Sedimentation in the Lower Hunter River Estuary: Some Insights from ^{137}Cs Distribution

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ABSTRACT: *The applicability of using ^{137}Cs as a tool for investigating the recent sedimentary history of Australian estuaries has been tested in the lower Hunter River estuary. Mean annual sedimentation rates determined from the ^{137}Cs sediment profiles closely correspond to a previously empirically measured rate. A strong consistency exists between the cores from similar sedimentary environments. The ^{137}Cs profile mean activity was used to suggest that there is a greater topsoil contribution to the suspended sediment load during high flow conditions than during normal flow.*

1. INTRODUCTION

Erosion and deposition are processes inherent in the natural geological cycle of the earth. Problems have arisen as a result of human interference in this cycle that has seen accelerated erosion and deposition as a result of poor land management practices.

The Hunter River catchment lies approximately 180 km north of Sydney on the east coast of NSW. The total catchment area comprises over 21000 km^2. The catchment has been considerably altered since European settlement to the point where it was considered, in the 1950s, as the most degraded coastal catchment in NSW. Since this time many millions of dollars has been spent on the control of soil and stream bank erosion across the catchment and on the removal of sediment from Newcastle Harbour to maintain navigable shipping channels.

The aim of this paper is to show the applicability of using ^{137}Cs in Australian estuarine environments. While it has been used extensively for soil erosion studies (e.g. Ritchie & McHenry, 1990; Loughran *et.al.*, 1992) and lacustrine sedimentation studies (e.g. Campbell, 1983; Walling & He, 1992), little work has focussed on its applicability to the study of estuarine sediments in Australia.

^{137}Cs is present within the environment solely as the result of atmospheric testing of nuclear weapons since the 1950's (Ritchie & McHenry, 1990). Large tests resulted in ^{137}Cs being distributed world-wide via stratospheric circulation from which the fallout has been measurable in soils since 1954 (Longmore, 1982).

This paper is part of a much broader study that is attempting to determine whether, or not, the sources and amount of sediment being deposited in the Lower Hunter River estuary has changed as a result of catchment stabilising efforts.

2. THE USE OF ^{137}Cs IN ESTUARINE ENVIRONMENTS

There have been questions raised about the applicability of using ^{137}Cs as a tool for examining the recent sedimentary history of an estuarine, or other similarly saline environments (Riel, 1970; Santschi *et.al.*, 1983; Zucker *et.al.*, 1984; Longmore *et.al.*, 1986). To date, the uncertainty has focussed on the possible desorption of ^{137}Cs from sediments under saline conditions, however, there are several other factors that must be considered when using ^{137}Cs in estuarine environments.

The strength of ^{137}Cs adsorption to sediment will ultimately be controlled by the clay mineralogy of that sediment. Certain clay minerals adsorb ^{137}Cs more strongly than others. The ^{137}Cs adsorption ability of specific clay minerals is directly related to the number, and type, of adsorption sites available within the crystal lattice structure of the mineral (Evans *et.al.*, 1983).

Interlayer sites (those sites in-between the separate layers of the repeated clay mineral crystal lattice) are the most permanent of ^{137}Cs adsorption sites. Coman & Hockley (1982) suggest that ^{137}Cs migrates relatively slowly along the crystal lattice towards the interlayer sites from where it is difficult to remove under normal environmental conditions.

The interlayer sites will eventually fill if there is sufficient ^{137}Cs available. Once the interlayer sites are saturated, excess ^{137}Cs will bind to less specific, and less permanent, adsorption sites on the clay mineral surface (Sawhney, 1970). This is most likely to occur under relatively high ^{137}Cs concentrations, such as those found in the effluent of nuclear processing plants.

The majority of ^{137}Cs desorption studies have been conducted on sediments contaminated with high concentrations of ^{137}Cs. Under these conditions the ^{137}Cs concentrations can be several orders of

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magnitude greater than those found within sediments of the lower Hunter estuary e.g. 6.2 Bq g^{-1} (Stanners & Aston, 1981) compared to 0.0045 Bq g^{-1} (highest value found during this study).

Singh & Gilkes (1990) found that ^{137}Cs retention is stronger for lower ^{137}Cs concentrations adsorbed by the sediment, irrespective of its clay mineralogy. This was due to excess ^{137}Cs binding to non-specific sites from which it was more easily removed.

Stanners & Aston (1981) reported a 30% desorption of ^{137}Cs from nuclear waste contaminated estuarine sediment. If only 30% of ^{137}Cs was readily exchangeable from sediment with a ^{137}Cs concentration more than 1000 times that found in this study then there is little evidence to suggest that ^{137}Cs specific adsorption sites of sediments will be saturated by the very low ^{137}Cs concentrations found in atmospheric deposition.

One must conclude that ^{137}Cs adsorbed onto sediments entering the estuary from higher in the catchment will remain strongly adsorbed to the sediment and will not be available for transport other than attached to the sediment.

Unlike a lacustrine system, an estuary is a freely open system. Sediment retention within lakes and reservoirs are generally very high, as opposed to estuarine systems, where a significant portion of the inflowing suspended sediment moves through the estuary and out to sea. There are no data available on the sediment trapping efficiency of the Lower Hunter estuary. The loss of this sediment limits the quantitative use of ^{137}Cs within the estuarine environment.

There is uncertainty about the degree to which direct atmospheric fallout of ^{137}Cs onto the estuarine water surface was incorporated into the estuarine sediments. The uptake of ^{137}Cs from water by suspended sediment is a rapid process (Aston & Duursma, 1971). The limiting factor for directly deposited ^{137}Cs being incorporated into the estuarine sediments is the sediment settling velocity. The sediment that has adsorbed the ^{137}Cs can move up or down stream, depending on the tide. This will strongly influence if, or where, the labelled sediment will be deposited. An unknown percentage of direct fallout will have been incorporated into the estuarine sediments which makes it very difficult to determine how much of the ^{137}Cs in the profile has been contributed by catchment soils.

Bioturbation can be a significant problem when attempting to date core profiles. Benthic fauna, if present and active, can cause mixing of the sediment profile (Sharma *et.al.*, 1987). Bioturbation tends to extend the 'tail' of the ^{137}Cs profile downward as the organisms mix the labelled sediment with the unlabelled sediment below. There is little evidence, direct or otherwise, to suggest that bioturbation in the Lower Hunter Estuary has resulted in significant changes to the core ^{137}Cs profiles.

2. METHODS

Nine sediment cores were taken from locations, known not to have been dredged, within the Lower Hunter Estuary between April and May, 1993. Some of the cores were taken in pairs to provide some degree of replicability to the results. Each core pair, and some individual cores, were taken from what were thought to be separate depositionary environments. The location of core sample sites are shown on Figure 1.

Cores were collected by driving a PVC drainage pipe (100 mm0) into the sediment with a slide hammer until consolidated sediments were reached. The pipe was then capped, extracted and returned to the lab where it was sectioned at 50 mm intervals. The upper sediments were very soft and there was no evidence of core compaction resulting from the sampling technique (e.g. dragged laminae). The samples were dried (45°C) and crushed to pass through a 2 mm sieve.

The ^{137}Cs content was determined using a G & E Ortec hi-purity germanium detector attached to a multi-channel spectrum analyser. Results were expressed on an areal activity basis (Loughran *et.al.*, 1988).

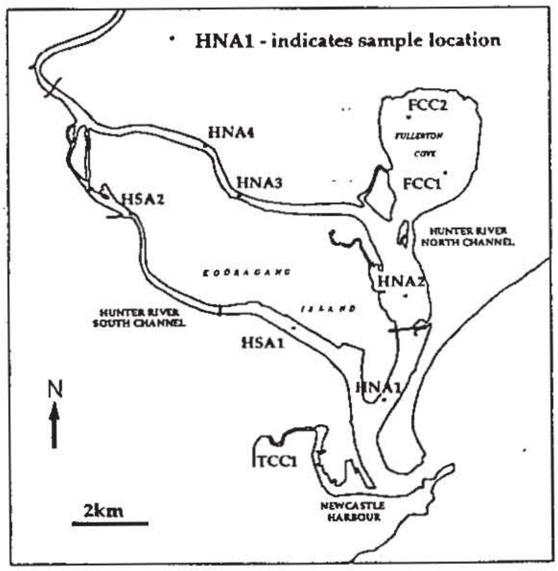

FIGURE 1 Map showing the location of the sediment cores in relation to the Lower Hunter River Estuarine morphology.

3. RESULTS

The most useful application of ^{137}Cs to estuarine sedimentation studies is that it enables a date to be ascribed to the first appearance of ^{137}Cs in the profile. While atmospheric ^{137}Cs fallout has been measurable in soils since 1954 (Longmore, 1982) the effect of radioactive decay and low initial concentrations would suggest that the presently measurable extent of ^{137}Cs should be ascribed a date several years later than 1954. The first minor peak in atmospheric ^{137}Cs fallout occurred in 1958 (Longmore, 1982) and it is this date that will be ascribed to the first presence of ^{137}Cs in the estuarine sediment profiles in this paper.

The depth to which ^{137}Cs was measured within the profile, the mean annual sedimentation rate, total core areal activity and mean core areal activity for all cores are shown in Table 1. Examples of the ^{137}Cs core profiles are shown as Figures 2a-d.

Cores that were taken from similar sedimentary environments (FCC1&2, HNA1&2, HNA3&4) showed a strong degree of within pair consistency. This would indicate that there is homogeneity within sedimentary environments suggesting that single cores (HSA1, HSA2, TCC1) would provide a reasonably adequate sample size.

Mean annual sedimentation rates calculated from the ^{137}Cs profiles show that considerable differences occur across the estuary. There has been between 0.3 and >1.5 m of depostion in the estuary since 1958. This represents deposition rates of between 8 and >42 mm yr^{-1}. The lowest sedimentation rates occur within Fullerton Cove, while the highest occur further up the estuary on the North Channel.

Fullerton Cove is a large (7 km^2) shallow (~2 m at high tide) basin off the Hunter River North Channel. This site is the only site within the study area where there exists sedimentation rate data from previous studies. The NSW Department of Public Works (1969) estimated, from physical model studies, that the sedimentation rate within Fullerton Cove was approximately 8 mm yr^{-1}. This is in strong agreement with the data from this study (8 and 10 mm yr^{-1}) and provides confidence in the use of ^{137}Cs as a dating tool in this estuarine environment.

Sedimentation rates close to Newcastle Harbour (HNA1, HNA2, HSA1) are all fairly consistent and close to 30 mm yr^{-1}. The greatest sedimentation rates occur at cores HNA3 and HNA4. On both these cores the bottom of the ^{137}Cs profile was not reached (e.g. Figure 2d). It must be noted that these cores were not taken in the middle of the channel due to problems with depth so they, more correctly, provide an indication of sedimentation rates close to the banks, in contrast to the entire channel.

TABLE 1. Summary of ^{137}Cs characteristics for all lower Hunter River estuarine cores. * Denotes best estimate from available data.

Core	Maximum Depth of ^{137}Cs (cm)	Mean Sedimentation Rate (mm yr^{-1})	Total ^{137}Cs Areal Activity (mBq cm^{-2})	Mean Activity (mBq cm^{-2} cm^{-1})
Fullerton Cove Core 1 (FCC1)	35	10	30.8	0.88
Fullerton Cove Core 2 (FCC2)	30	8	32.2	1.07
Hunter North Arm Core 1 (HNA1)	100	28	142.7	1.43
Hunter North Arm Core 2 (HNA2)	95	26	102.3	1.08
Hunter North Arm Core 3 (HNA3)	>150	>42	>355	2.37(*)
Hunter North Arm Core 4 (HNA4)	>100	>28	>218	2.18(*)
Hunter South Arm Core 1 (HSA1)	115	32	218.1	1.89
Hunter South Arm Core 2 (HSA2)	75	21	52.7	0.70
Throsby Creek Core 1 (TCC1)	55	15	97.5	1.77

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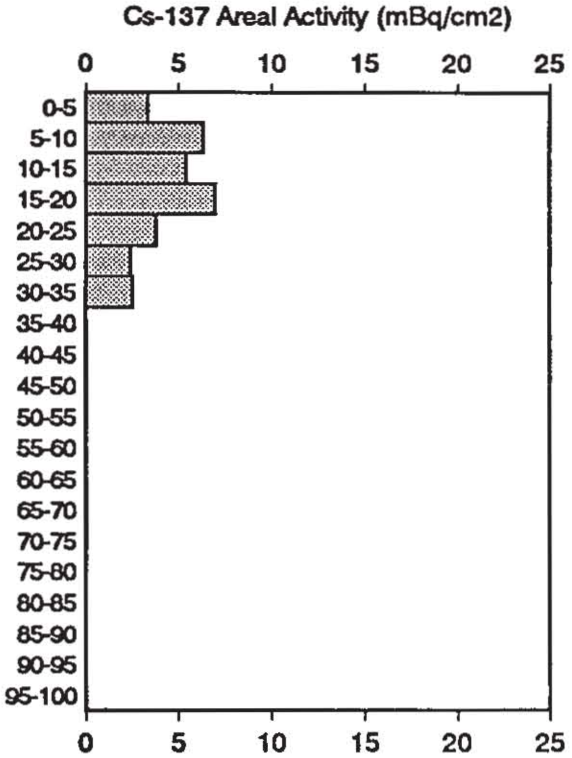

Figure 2a. Cs-137 profile from core FCC1 (Fullerton Cove).

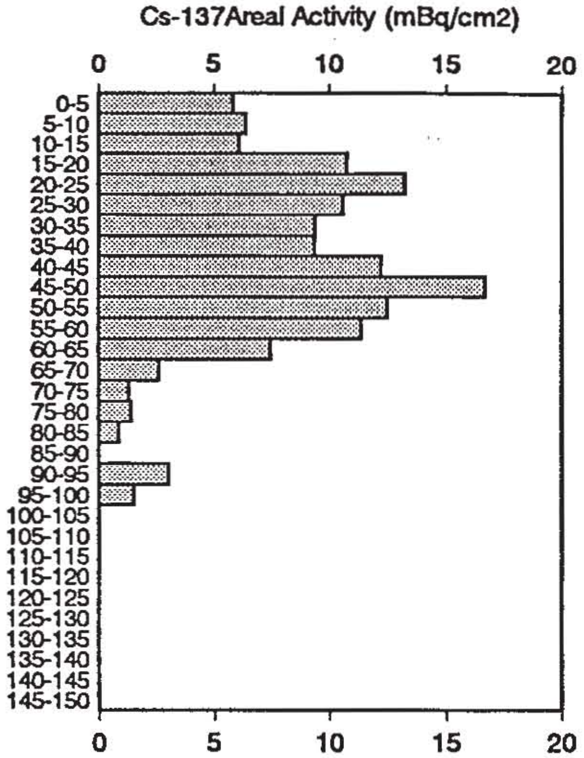

Figure 2b. Cs-137 profile from core HNA1 (Hunter River North Arm).

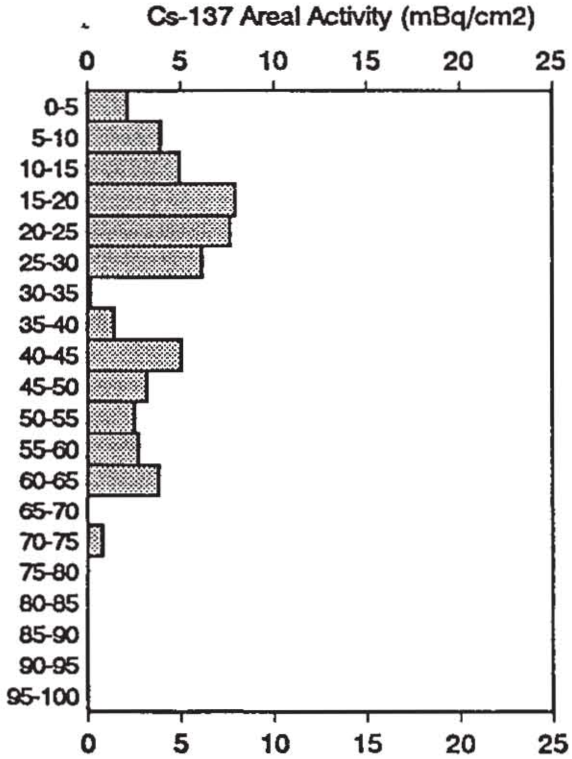

Figure 2c. Cs-137 profile from core HSA2 (Hunter River South Arm).

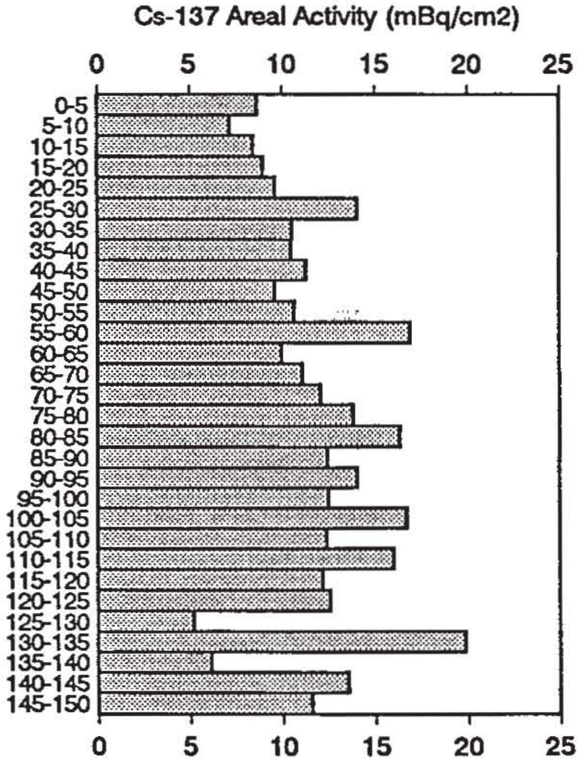

Figure 2d. Cs-137 profile from core HNA3 (Hunter River North Arm).

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Sedimentation rates in the Hunter River South Channel appear to be lower than elsewhere in the open estuary (see Figure 2c). Core HSA2 shows a sedimentation rate of 21 mm yr^{-1} which may be significantly influenced by the presence of barrages (built to low tide water level) at the upstream end of the South Channel. These barrages, while originally built to reduce harbour sedimentation (Ford, 1958), are suspected of reducing tidal flushing of sediment at the harbour end of the South Channel, resulting in the higher sedimentation rate at HSA1.

The usefulness of the whole core ^{137}Cs activity values to quantitatively estimate sediment sources (e.g. Loughran *et.al.*, 1988; Peart & Walling, 1986) is limited by the unknown degree to which direct atmospheric fallout has been incorporated into the estuarine ^{137}Cs profiles. However, assuming that the atmospheric fallout incorporation rate has been constant across the estuary, inter-core comparisons can be made. The mean activity (mBq cm^{-2} cm^{-1}), shown in Table 1, is an indication of the 'strength' of ^{137}Cs labelling of the respective cores.

One conclusive observation from these results is the significant difference between the mean activities of the upper estuarine cores (HNA3 & 4) compared to the Fullerton Cove cores. Several of the other cores had a variable particle size distribution that included some significant sand layers. This may 'dilute' the ^{137}Cs due to its reduced adsorption on sand particles. Cores HNA3 & 4 and FCC1 & 2 had consistent silt/clay particle size compositions, enabling strong comparisons to be made between the two depositionary environments.

Cores HNA3 & 4 had higher mean activities compared to FCC1 & 2. This would suggest that there is preferential deposition of labelled sediments, presumably a soil source, higher in the estuary.

3. DISCUSSION

3.1. Sediment Sources

Sedimentation rates suggest that a significant proportion of sediment being deposited within the lower Hunter River estuary is deposited within the North Channel, upstream of Fullerton Cove. While it is uncertain the degree to which the channel depth is changing, there is considerable evidence to suggest that channel narrowing is occurring. Furthermore, this sediment which is being deposited higher in the estuary is more strongly labelled with ^{137}Cs (compare Figures 2a & c with 2b & d), indicating a topsoil source. There are two possible explanations for this effect. Either labelled sediment (topsoil) is preferentially deposited or deposition is occurring at this site when a greater proportion of the suspended sediment is labelled with ^{137}Cs.

NSW Dept. of Public Works (1969) suggests that the lower Hunter River estuary acts as a stratified estuary with a clearly defined salt wedge during flows of 300 to 2000 m^3s^{-1} (approximately 5% of the time). Analysis of the sediment rating curve and the flow duration curve for the lower Hunter River (NSW Dept. of Public Works, 1969) suggest that approximately 50% of the mean annual sediment load will enter the estuary under these conditions. Therefore, while the salt wedge may be operating for a relatively small amount of time it can influence a significant proportion of the suspended sediment. A salt wedge will increase the flocculation of the sediments resulting in greater sedimentation at the turbidity maximum (Knox, 1986). The results tend to suggest that this turbidity maximum, under salt wedge conditions, is usually positioned upstream of Fullerton Cove on the North Channel.

It therefore seems likely that soil sources contribute more to the suspended sediment load during periods of high flow than at other times.

3.2. Sediment Remobilisation

Fullerton Cove acts as a primary sedimentation zone within the estuary (NSW Dept. of Public Works, 1969). Sediment is deposited under conditions of high suspended sediment concentrations. During the intervening periods between these events sediment is eroded and redeposited elsewhere within the estuary, predominantly Newcastle Harbour.

Due to the shallow nature of Fullerton Cove, strong winds can cause significant turbulence within the water column that results in the re-suspension of sediments which are then removed on the ebb tide (NSW Dept. of Public Works, 1969). This would account for the greatly reduced total ^{137}Cs activity of the Fullerton Cove cores.

4. CONCLUSION

The use of ^{137}Cs within an Australian estuarine environment has been shown to yield useful information about the recent sedimentary history of the estuary. Sedimentation rates suggest that a significant amount of sediment is being deposited across the lower Hunter River estuary, with the greatest mean sedimentation rates occurring higher in the estuary. The ^{137}Cs determined sedimentation rate within Fullerton Cove was shown to match very closely to a previously determined sedimentation rate. ^{137}Cs has again been shown to be a useful tracer of labelled topsoil material within the fluvial environment.

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