Chapter 10 The contribution of different erosion sources to the fine grained sediment in the Darling-Barwon river system

10.1 Introduction

A proportion of soil eroded from slopes and channels enters streams where it may adversely impact on river environments (Walling 1988). Impacts include higher levels of turbidity and increased concentrations of sediment associated nutrients such as phosphorus. If management strategies are being developed to reduce the delivery of sediment-associated nutrients to rivers, then the sediment sources need to be identified so that problem areas can be effectively targeted. This chapter reports on the use of fallout radionuclides as tracers to determine which land use or land form types are the predominant sources of sediment delivered to the waterways of the Darling-Barwon river system.

The major land uses within the catchment are pasture, rangelands and forests. These land uses occupy 95% of the total basin area while cropping occurs in the remaining 5% of the basin (Peter Crabb pers. comm.). Pasture and rangelands are ubiquitous throughout the western and northwestern tributaries (eg Paroo River, Figure 8.1). Extensive grazing also occurs within the sandy and black soil plains of the northern tributaries (Warrego, Culgoa, & Macintyre Rivers, Figure 8.1), and extends through the eastern and southeastern catchments (Gwydir, Namoi, Castlereagh, & Bogan Rivers, Figure 8.1). However, within these broader areas are localised regions of intensive agriculture for cotton, wheat, and cereals, such as in the Liverpool Plains (Namoi basin) and the Darling Downs near Toowoomba (Condamine catchment). Sediment yields from cultivated land have been measured at up to 780 t km^{-2} yr^{-1} from Gunnedah (Edwards 1980) and as high as 5,300 t km^{-2} yr^{-1} from within the Darling Downs (Ciesolka & Freebairn 1982). However, most of this sediment is probably deposited before reaching the trunk streams (Olive & Reiger 1986).

In addition to surface soil erosion, the catchment is also significantly channellised. Major sections of slumping and bank collapse have occurred along the main river channel from Mungindi on the Queensland/NSW border to its confluence with the Murray River about 2000 kilometres downstream (Thoms *et al.* 1996). The western and northwestern regions are characterised by wind deflation and gully erosion of the clay pans to 2-3 metres depth. Significant gully networks also exist within first and second order streams of the eastern perimeter of the basin, including the headwaters of the Liverpool Ranges in the Namoi, and the Macintyre, Gwydir, and Macquarie basins.

10.2 Fallout tracer methods for calculating the depth origin of sediments

The sources of suspended sediments can be identified by using a variety of tracers including particle properties such as mineral magnetics, major and minor element composition (Chapter 9) and radionuclide concentrations (Wall & Wilding 1976; Oldfield *et al.* 1979; Peart & Walling 1986; Olley *et al*. 1993). Radioisotopes of caesium (^{137}Cs) and lead (^{210}Pb) have been used as tracers of soils and sediments in a variety of geomorphic settings (Peart & Walling 1986; Wasson 1987; Loughran 1982; Wallbrink & Murray 1993, 1998; Walling *et al*. 1993; Hutchinson 1995).

Atmospheric fallout ^{210}Pb (half-life 22 years), also known as ^{210}Pb excess ($^{210}Pb_{ex}$), is generated from the decay of radon (^{222}Rn) in the atmosphere. Radon is a gaseous intermediate decay daughter of radium (^{226}Ra) that occurs naturally in soils. Radon that is formed in soils diffuses into the atmosphere where it decays through a series of short-lived daughters to ^{210}Pb. This nuclide is then continually precipitated on the soil surface, mainly by rainfall. The $^{210}Pb_{ex}$ is defined as the excess of ^{210}Pb activity over its parent ^{226}Ra. In uncultivated, undisturbed soils, maximum concentrations of $^{210}Pb_{ex}$ are usually found at the surface, decreasing exponentially with depth and are typically undetectable at depths of >10 centimetres (Fisenne 1968; Nozaki *et al*. 1978; Matthews & Potipin 1985; Wallbrink *et al*. 1993). In cultivated soils $^{210}Pb_{ex}$ is distributed deeper into the soil by ploughing. The surface layers of the soil may then accumulate additional $^{210}Pb_{ex}$, depending on patterns of interceding rainfall.

Anthropogenic ^{137}Cs (half-life 30.2 years) is a product of above-ground nuclear weapons testing that occurred during the 1950s-70s (Longmore *et al*. 1983; Walton 1963). It is also distributed exponentially with depth in undisturbed soils, although often with a slight maximum below the soil surface (Walling & Bradley 1988; Basher *et al.* 1995; Owens *et al*. 1996). Studies in Australia have found that the majority of this nuclide (>90%) is retained within the top 10 centimetres of the soil (Campbell *et al*. 1982; Loughran *et al*. 1992; McCallan *et al.* 1980; Wallbrink & Murray 1993). In cultivated soils ^{137}Cs may also be distributed down to the depth of the plough layer (Quine *et al.* 1994). Total soil inventories (Bq m^{-2}) in Australia are about an order of magnitude lower than those in the Northern Hemisphere (Longmore *et al.* 1983).

The fallout of ^{137}Cs in Australia had effectively ceased by the mid-1970s. In contrast, about half of the present inventory of $^{210}Pb_{ex}$ fallout has occurred in the last 20 years. Consequently, the various regions of the Darling catchment may have nuclide concentrations that are distinct from one another, as a result of their differing land uses and exposure histories. These tracer properties can potentially be used to determine the relative contributions of these areas to the sediments in the Darling-Barwon River.

On the basis of the expected differences in tracer properties outlined above, the major sources of sediment in the Darling Basin were divided into three broad categories:

(i) areas that are uncultivated (such as pastureland, rangelands, and forests);

(ii) areas that are cultivated (such as cotton, wheat, soy beans, oil seeds), and;

(iii) sub-soil material generated from channel and gully erosion.

If C_u, C_c, C_b and P_u, P_c, P_b represent the ^{137}Cs and ^{210}Pb$_{ex}$ concentrations from uncultivated (u), cultivated (c), and channel bank sources (b), and C_s and P_s represent the respective total concentrations of ^{137}Cs and ^{210}Pb$_{ex}$ in suspended sediments, then the amounts contributed from these sources can be calculated using a three component mixing model of the form:

$$A.C_u + B.C_c + C.C_b = C_s$$

$$A.P_u + B.P_c + C.P_b = P_s \qquad \textbf{(10.1)}$$

A, B and C represent the relative contributions from channel banks, uncultivated and cultivated lands, respectively and A + B + C = 1 (Wallbrink *et al.* 1998). This assumes that no major physical or chemical alteration to particulates occurs during transport (Wallbrink *et al.* 1998), and that when sediment is delivered to a river channel it retains the radionuclide concentrations present in the soil before it was eroded.

The analytical methods employed here were those of Murray *et al.* (1987). All samples were oven dried then ashed at 450°C and analysed by gamma spectrometry for ^{137}Cs, ^{226}Ra and ^{210}Pb$_{ex}$ concentrations (Bq kg^{-1}). Unless otherwise noted, all mean values are reported with the associated uncertainties of one standard error.

10.3 Sediments of the Darling Barwon River system (C_s and P_s)

Previous measurements (Woodyer 1978) indicated that 80-95% of the material in suspension in the Darling-Barwon River is <2µm in diameter. Large (gram) quantities of suspended sediments were collected from the Darling-Barwon by continuous flow centrifugation (CFC) of river water using an Alfa Laval centrifuge (model MAB103b). The CFC samples were collected during two sampling trips along the river from Mungindi to Wilcannia (Figure 10.1). On these occasions deposited sediments were also collected from the riverbed. The fine silt and clay particles (consistent with the particle size of the suspended river sediments) were extracted from the riverbed samples by a combination of wet sieving and settling in a water column.

Drought conditions prevailed during the study period and flows in the river were very low, so the opportunity was taken to obtain additional samples of recently deposited, fine grained flood sediment from within channels throughout the catchment (Figure 10.1). The sediment samples were fractionated in the same way as the riverbed sediments to recover the fine silt and clay fraction (<10µm).

10.4 Sampling cultivated (C_p and P_p) and uncultivated (C_u and P_u) lands, and channel/gully sediments (C_b and P_b)

The radionuclide signatures from uncultivated and cultivated lands were determined from soil samples taken along several transects, each approximately 100 kilometres long (Figure 10.1). Every 10 kilometres along the transect, five soil samples (scrapes) to ~5 millimetres depth were taken of surface material that appeared to be either in, or available for, active transport (n = 50 per transect).

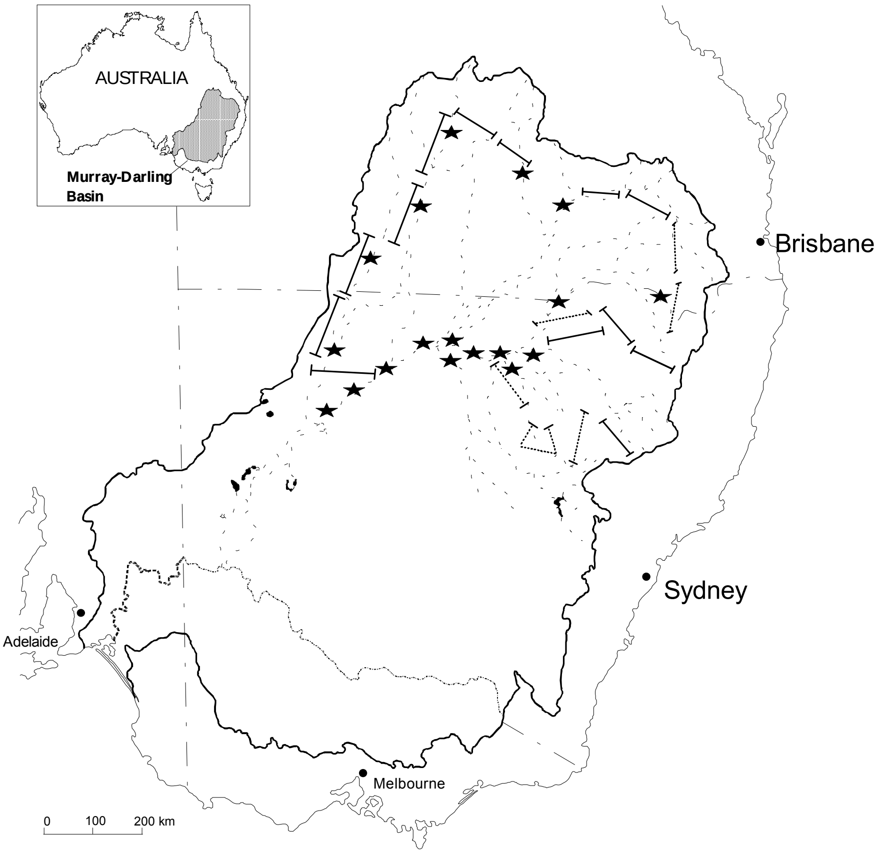

Figure 10.1 The Darling River Basin showing the location of sampling points for sediment and catchment source samples. Stars denote CFC and deposited sediment sampling locations. Solid bars represent transects for sampling uncultivated soils and dotted bars transects for sampling cultivated soils.

The fifty samples from each transect were then combined for analysis. The fine silt and clay particles were extracted from the mixed samples by a combination of wet sieving and settling in a water column, this is the same method used for the deposited river sediments. The fine fraction was then analysed to characterise the $^{210}Pb_{ex}$ and ^{137}Cs concentrations of particles associated with the predominant land use in the transect area. Thirteen transects were taken from uncultivated lands in the basin, and six transects were sampled in the cultivated regions of the Darling Downs and the Liverpool Plains (Figure 10.1).

The sampling protocol assumes that contemporary erosion from cultivated and uncultivated surfaces in this region is primarily by sheet or rill erosion of surface particles to a depth of ~5 millimetres. This is believed to be an upper limit for the loss of soil that would occur from cultivated or uncultivated surfaces at any one time, although it is acknowledged that in some circumstances local erosion may exceed this depth.

Estimates of the radionuclide concentrations in material from channel and gully banks were made from measurements of the average $^{210}Pb_{ex}$ and ^{137}Cs concentration in soil cores of 200 millimetres depth sampled from uncultivated lands in the Darling catchment. These cores were obtained from the same thirteen transects used to sample uncultivated land for surface sediments, but were not replicated at each point on the transect, resulting in 10 samples per transect. The 10 soil cores collected from each transect were combined, producing 13 samples, with the fine fraction (<10µm) extracted and analysed. Radionuclide measurements of the soil cores were averaged over the sampling depth of 200 millimetres and then divided by the estimated average depth of channels and gullies in the catchment (3 metres) to calculate the $^{210}Pb_{ex}$ and ^{137}Cs concentrations of eroded bank sources. Calculations were repeated using a series of values for average gully and channel bank height to assess the impact of the assumed channel height on estimated contributions of sediment from these sources.

10.5 Results

Radionuclide concentrations of the fine-grained material from the catchment sources are summarised in Table 10.1. The highest values of $^{210}Pb_{ex}$ and ^{137}Cs (Bq kg^{-1}) occur in the material from uncultivated sources. This is consistent with the initial deposition of these radionuclides at the soil surface. The nuclide values for cultivated lands are lower than those from uncultivated lands, probably due to the effects of mixing and dilution by ploughing.

Table 10.1 Concentrations of $^{210}Pb_{ex}$ and ^{137}Cs in material from potential erosion sources and suspended sediments from the Darling-Barwon basin.

		$^{210}Pb_{ex}$			^{137}Cs			
Landform/land use	**Total sample number**	**code**	**Bq kg^{-1}**	**se**	**code**	**Bq kg^{-1}**	**se**	**Ratio**
Uncultivated lands	13	P_u	190	40	C_u	21	3.3	9.0
Cultivated lands	6	P_c	15	6	C_c	4.8	0.6	3.3
Channel/gullies *	13	P_b	2.53	0.7	C_b	0.54	0.1	4.4
Sediments	170	P_s	18.5	1	C_s	1.73	0.1	10.7

*assuming 3 metres height

The nuclide concentrations in the cultivated soils are also much lower than those found in cultivated Murrumbidgee River catchment soils where $^{210}Pb_{ex}$ is ~118 Bq kg^{-1} and ^{137}Cs is ~18 Bq kg^{-1} (Wallbrink *et al.* 1998). This may be due to the different methods of cultivation in these two areas. In the Murrumbidgee wheat belt harrowing generally results in a horizontal movement of the soil particles, and analysis of the ^{137}Cs distribution in sectioned cores reveals that there is little vertical mixing. In the Darling Downs and Liverpool Plains the distribution of ^{137}Cs is essentially uniform to cultivation depth, suggesting that vertical mixing is a significant process in these soils.

The estimated tracer concentrations in soil profiles from channels and gullies are the lowest of the potential erosion sources. It should be noted that this assumes an average channel height of 3 metres. If the actual height is half of this amount, then the calculated ^{137}Cs and $^{210}Pb_{ex}$ concentrations increase by a factor of two, but would still be much less than concentrations measured in samples from the other two erosion sources.

The ^{137}Cs concentrations in the river sediments (C_s) are lower than those measured in cultivated and uncultivated lands, but they are higher than the channel bank and gully sources (Table 10.1). The concentrations of $^{210}Pb_{ex}$ in the sediments are much higher than those estimated for the channel/gully material, slightly higher than the cultivated lands but significantly lower than those of the uncultivated soils. The ratio of $^{210}Pb_{ex}$ to ^{137}Cs in the sediments is larger than measured in any of the potential sources (Table 10.1). Given the large size of the Darling-Barwon River system this probably reflects the direct addition of fallout ^{210}Pb to sediment in the channels. This highlights the need to consider the residence time of sediment within the channel system when interpreting the ^{137}Cs and $^{210}Pb_{ex}$ data.

It is possible that some sediment is resident within the channel for a length of time that is comparable or longer than the ^{210}Pb half-life of 22 years. In this situation the $^{210}Pb_{ex}$ sediment label will be affected by the addition of direct fallout ^{210}Pb, and also the radioactive decay of the catchment derived component. Similarly, if sediment residence times are >40 years then all of the ^{137}Cs in the channel could have been derived from direct fallout. For residence times of <30 years, however, ^{137}Cs is unaffected by this process because most of the fallout occurred >30 years ago, and decay is thus uniform in soil and sediment samples.

If most of the sediment within the channel has been eroded and transported within the last 30 years (Scenario 1), then the ^{137}Cs in the sediments will originate entirely from eroded catchment sources. Assuming this is the case, an estimate of the maximum and minimum amounts of ^{210}Pb addition can be calculated from the maximum and minimum ratios of ^{210}Pb to ^{137}Cs associated with the various catchment sources. For example, the highest $^{210}Pb_{ex}$ to ^{137}Cs ratio (~9:1) was found in soil from uncultivated lands. If the soil from this source represented 100% of the total sediment flux in this river system (and thus the total amount of $^{210}Pb_{ex}$), then the ratio in the sediments could not be higher than ~9:1. The maximum ^{210}Pb concentration in the river sediments could only be 15.6 Bq kg^{-1}, nine times the ^{137}Cs concentration given. Alternatively, if all the sediment were derived from cultivated soil then the $^{210}Pb_{ex}$ to ^{137}Cs ratio for suspended sediment would be 3.3, equivalent to a ^{210}Pb concentration of only 5.7 Bq kg^{-1}.

These estimates can be further refined using the ^{137}Cs concentrations in the river sediment and catchment soil samples. For example, the ^{137}Cs concentration in the river sediments is 1.73 Bq kg^{-1}. This can be from a combination of uncultivated lands (6%) plus subsoil material from channel banks (94%) where 21 Bq kg^{-1} and 0.54 Bq kg^{-1} of ^{137}Cs occur on these sources respectively (Table 10.1). In this case the $^{210}Pb_{ex}$ concentration would be 13.4 Bq kg^{-1} (94% x 2.53 Bq kg^{-1} + 6% x 190 Bq kg$^{-1;}$ Table 10.1). Alternatively, the ^{137}Cs concentration in the river sediments could be attributed to cultivated lands (27%), and channel banks (73%), in which case the corresponding $^{210}Pb_{ex}$ river sediment value would be ~5.9 Bq kg^{-1}. Thus the range of catchment derived $^{210}Pb_{ex}$ can now be considered to lie between 5.9-13.4 Bq kg^{-1}. The minimum amount of $^{210}Pb_{ex}$ added from direct fallout is ~5.1 Bq kg^{-1} (ie 18.5-13.4 Bq kg^{-1}see Table 10.1), and the maximum is ~12.6 Bq kg^{-1} (ie 18.5-5.9 Bq kg^{-1}). Placing these limits on the catchment derived $^{210}Pb_{ex}$, in conjunction with the measured values of ^{137}Cs, allows us to determine relative source contributions within the last 30 years using Equation 10.1.

Another possibility (Scenario 2) is that residence time of sediment in the Darling-Barwon is long, and that the sediment remains stored in the channel for more than 40 years. In this case the ^{137}Cs concentrations (Bq kg^{-1}) in the sediment will result from the total ^{137}Cs fall out load into the river alone, and there will be no catchment derived ^{137}Cs contribution to the sediments. From analysis of catchment cores, the average ratio of fallout $^{210}Pb_{ex}$ to ^{137}Cs in this region is in the order of ~3.0. Thus, the average concentration of fallout $^{210}Pb_{ex}$ in these sediments before 40 years ago would have been ~5.2 Bq kg^{-1} (3 x 1.73 Bq kg^{-1}). The remainder, 13.3 Bq kg^{-1} (18.5-5.2 Bq kg^{-1}) will have come from eroded catchment sources prior to this time. (It should be noted that this value is equivalent to 46.9 Bq kg^{-1} when corrected for 40 years decay since this time). The combination of catchment sources required to support this $^{210}Pb_{ex}$ value (in the river sediments) can then be calculated as a two component mix of the dominant catchment sources at that time, using Equation 10.2:

$$A.P_u + B.P_b = Ps \qquad \textbf{(10.2)}$$

A and B represent the unknown relative contributions from uncultivated lands and channel banks respectively, A + B = 1, and P_u, P_b and P_s, remain as for Equation 10.1.

These two scenarios allow us to constrain the river sediment $^{210}Pb_{ex}$ values used in the mixing models so that they represent erosion of catchment sources alone. Figure 10.2 illustrates this, where the postulated contribution from various catchment sources is calculated for Scenario 1 (Equation 10.1, residence time <30 years), and for Scenario 2 (Equation 10.2, residence time >40 years). The calculated contributions from catchment sources are unknown for the period in between these two possible scenarios. It has been assumed that cultivated lands are not significant sources more than 40 years ago (remembering that even today they only represent some 5% of the total catchment area). It has also been assumed that the initial concentrations of $^{210}Pb_{ex}$ in catchment soils have not changed to the present day because deposition is continuous.

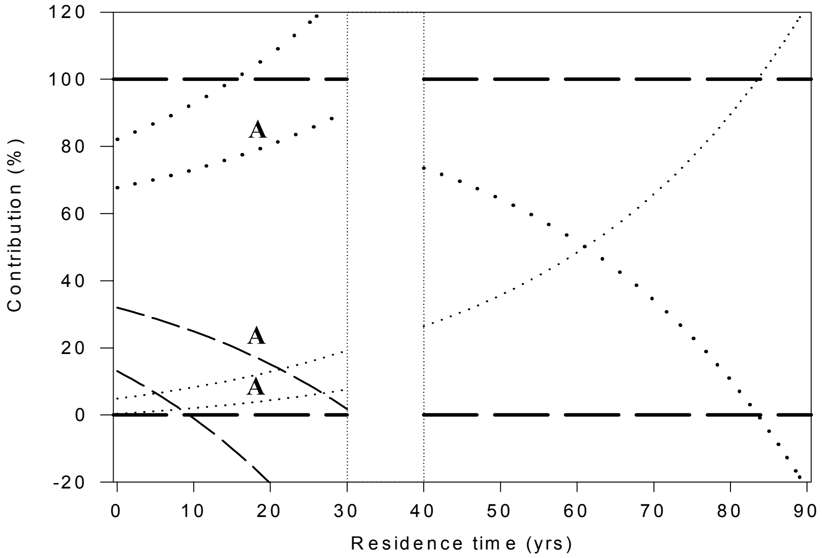

Figure 10.2 Potential contribution of sediments from channel banks (heavy dotted lines), cultivated (dashed lines), and uncultivated land (light dotted lines) estimated under two different scenarios of sediment residence time (<30 years & >40years). Two sets of responses are depicted in the shorter residence time scenario assuming either maximum or minimum amounts of $^{210}Pb_{ex}$ addition from direct fallout. The horizontal dashed lines represent minimum and maximum inputs from these sources at 0 and 100% respectively.

It has been assumed in the analysis that the average height of the channels and banks within the Darling-Barwon basin is 3 metres. The effect on the relative contributions from this source can also be estimated assuming a range of different gully and channel bank heights. Table 10.2 presents the results of an analysis in which the ^{137}Cs and $^{210}Pb_{ex}$ concentrations estimated for channel bank and gully sources have been changed assuming bank heights of 1 to 5 metres. These estimates have been made using the lowest ^{210}Pb fallout in the suspended sediments (5.1 Bq kg^{-1}), and a residence time of 5 years. The difference in contributions from channel/gully bank varies by ~18%. However, it is unlikely that the average minimum channel/gully height in this system is only one metre, especially given that the average height of the banks for ~800 kilometres of the main channel has been measured at 4 to 9 metres (Woodyer 1978).

Table 10.2 Effect of different channel/gully bank heights on the estimated contribution from catchment sources to fine grained sediment in the Darling-Barwon River.

	Average channel/gully height (m)				
Source	**1**	**2**	**3**	**4**	**5**
Uncultivated lands (%)	-1	0	0	0	0
Cultivated lands (%)	14	26	29	30	31
Channels/gullies (%)	87	74	71	70	69

Observation of other parts of the catchment indicates that an average height of ~5 metres is equally unlikely. Consequently, a more realistic range is between 2-4 metres, and the change to the estimated cultivated and channel/gully contributions using these assumptions is about ~4%. This is within the estimates of uncertainty for both of these sources.

10.7 Discussion

The interpretation of source contributions in Figure 10.2 depends upon the residence time of the sediment. If, on the one hand, sediment moves through the catchment in association with the flood flows, known to be about 60-120 days duration (Woodyer 1978), then transit times must be short. In this case more confidence would be placed on the results of Scenario 1. However, it is also known that the sediment in the Darling-Barwon is highly weathered compared to headwater catchment sediment (Chapter 9). This observation can support both scenarios but changes the interpretation of the data. The origin of the river sediment could be contemporary erosion of sites where material is stored for significant lengths of time, such as the floodplains, and this is consistent with Scenario 1. In contrast, erosion may have occurred some time previously but material remains resident within the channels for a very long time and is weathered, this is consistent with Scenario 2. Ultimately, confidence in the predictions of either scenario requires clarification of the sediment transport processes and residence time of fine sediment in the river system.

The minimum subsoil contribution from channel banks, assuming that transit times are less than ~30 years, is 69 ± 11%. The maximum contribution from cultivated lands is 31 ± 13%. The maximum contribution from uncultivated lands is 10 ± 3%. However, the contributions from all these sources must sum to 100%. Therefore, it is not possible for these different estimated contributions to be delivered at the same time. The effective boundaries of this condition are shown as the solid lines defining 0-100% in Figure 10.2. For example, if the channel/gully (subsoil) contribution is 69%, then the cultivated land contribution is at 31%, and the uncultivated land contribution is zero. It can be seen that the estimated contribution from this latter source increases with postulated residence time, while the contribution from cultivated land decreases.

The relative contributions from cultivated and uncultivated lands can be converted to a relative yield from each source, based on the relative proportion of land surface area occupied by each. The cultivated lands occupy a maximum of 5% of the Darling-Barwon catchment area, while uncultivated land occupies the remaining 95%. If the maximum contribution from each of them (31% cultivated, and 10% uncultivated) is normalised to catchment area, their relative yields are 5 and 0.11 respectively. On this basis the production of sediment per unit area from the cultivated lands is approximately 45 times greater than that from uncultivated lands.

In Chapter 9 an analysis of major and minor elements was used to demonstrate that sediment in the Darling-Barwon River is mainly derived from granitic and sedimentary rocks. Very little sediment comes from soils developed on basalt. This implies that either, erosion of material from soils on this lithology are negligible, or that the transit time of contemporary eroded material from these soils is very long. It was also found that the chemical index of alteration (CIA) for the river sediment is very high (>0.75), indicating that it is highly weathered compared to sediment in headwater catchments. This means that sediment in the lower reaches of the system has probably been derived from erosion of granitic/sedimentary material previously deposited within the floodplains of the basin.

Measurements of contemporary channel bank erosion of floodplain sediment (Thoms *et al.* 1996) is consistent with the high estimated contribution from channel bank and gully sources. However, the presence of very little basalt in the river sediments suggests that sheet erosion from cultivated basaltic soil (such as the Liverpool Plains) is not currently being transported to the Darling-Barwon channel. The contribution from this source is limited to <5%. In this case the predicted maximum of 30% material coming from cultivated sources is presumably derived from regions where cultivation takes place on granitic/sedimentary soils. Thus the significant contribution of surface eroded material predicted with increasing residence time in Scenario 2 would necessarily occur from non-basaltic sources.

If it is assumed that residence time is less than 30 years, then the dominant contribution of subsoil material from channel banks and gully walls in the Darling-Barwon Basin is consistent with findings elsewhere. For example, Neil and Fogarty (1991) and Sebire (1991) found in a survey of 131 farm dams in the Southern Tablelands, NSW, that sediment derived from within channels and gullies exceeded that from surface soils by up to an order of magnitude in catchments where gullies occurred. Similarly, Mackenzie *et al.* (1991) found that subsoil material dominated sediment flux from gullied catchments near Goulburn, NSW. Crouch (1990) calculated that the release of material from gully sides near Bathurst, NSW, was about four times that from sheet and rill erosion. This is also consistent with measurements of up to 80% contribution from subsoil sources in selected basins in the United States (Bradford & Piest 1980; Glymph 1957; Osborn & Simanton 1989). Wallbrink *et al.* (1996a,b) calculated that the relative contribution of subsoil from channel banks and gullies to sediment in the Murrumbidgee River was approximately 90%.

Part of the reason for the large contribution of subsoil sources is the degree to which they are connected to the streamlines. Subsoil eroded from channel/gully banks is directly contributed to flow paths. In this situation a large fraction of the eroded material is delivered directly into the drainage system. In many cases the sediment delivery ratio (SDR)(Walling 1983) will be one. By comparison, eroded surface soil will have a low SDR in Australia. This is because surface sources are poorly connected to streamlines, resulting in the inefficient delivery of eroded surface soil. The low average gradients in the Darling-Barwon Basin, and the generally low rainfall and runoff also contribute to the inefficient delivery of eroded surface soil (Loughran *et al.* 1982; Olive & Reiger 1986; Wasson 1987).

10.8 Key points

- The relative amounts of sediment derived from three potential catchment sources in the Darling-Barwon Basin, (cultivated soils, uncultivated soils and bank erosion from channels or gullies) have been determined using radionuclide tracers.

- The concentrations of $^{210}Pb_{ex}$ and ^{137}Cs distinctly characterise each of the potential catchment sources.

- Calculation of the relative contributions from the three potential sources depends on assumptions about the residence time of the sediment, the height of the channel/gully banks and the unknown addition of ^{210}Pb by direct fallout to river sediment sampled from the main channel.

- Two different residence time scenarios that constrained the maximum and minimum values of catchment derived ^{210}Pb in transported sediments were considered. These values were incorporated into a three-component, and a two-component mixing model that enabled estimates of the maximum and minimum contribution from potential erosion sources to be determined.

- If residence time is assumed to be <30 years, then the minimum relative sediment contribution from channel bank and gully sources is $69\pm11\%$, the maximum contribution from cultivated land is $31\pm13\%$, and the lowest contribution (maximum $10\pm3\%$) is from uncultivated regions of the catchment.

- For a residence time <30 years the relative yield of sediment from cultivated land exceeds that from uncultivated lands by a factor of up to 45.

- For residence times longer than 40 years, the input from cultivated lands can be neglected. A two component model suggests that as residence time increases there is a reduction in the relative sediment contribution derived from gully bank erosion (decreasing from a maximum of 75%) and a continual increase in sediment contribution derived from uncultivated land (rising from a minimum of 25%).