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Spatial variation in suspended sediment transport in the Murrumbidgee River, New South Wales, Australia

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Abstract The Murrumbidgee is a large regulated river within the Murray-Darling basin. Spatial variation in suspended sediment transport is examined based on turbidity records for six stations along a 1200 km reach of the river. Transport is dominated by flood events. The downstream patterns of suspended sediment concentrations and loads show an increase to Wagga Wagga and then a significant decrease in the lower section of the river. The upstream tributaries are the major source of sediment which is only transported a short distance in the trunk stream to be deposited on the flood plain, especially between Wagga Wagga and Narrandera. Some additional sediment is lost to irrigation abstractions. Less than 20% of the sediment load at Wagga Wagga is delivered to the Murray River.

INTRODUCTION

Australian rivers are noted for their low sediment yields and high variability in sediment transport, especially the rivers of Australia's largest basin the Murray-Darling. Most studies of Australian rivers have examined basins at one location and have thus characterized temporal variation. Spatial variability has been considered in some parts of the Murray-Darling basin (Olive & Rieger, 1986) but this was based on limited data of doubtful accuracy. Also, Thoms & Walker (1991) have reported on spatial trends in sediment transport in the Murray River. In this paper spatial variability is examined along a 1200 km reach of the Murrumbidgee River.

THE MURRUMBIDGEE BASIN

The Murrumbidgee River forms part of the Murray-Darling basin and drains an area of approximately 82 000 km^2 (Fig. 1). The river rises in the Snowy Mountains and flows through undulating terrain with a well defined valley to Wagga Wagga. Downstream of Wagga Wagga there is a decrease in relief and the gradient is extremely low as it crosses the Riverine and Hay Plains. There is a flood plain 1 to 2 km wide between Gundagai and Wagga Wagga which broadens considerably between Wagga Wagga and Narrandera to widths of 5 to 20 km. Below Narrandera the river is highly sinuous to its junction with the Murray River. The study area extends from Burrinjuck and Blowering Dams

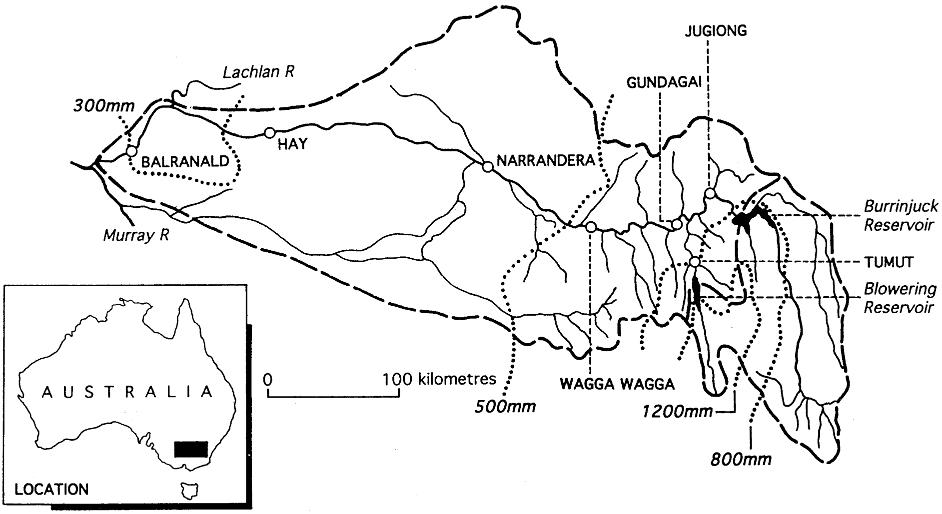


Fig. 1 The Murrumbidgee basin.

downstream to the Murray junction. The major tributaries join the river between the storages and the area around Wagga Wagga. Downstream of Wagga Wagga there are a number of distributaries, some of which leave the Murrumbidgee system and enter the Murray River. The only major tributary in the lower basin is the Lachlan River which drains a large basin and joins the Murrumbidgee above Balranald. The Lachlan passes through an extensive area of low gradient marshes above the junction where its flow is dissipated, thus it only contributes flow to the Murrumbidgee during infrequent large flood events. There was no significant contribution from the Lachlan during the period reported in this paper.

The upper part of the basin is predominantly used for grazing, while the more undulating area around Wagga Wagga is a major grain producing area. Extensive grazing is widespread in the Riverine and Hay Plains, with intensive cropping in the irrigation areas.

There is a strong rainfall gradient across the basin. Average annual totals vary from 1600 mm in the Snowy Mountains to 300 mm at Balranald (Fig. 1). Most of the flow in the study reach is derived from the storage reservoirs and the upstream tributaries. Discharge is a maximum at Wagga Wagga while downstream the river enters a semi-arid area and there is a progressive decrease in flow. The river has been increasingly regulated during this century to provide irrigation water. There are two large storage reservoirs, Burrinjuck on the Murrumbidgee and Blowering on the Tumut River (Fig. 1) with a series of low diversion weirs downstream. Major extractions occur at Berembed Weir and Gogelderie Weir with smaller extractions throughout the downstream sections. Prior to regulation, flow regimes exhibited winter maximums, but flows were highly variable. Regulation has altered the flow to a summer dominated regime when irrigation demands are greatest. The impact of regulation on flood events varies according to their magnitude. The occurrence of small and moderate floods has been reduced as flow from the upper basin can be contained by the storage reservoirs (Page, 1988). The hydrologic response for larger events remains similar to the pre-regulation regime, especially in the mid and lower river where weir gates are lifted during these events.

THE DATA

A good discharge record is available from a network of continuous gauging stations. However, the sediment record is far less detailed and samples are only taken at 4 to 6 weekly intervals. This is not sufficient to determine changes in sediment concentration which can occur over intervals of several days. An alternative data base has been used, based on turbidity observations made at water treatment plants at six towns which derive their water supply from the river (Fig. 1). Most plants were established in the late 1980s but longer records do exist up to a maximum of 44 years at Wagga Wagga. The river water is generally too turbid for direct domestic use and turbidity is measured to determine treatment dose rates for sediment removal. Samples are taken from the water supply inlet at a fixed point in the section. These were found to be representative of the cross-sectional average as sediment was well mixed. Readings are usually taken daily, but during flood events when turbidity changes more quickly additional observations are made. Hach 2100A turbidity meters were used at all stations except for Wagga Wagga, where observations were made by visual comparison with a set of formazine standards.

A relationship between turbidity and suspended sediment concentration has been established at each location by sampling a wide range of turbidities and sediment concentrations over a three year period. These were all significant to the $p = 0.05$ level. Most storm events have a duration of at least 2 to 3 days so, while the daily sample may underestimate actual peak values, turbidity events will not be completely missed (Figs 2 and 3). Detailed sampling of a flood in July 1991 at Narrandera revealed only minimal information loss resulting from the use of daily samples. However this loss may be

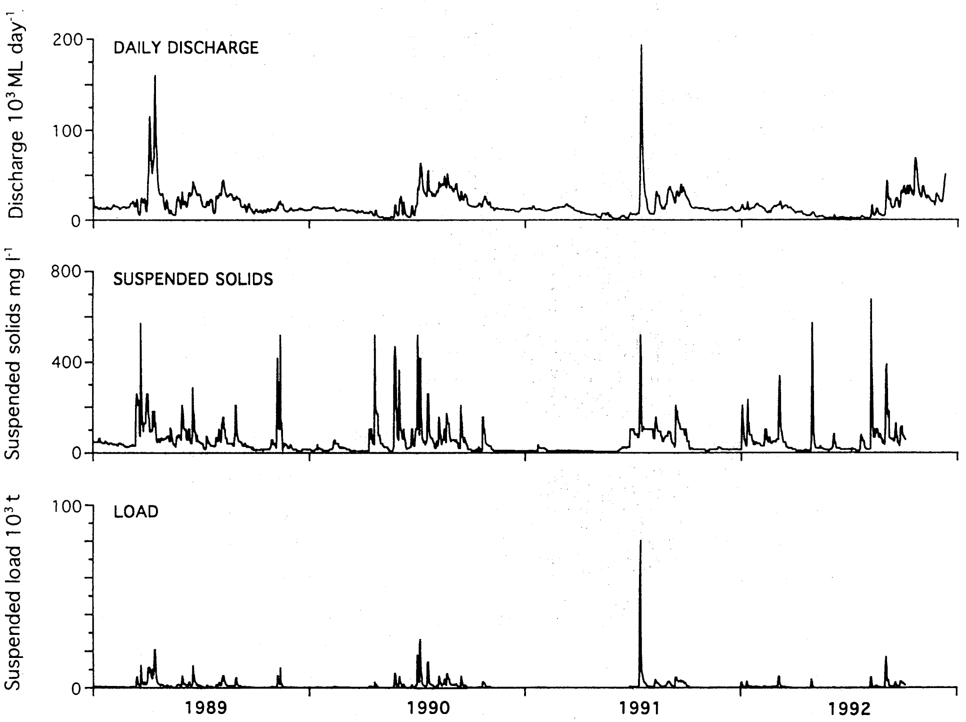


Fig. 2 Murrumbidgee River at Wagga Wagga – discharge and sediment 1989-1992.

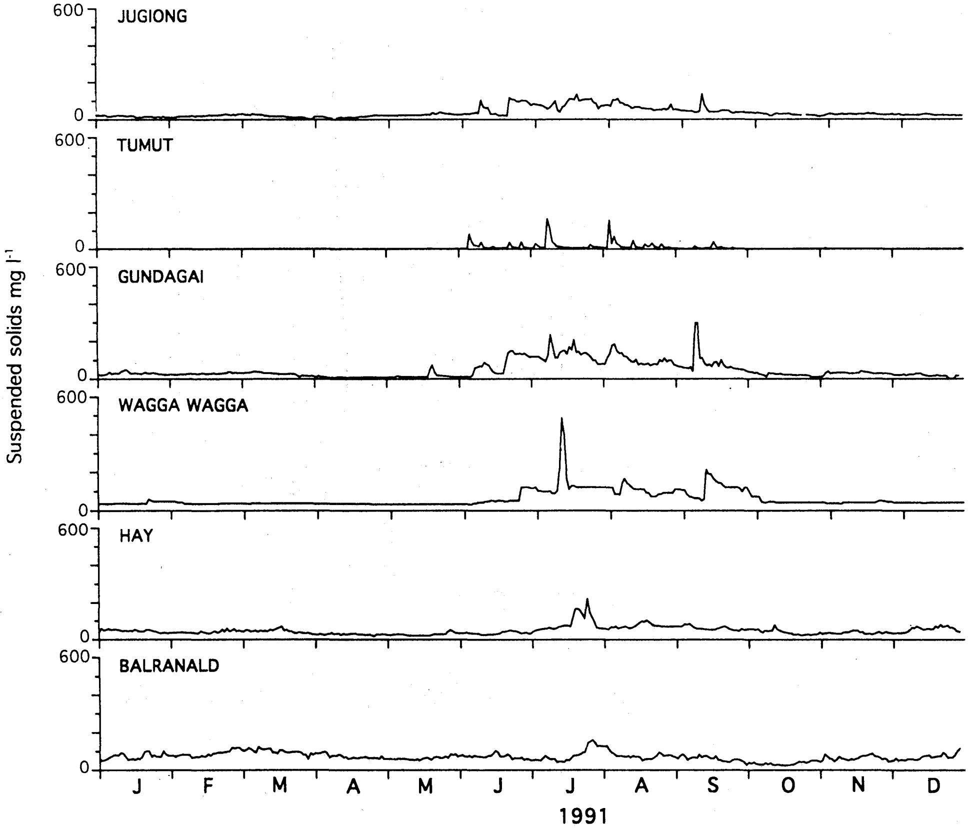


Fig. 3 Murrumbidgee River suspended sediment concentrations 1991.

greater upstream where sediment response times are shorter. The loss of resolution will decrease downstream, where response patterns are attenuated and changes occur less rapidly.

A second source of data was a detailed sampling of a flood event at Narrandera in 1991. Samples were obtained every six hours by pumping from a fixed point. Cross-sectional sampling during the event showed that the fixed point sample was representative. In all cases, suspended sediment concentrations were determined using 0.45 μm membrane filters.

RESULTS

Sediment concentrations

There is great variation in sediment concentrations. This is evident in the 1989 to 1992 results for Wagga Wagga (Fig. 2) which show that while flow is dominated by two large flood events in 1989 and 1991, there are many peaks in suspended sediment concentration often associated with much smaller flow events.

Variations in concentration for all stations throughout the system during 1991 are shown in Fig. 3. A number of general patterns can be observed. Low flow concentrations increase downstream, as shown in Fig. 4, which shows the frequency ranking of sediment concentration observations by percentiles (10, 50 (median) and 90). This observation is supported by four low flow samplings carried out along the length of the river over a two year period by Murray *et al.* (1993) and the results of Bek & Robinson (1991).

Storm responses are more peaked and high sediment concentrations are of shorter duration at Tumut on the Tumut River than those on the Murrumbidgee River. On the Murrumbidgee, sediment response peakedness increases downstream to Wagga Wagga and then decreases significantly below there with increasing attenuation of the storm responses. In contrast to the low flow pattern, concentrations increase from the upstream stations to Wagga Wagga then decrease considerably in the two downstream stations, as shown in the 90 percentile values in Fig. 4. At Jugiong the more pronounced peaks were associated with high flows in Jugiong Creek, which is the only significant tributary between Jugiong and Burrinjuck Reservoir. In the lower river, at Hay and Balranald, there were no concentration peaks which were not also present at Wagga Wagga, suggesting that events in the downstream section of the basin do not contribute significantly (Murray *et al.*, 1993).

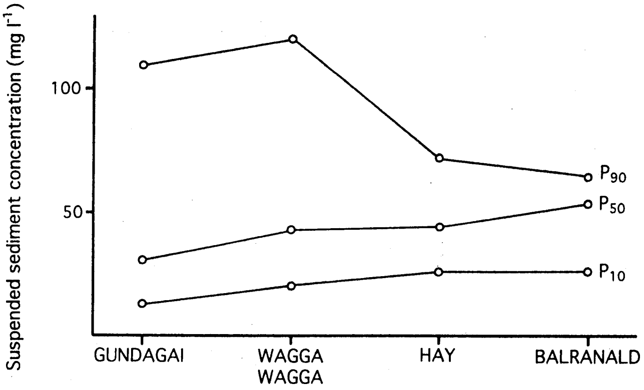


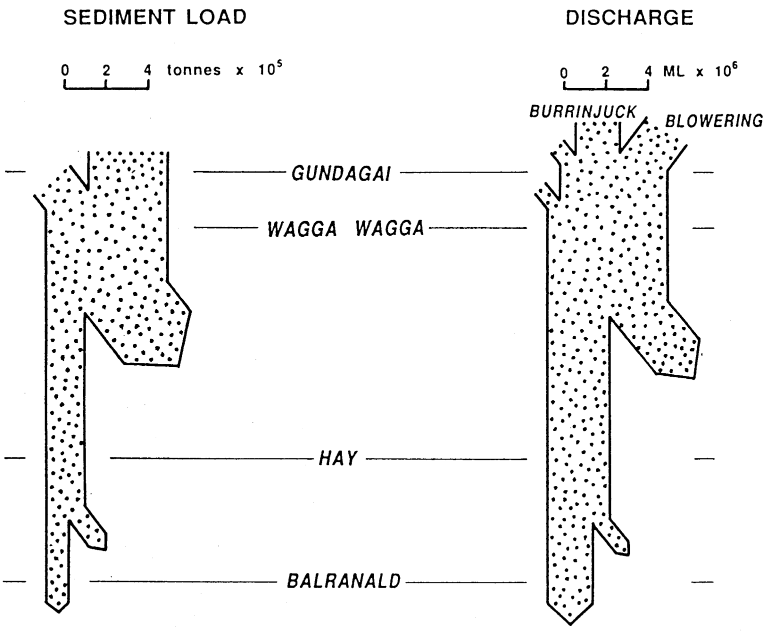
Fig. 4 Sediment concentration frequency ranking by percentile.

Sediment loads

Sediment loads have been calculated, based on the data for 1990 and 1991. They are determined using the total daily discharge and the suspended sediment concentrations from daily turbidity readings. Inevitably errors will result from the use of a single daily turbidity value, especially during flood events when sediment concentration is changing more rapidly. The magnitude of these errors was tested during the 1991 flood at Narrandera, and was relatively small.

Detailed load results are presented for Wagga Wagga for the period 1989 to 1992 (Fig. 2) and show the dominance of storm events in the transport of sediment loads. Fig. 2 reveals that while there are a relatively large number of high sediment concentration peaks, the load exhibits fewer peaks. Many of the sediment concentration peaks were associated with minor discharge events where flow was derived from tributary runoff and the resulting mass of sediment transport was relatively small. During the four year period, shown transport was dominated by the large flood in July 1991, which had a return period of approximately 10 years. During this flood, approximately 220 000 t of sediment were transported at Wagga Wagga, 37% of the long term average annual load of 600 000 t.

(a) ANNUAL



(b) FLOOD JULY-AUGUST 1991

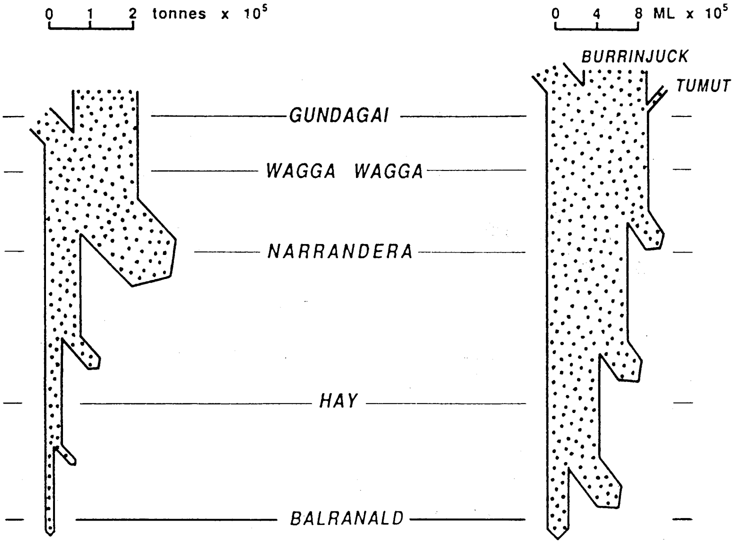


Fig. 5 Murrumbidgee River sediment budgets (a) annual sediment loads (b) sediment loads for flood July-August 1991.

Downstream trends in sediment load and discharge are shown in the annual sediment budget and flows for the trunk stream based on 1990 and 1991 data (Fig. 5(a)). Although the value for Wagga Wagga was close to the long term average, care must be taken with these results because sediment transport in the Murrumbidgee is highly variable and two years of record may not accurately characterize longer term trends (Olive & Rieger, 1992).

A significant proportion of the flow was generated by releases from the two storage reservoirs accounting for approximately 70-75% of the flow at Wagga Wagga. With tributary contributions, discharge increased steadily downstream to reach a maximum at Wagga Wagga. Below Wagga Wagga there was a large decrease in discharge due to extraction of irrigation water and transmission losses. Flow at Hay and Balranald was approximately 50% and 35% respectively of that at Wagga Wagga.

Sediment loads cannot be calculated for the upstream station at Jugiong as there are no discharge data. However, the data available for Burrinjuck Dam and Jugiong Creek suggests that most of the load at Jugiong was derived from Jugiong Creek. The load for the Tumut River at Tumut was approximately 13 400 t year^{-1} with a discharge of 2 200 000 Ml year^{-1}. By Gundagai the annual load was 380 000 t year^{-1}. These results indicate that the storage reservoirs were not significant sources of sediment. The load increased downstream to 580 000 t year^{-1} at Wagga Wagga. It then decreased significantly downstream to approximately 180 000 t year^{-1} at Hay and 115 000 t year^{-1} at Balranald. Less than 20% of the sediment transported through Wagga Wagga was delivered by the Murrumbidgee to the Murray River.

Some of the decrease in load was associated with irrigation abstractions. The magnitude of this loss cannot be accurately calculated but an approximate figure can be derived. During the irrigation season approximately 75% of the water passing Wagga Wagga was abstracted. Assuming that the same proportion of load was lost, then over the two years considered, the average loss of sediment from the river was approximately 105 000 t year^{-1}. This is 26% of the decrease between Wagga Wagga and Hay. The abstractions involve a significant quantity of water, most of which comes from dam releases where sediment concentrations in the river are low. Conversely, during significant storm events, when most of the sediment was transported, there was little demand for irrigation water. This is especially so in winter and early spring, which is the most common period for flood events.

A sediment budget has been determined for the large flood in July-August 1991 (Fig. 5(b)) and includes data from detailed sampling at Narrandera (Murray *et al.*, 1993). A more thorough analysis of this flood is given in Olive *et al.* (submitted). This flood made up a significant portion of the annual budget (Fig. 5(a)). Approximately 60% of the flow at Gundagai was accounted for by release from Burrinjuck Dam with the remainder from the tributaries. Total discharge was similar from Gundagai to Wagga Wagga, while below Wagga Wagga there was a decrease in flow. Narrandera had 83% of the Wagga Wagga flow, Hay 50% and Balranald 20%. The sediment load increased to Wagga Wagga, but then decreased significantly to Narrandera, where it was approximately 37% of the Wagga Wagga load. Smaller decreases occurred further downstream, with Hay having 20% and Balranald 9% of the Wagga Wagga load. A similar pattern was observed in a smaller flood generated by a Blowering Reservoir release and tributary runoff in October-November 1992.

DISCUSSION

The spatial variations in both sediment concentrations and loads show a consistent pattern. Both are relatively low in the upper section immediately below the storage reservoirs, increase progressively downstream to Wagga Wagga and then decrease significantly below Wagga Wagga. The magnitude of the decrease is much greater than the corresponding decrease in river discharge. This pattern is also evident during the flood event of July-August 1991, but the relative magnitude of the decrease of sediment concentration and load is greater than the annual average trends. In contrast, the low flow sediment concentration pattern shows a progressive downstream increase. The section above Wagga Wagga, where sediment increases, corresponds to the region with all the major tributaries, is steeper and drains agricultural land. Downstream, where sediment decreased, there are few tributaries and relief is much less. This pattern is in direct contrast to the results of Thoms & Walker (1991) for the adjacent Murray River, a basin with similar topography but with tributaries throughout the reach studied. Their results show a progressive downstream increase in sediment load. In addition, the Murrumbidgee at Wagga Wagga has more than double the annual load of the highest loads reported in the Murray but the total discharges are very similar. However, care must be taken with this comparison, because Thoms and Walker used sediment rating curves to estimate loads and these are known to commonly underestimate loads (Walling & Webb, 1988). The Murrumbidgee pattern is consistent with other results from the Murray-Darling basin (Olive & Rieger, 1986). This pattern of spatial variation is the result of the limited area of sediment sources and the pattern of deposition.

The evidence suggests that the two storage reservoirs do not contribute a large amount of sediment to the river. Sediment loads at Tumut, downstream of Blowering Reservoir, are low and the response at Jugiong indicates that the majority of sediment passing there is not derived from Burrinjuck Reservoir. Tributary streams appear to be the major source of sediment in the reach from the reservoirs to Wagga Wagga. In this reach, the trunk channel has remained relatively stable over the past 50 years (Murray *et al.*, 1993) and so the sediment can only come from the tributaries. The precise source within these basins has not been determined at present. All sediment sampled in the river system has measurable ^{137}Cs suggesting that there is a top soil component and ^{210}Pb/^{137}Cs ratios indicate some element of surface material (Murray *et al.*, 1993). However, the ^{137}Cs concentrations are relatively low, indicating a significant subsurface source. Wasson (this volume) concludes, that within Murray-Darling basin a large part of the variance of sediment yield in gullied basins can be accounted for by drainage density, and gullies and channel erosion in small basins are a significant source. In the Murrumbidgee tributary area such gullies, cut into the almost ubiquitous valley infill deposits, are common. Research is continuing to establish the sediment sources within the tributaries.

The decrease in sediment load below Wagga Wagga is the result of two factors. Sediment loss associated with irrigation abstraction accounts for approximately 25% of the decrease, considerably less than the proportion of flow abstracted. The most important decrease in sediment is through deposition of sediment on the flood plain. Below Wagga Wagga there is a considerable decrease in gradient with a resulting loss in energy. Also, there is a major widening of the flood plain from 1 to 2 km above Wagga Wagga to 5 to 20 km between Wagga Wagga and Narrandera. The detailed results for the 1991 flood indicate that majority of the deposition occurs in the reach between Wagga Wagga and Narrandera, where approximately 60% of the load is lost, with continuing but reduced deposition downstream. Deposition rates for this flood were calculated as 216 t km^{-2} on the flood plain in the Wagga Wagga-Narrandera reach, and 40 t km^{-2} for the Narrandera-Hay reach (Olive *et al.*, submitted).

CONCLUSIONS

The Murrumbidgee River shows considerable spatial variation in the transport of sediment through the 1200 km reach studied. Sediment concentrations show two patterns:

(a) a downstream increase in concentrations during periods of low flow;
(b) an increase downstream to Wagga Wagga, then a decrease below Wagga Wagga during flood events.

The flood sediment loads have a similar pattern to the flood concentrations. The annual sediment loads are dominated by flood sediment transport. Most of the sediment is generated in a limited area from the tributaries above Wagga Wagga. It is then transported only a short distance to be deposited on the flood plain between Wagga Wagga and Narrandera, with deposition continuing downstream. Sediment transport is minimal over much of the lower low energy semi-arid section. While this pattern differs from that reported by Thoms & Walker (1991), it is consistent with the other research in the Murray-Darling basin, suggesting a very inefficient delivery of sediment (Olive & Rieger, 1986).

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