2 and Fig. 2. Again the delivery of this increased sediment is inefficient and much of it remains in the drainage basins.

CONCLUSIONS

Erosion in Australia at the local scale is relatively high with similar contributions from both sheet and rill erosion and gully erosion. Much of this material, particularly the sheet and rill derived sediment, is transported only short distances. As a result river yields are low and appear to be dominated by gully and channel derived sediments. The current rate of erosion, reflecting human impacts, is much higher than the "natural' rates with increases of multiples up to 400 times. The contribution of fluvial sediment to the oceans is low compared to world averages and is dominated by material from the northern tropical basins. While the post human disturbance yields to the oceans have doubled, they are still relatively low. A considerable amount of sediment is moving in the landscape but little of it is actually delivered to the oceans.

REFERENCES

Barnett, E. J. (1994) A Holocene palaeoenvironmental history of Lake Alexandrina, South Australia. *J. Palaeolimnol.* **12**, 59-68.

Bierman, P. & Turner, J. (1995) ^{10}Be and ^{26}Al evidence for exceptionally low rates of Australian bedrock erosion and the likely existence of pre-Pleistocene landscapes. *Quatern. Res.* **44**(3), 378-382.

Boon, S. & Dodson, J. R. (1992) Environmental response to land use at Lake Curlip, East Gippsland, Victoria. *Austral. Geogr. Stud.* **30**, 206-221.

Dedkov, A. P. & Mozzherin, V. I. (1984) *Erosion and Sediment Yield on the Earth* (in Russian). Kazan Univ. Press.

Department of Environment, Sport and Territories (1995) *Our Sea, our Future: Major Findings of the State of the Marine Environment Report for Australia.* Commonwealth of Australia, Great Barrier Reef Marine Park Authority.

Department of Environment, Sport and Territories (in press) *Commonwealth State of the Environment Report.* Commonwealth of Australia.

Dodson, J. R., McRae, V. M., Molloy, K., Roberts, F. & Smith, J. D. (1993) Late Holocene human impact on two coastal environments in New South Wales, Australia: a comparison of Aboriginal and European impacts. *Veget. Hist. Archaeobot.* **2**, 89-100.

Edwards, K. (1991) Soil formation and erosion rates. In: *Soils, their Properties and Management* (ed. by P. E. V. Charman & B. W. Murphy), 36-47. Sydney Univ. Press.

Fanning, P. (1994) Long-term contemporary erosion rates in an arid rangelands environment in western New South Wales, Australia. *J. Arid Environ.* **28**, 173-187.

Harris, P. T. (1995) Marine geology and sedimentology of the Australian continental shelf. In *The State of the Marine Environment Report for Australia*, Technical Annex 1 (ed. by L. P. Zann & P. Kailola), 11-24. Department of the Environment, Sport and Territories, Canberra.

Knight, A. W., McTainsh, G. H. & Simpson, R. W. (1995) Sediment loads in an Australian dust storm: implications for present and past dust processes. *Catena* **24**, 195-213.

Loughran, R. J. (1984) Studies of suspended sediment transport in Australian drainage basins – a review. In: *Drainage Basin Erosion and Sedimentation* (ed. by R. J. Loughran), 139-146. Univ. Newcastle, NSW.

Loughran, R. J. & Elliott, G. L. (1996) Rates of soil erosion in Australia determined by the caesium-137 technique: a national reconnaissance survey. In: *Erosion and Sediment Yield: Global and Regional Perspectives* (ed. by D. E. Walling & B. W. Webb). IAHS Publ. no. 236 (this volume).

Milliman, J. D. & Syvitski, J. P. M. (1992) Geomorphic/tectonic control of sediment discharge to the ocean: the importance of small mountainous rivers. *J. Geol.* **100**, 525-544.

Neil, D. T. & Fogarty, P. (1991) Land use and sediment yield on the Southern Tablelands of New South Wales. *Austral. J. Soil and Wat. Conserv.* **4**(2), 33-39.

Olive, L. J., Olley, J. M., Murray, A. S. & Wallbrink, P. J. (1994) Spatial variation in suspended sediment transport in the Murrumbidgee River, NSW, Australia. In: *Variability in Stream Erosion and Sediment Transport* (ed. by L. J. Olive, R. J. Loughran & J. A. Kesby) (Proc. Canberra Symp., December 1994), 241-249. IAHS Publ. no. 224.

Olive, L. J., Olley, J. M., Murray, A. S. & Wallbrink, P. J. (1995) Variations in sediment transport at a variety of temporal scales in the Murrumbidgee River, NSW, Australia. In: *Effects of Scale on Interpretation and Management of Sediment and Water Quality* (ed. by W. R. Osterkamp) (Proc. Boulder Symp., July 1995), 275-284. IAHS Publ. no. 226,

Olive, L. J. & Rieger, W. A. (1986) Low Australian sediment yields – a question of inefficient sediment delivery? In *Drainage Basin Sediment Delivery* (ed. by R. F. Hadley) (Proc. Albuquerque Symp., August 1986), 355-364. IAHS Publ. no. 159.

Olive, L. J. & Walker, P. H. (1982) Processes in overland flow – erosion and production of suspended material. In *Prediction in Water Quality* (ed. by E. M O'Loughlin & P. Cullen), 87-121. Austral. Academy Science, Canberra.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R. & Blair, R. (1995) Environmental and Economic Costs of Soil Erosion and Conservation Benefits. *Science* **267**, 1117-1123.

Prove, B. G. (1984) Soil erosion and conservation in the sugar canelands of the wet tropical coast. *Erosion Res. Newslett.* **10**, CCNT, Darwin.

Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K. & Yoder, D. C. (in press) *Predicting Soil Loss by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE).* US Dept Agriculture, Agriculture Handbook 703, USDA, Washington, DC.

Rieger, W. A. & Olive, L. J. (1988) Channel sediment loads: comparisons and estimations. In: *Fluvial Geomorphology of Australia* (ed. by R. F. Warner), 69-85. Academic Press, Sydney.

Rosewell, C. J. (1993a) SOILOSS – a program to assist in the selection of management practices to reduce erosion. *Tech. Handbook 11* (2nd edn). Soil Conserv. Serv., NSW, Sydney.

Rosewell, C. J. (1993b) Estimation of rainfall erosivity. *Erosion Res. Newslett.* **11**, CSIRO Div. Soils, Canberra.

Rosewell, C. J. (in press) Sheet and rill erosion and phosphorus transport. In: *Australia, Tech. Report for Commonwealth State of the Environment Report.* Dept of the Environment, Sport and Territories, Canberra.

Rutherfurd, I. (in press) Erosion and sedimentation in Australian streams: review and implications. *Tech. Report for Commonwealth State of the Environment Report.* Dept of the Environment, Sport and Territories, Canberra.

Stone, J., Allan, G., Fifield, L. K., Evans, J. M. & Chivas, A. R. (1994) Limestone erosion measurements with cosmogenic chlorine-36 in calcite – preliminary results from Australia. *Nuclear Instruments and Methods. Physics Research B* **92**, 311-316.

Taylor, G. (1976) The Narwon River – a study of basinfill by a low gradient stream in a semi-arid climate. Unpub. PhD thesis, Australian National Univ.

Thoms, M. C. & Walker, K. F. (1992) Sediment transport in a regulated semi-arid river: the River Murray, Australia. In: *Aquatic Ecosystems in Semi-arid Regions: Implications for Resource Management* (ed. by R. D. Robarts & M. L. Bothwell), 239-250. NHRI Symposium Series 7, Environment Canada.

Van de Graaff, W. J. E. (1981) Palaeogeographic evolution of a rifted cratonic margin: SW Australia – Discussion. *Palaeogeogr., Palaeoclim., Palaeoecol.* **34**, 163-172.

Wallbrink, P. J., Olley, J. M., Murray, A. S. & Olive, L. J. (1996) The contribution of subsoil to sediment yield in the Murrumbidgee River basin, New South Wales, Australia. In: *Erosion and Sediment Yield: Global and Regional Perspectives* (ed. by D. E. Walling & B. W. Webb). IAHS Publ. no. 236 (this volume).

Warner, R. F. (1986) Hydrology. In: *Australia a Geography*. Vol. 1: *The Natural Environment* (ed. by D. N. Jeans), 49-79. Sydney Univ. Press, Sydney.

Wasson, R. J. (1994) Annual and decadal variation of sediment yield in Australia, and some global comparisons. In: *Variability in Stream Erosion and Sediment Transport* (ed. by L. J. Olive, R. J. Loughran & J. A. Kesby) (Proc. Canberra Symp., December 1994), 269-279. IAHS Publ. no. 224.

Wasson, R. J., Caitcheon, G., Murray, A. S., Wallbrink, P., McCulloch, M., & Quade, J. (1994) Sources of sediment in Lake Argyle. *CSIRO Div. Water Resources, Consultancy Report no. 94/8.*