## 3.2 Sediment accumulation rates

The results of the radioisotope analysis of sediment cores are described in this section and summarised in Table 3-1. They provide an estimate of time-averaged sediment accumulation rates in the Whangarei Harbour system over the last 38–180 years based on<sup>137</sup>Cs and <sup>210</sup>Pb dating.

The maximum age of sediments dated using <sup>210</sup>Pb profiles depends on the maximum depth of unsupported <sup>210</sup>Pb in each sediment core. This maximum depth varies from core to core depending on the sediment accumulation rate, surface concentration of unsupported <sup>210</sup>Pb, particle size and degree of sediment reworking after deposition (i.e., radioisotope concentrations generally increase with mud content). Small amounts of unsupported <sup>210</sup>Pb may occur below the apparent maximum depth but are below detectable levels. The dating of older sediments relies on the use of complimentary radioisotopes/absolute dating methods, such radiocarbon (<sup>14</sup>C, half-life 5,730 yr), which have longer half-lives than <sup>210</sup>Pb (half-life 22 yr).

Compartment	Core Site	<sup>7</sup> Be SML (cm)	<sup>137</sup> Cs max depth (cm)	<sup>137</sup> Cs SAR (mm/yr)	<sup>210</sup> Pb SAR (mm/yr)	<sup>210</sup> Pb depth/(age) range (cm)	r <sup>2</sup>	n
Mangapai Arm	WHG-1	3	19	2.7	4.9	3-31 ( <i>1949–2012</i> )	0.87	6
					32.8	31-101 ( <i>1928–1949</i> )	0.70	4
	WHG-2	2	23	3.6	3.0	6-31 ( <i>1909-2012</i> )	1.0	4
					126.2	31-61 ( <i>1907-1909</i> )	0.89	3
	WHG-3	1	14	2.4	3.0	1-13 ( <i>1969–2012</i> )	0.52	5
Hātea Arm	WHG-6	2	19	2.9	2.8	20-52 ( <i>1830–2012</i> )	0.92	5
	WHG-14	0	25	4.7	6.5	0-25 ( <i>1974–2012</i> )	0.67	9
Parua Bay	WHG-10	0	19	3.2	2.2	0-17 ( <i>1935–2012</i> )	0.89	8
	WHG-11	1	19	3.0	2.9	1-17 ( <i>19</i> 53–2012)	0.82	6
					11.9	17-51 ( <i>1924–1953</i> )	1.0	3
Munro Bay	WHG-7	1	19	3.0	3.1	1-17 ( <i>1957–2012</i> )	0.93	7
Takahiwai	WHG-8	2	0	_	1.9	2-11 ( <i>1954–2012</i> )	0.58	5

Table 3-1:	Summary of sediment accumulation rates – Whangarei Harbour. <sup>137</sup> Cs SAR
corrected for	sediment mixing in the surface-mixed layer (SML, maximum <sup>7</sup> Be depth).

#### 3.2.1 Residence time of sediments in the surface mixed layer

At any point in time, remobilisation of surficial sediments by currents, wave action and/or by benthic fauna is possible within the surface mixed layer (SML). Only when sediments are removed from the SML by progressive burial are they no longer part of the active sedimentary system.

The depth of the SML in seabed sediments can be evaluated using the maximum depth of the short-lived berylium-7 (<sup>7</sup>Be,  $t_{1/2}$  = 53 days) profile. In turn the residence time of sediments in the SML can be estimated from the maximum <sup>7</sup>Be depth (mm) and <sup>210</sup>Pb SAR (mm/yr).

The maximum depth of the SML in the Whangarei Harbour cores varies between 0 and 3 cm, which is consistent with observations in other North Island estuaries and coastal marine environments. The presence of <sup>7</sup>Be indicates that these surface sediments are being mixed over time scales of weeks to months by physical and/or biological processes (Appendix C). Long-term accumulation of sediments occurs once they have been removed from the SML by burial as sediments continue to deposit. A first order estimate of the residence time (*R*) of sediments within the SML can estimated from radioisotope data as:

R = T/S

where *T* is the thickness of the SML (mm) given by the maximum depth of <sup>7</sup>Be in the sediment column and *S* is the <sup>210</sup>Pb SAR (mm/yr) (Table 3-2). This analysis indicates that the average residence time of sediments in the SML is 5.4 years (standard error = 1.2 years), with a range of 1.1 to 10.5 years.

Core sites	Max. <sup>7</sup> Be depth (mm)	<sup>210</sup> Pb SAR (mm/yr)	R (years)
Mangapai Arm			
WHG-1	30	4.9	6.1
WHG-2	20	3.0	6.7
WHG-3	10	3.0	3.3
Hātea Arm			
WHG-6	20	2.8	7.1
WHG-14	0	6.5	-
Parua Bay			
WHG-10	0	2.2	-
WHG-11	10	2.9	3.4
Munro Bay			
WHG-7	10	3.1	3.2
Takahiwai			
WHG-8	20	1.9	10.5

 Table 3-2:
 Estimated residence time (R) of recent sediments in the surface mixed layer (SML) at core sites.

The residence time can be used to define the age of recent sediment deposits as sediments, deposited (on average) over the previous ~5 years. Thus sediments within the SML are composed of:

- Soils eroded by seasonal-annual storms and discharged by rivers draining the present-day catchment.
- Soils that were eroded from the catchment within the past two decades and are presently being reworked on the seabed by physical and/or biological processes within the SML.
- Older sediment deposits mixed upwards within the SML with ages typically <*R*.

An implicit assumption in this type of analysis is that the SML characteristics are constant over time. In reality, infrequent natural events, such as large-magnitude storms can erode older deposits and mix these with more recent near-surface sediments.

### 3.2.2 Recent sediment accumulation rates

Recent sediment accumulation rates (SAR) have been estimated from <sup>137</sup>Cs and excess <sup>210</sup>Pb profiles, dating sediments deposited over the last ~150 years.

Time-averaged SAR have been estimated from the maximum depth of the <sup>137</sup>Cs in each core, corrected for the <sup>7</sup>Be SML depth as described in the methods section. Sediments labelled with <sup>137</sup>Cs indicate deposition since the early 1950s. The <sup>137</sup>Cs SAR vary between 2.4 and 4.2 mm/yr (Table 3-1). Although some of the <sup>137</sup>Cs SAR values are similar to the <sup>210</sup>Pb estimates, several factors suggest that the former data should be used with caution: (1) <sup>137</sup>Cs activity has substantially reduced even since the early-1960s <sup>137</sup>Cs deposition peak (i.e., t<sub>1/2</sub> = 30 years) so that <sup>137</sup>Cs activities are below detectable levels in deeper deposits and the maximum <sup>137</sup>Cs is under-estimated; (2) we assume that the <sup>7</sup>Be SML has been constant over time. In fact, deeper mixing over annual–decadal time scales is indicated by some of the <sup>137</sup>Pb profiles (e.g., cores WHG-2 and WHG-6) so that mixing maybe deeper, with the result that the maximum <sup>137</sup>Cs is over-estimated; (3) the early-1960s <sup>137</sup>Cs deposition peak observed in New Zealand wetland deposits (Gehrels et al. 2008), and the most reliable <sup>137</sup>Cs time-horizon for dating, is absent in NZ estuarine and coastal marine sediments (Appendix C).

The <sup>210</sup>Pb profiles provide time-averaged SAR (i.e., most sites 1.9–9.4 mm/yr) that are generally higher than <sup>137</sup>Cs estimates. Apparent reductions in SAR in the late 1940s/early 1950s are observed at two core sites: WHG-1 in the Mangapai Arm (from 32.7 mm/yr to 4.9 mm/yr) and WHG-11 in Parua Bay (from 11.9 mm/yr to 2.9 mm/yr).

The <sup>210</sup>Pb estimates are considered to be more reliable as the dating is based on regression fits to the excess <sup>210</sup>Pb data and therefore have a statistical basis rather than purely relying on the reliability of a marker horizon as is the case for <sup>137</sup>Cs. In some situations the <sup>210</sup>Pb SAR estimate may overestimate the "true" value if recent (i.e., high activity) <sup>210</sup>Pb is mixed deeply into the seabed. This results in a steeper profile and therefore higher apparent SAR value. In most cases the SML is a small fraction of the excess <sup>210</sup>Pb profile depth so that we consider that the <sup>210</sup>Pb SAR are reliable estimates.

Figures 3-4 to 3-16 present the sediment-core radioisotope data for each sedimentary compartment of Whangarei Harbour.

## 3.3 Spatial variations in recent sediment accumulation rates

## 3.3.1 Mangapai arm

The Mangapai arm includes core sites WHG-1, WHG-2 and WHG-3 located on intertidal flats south of Limestone Island (Fig 2-1, site map).

The x-radiographs for core WHG-1 display a range of sediment fabrics: a near-surface layer of finely laminated muds and fine sands (0–12 cm depth) containing fragments of shell valves and an intact gastropod (Fig. 3-4). This surface layer caps a lower-density sediment containing numerous shell valves (12–146 cm depth). The content increases near the base of the core below 146-cm depth. The sediments below the surface layer have a mottled appearance with bedding not well developed.



**Figure 3-4: Core WHG-1 X-radiographs (0–161 cm).** These images have been inverted so that relatively high-density objects appear white (e.g., shell valves) and low-density materials such as muds or organic material appear as darker areas (format: 8bit tiff, export:256 greyscale, scale 400%, png).

The X-radiographs for core WHG-2 also show a range of sediment fabric (Fig. 3-5). A sandlayer (0-20 cm) containing numerous valves of the estuarine wedge shell, *Macamona lilliana*, caps the muddy sands below. These shellfish are typical of intertidal flats and generally more tolerant of mud substrates than other common shellfish, such as cockles (*Austrovenus*  *stutchburyi*) (Morton and Miller 1973). Pockets of sand within the underlying mud are indicative of the burrowing activities of infauna (20-36 cm). Numerous traces of burrows can be seen within the sandy-muds. Although some bedding is preserved at various depths, these sediments have a mottled appearance that is consistent with mixing by infauna.



Figure 3-5: Core WHG-2 X-radiographs (0–171 cm). (Format: 8bit tiff inverted; export:256 greyscale, scale 400%, png).

The X-radiographs for core WHG-3 are similar to WHG-2, with a near-surface sand-layer (0-20 cm) containing *Macamona Lilliana* (Fig. 3-6). Beneath this surficial sand, the underlying mud has a mottled appearance that is consistent with mixing of the sediment by infauna.



Figure 3-6: Core WHG-3 X-radiographs (0–59 cm). (Format: 8bit tiff inverted; export:256 greyscale, scale 400%, png).

Dry-bulk sediment density ( $\rho_b$ ) profiles for the cores provide information on the composition of the sediment deposits preserved in the Mangapai cores (Fig 3-7). For example, the  $\rho_b$  values for estuarine sand deposits are typically of the order of 1.5–1.7 g/cm<sup>3</sup>, whereas a mud deposit with high water content can typically have a  $\rho_b$  of ~ 0.5 g/cm<sup>3</sup>.

The Mangapai sediment cores have  $\rho_b$  values indicative of a range of sediment composition, from muddy-sands to sandy-muds. At WHG-1, the  $\rho_b$  profile shows a trend of reducing bulk density in the top ~20-cm of the core (i.e., post 1950s), from ~1 to 0.75 g/cm<sup>3</sup>. This is consistent with increasing mud deposition at the site. By contrast at WHG-2 and WHG-3,  $\rho_b$  appears to generally increase in the top 20-cm of the cores (~1 to 1.6 g/cm<sup>3</sup>) and is more characteristic of sand deposits. These differences may reflect winnowing of muds by waves at the more exposed WHG-2 and WHG-3 sites as the intertidal-flat has accreted. Below 20-cm depth,  $\rho_b$  values at all three sites are relatively uniform at ~1 ±0.2 g/cm<sup>3</sup>.



**Figure 3-7: Whangarei Harbour dated sediment cores – dry bulk sediment density.** Vertical profiles of dry-bulk sediment density (g/cm3) derived from dated sediment cores collected from the (a) Mangapai and (b) Hātea arms, (c) Parua Bay and (d) Munro Bay and Takahiwai.

The radioisotope profiles record the sedimentation history of the Mangapai arm over the last century. Figure 3-8 presents the excess <sup>210</sup>Pb profiles (<sup>210</sup>Pb<sub>ex</sub>) and maximum <sup>7</sup>Be and <sup>137</sup>Cs depths for these core sites. A notable feature of the <sup>210</sup>Pb<sub>ex</sub> profiles at WHG-1 and WHG-2 are apparent decreases in sediment accumulation rates (SAR) during the last century (Fig. 3-8). At WHG-1 <sup>210</sup>Pb<sub>ex</sub> SAR averaged 33 mm/yr prior to 1949 and declined to 4.9 mm/yr since that time. The base of the <sup>210</sup>Pb<sub>ex</sub> profile dates to 1928.

Core WHG-2 was collected from the intertidal flats ~ 500 m south-west of the cement plant. Here <sup>210</sup>Pb<sub>ex</sub> SAR averaged 126 mm/yr during a two-year period between 1907 and 1909 and subsequently declined to 3.0 mm/yr after that time. This apparent rapid sedimentation may also represent a single or series of coincident sedimentation events, such as could occur during a large-magnitude storm. The <sup>137</sup>Cs dating at WHG-1 and WHG-2 is consistent with the <sup>210</sup>Pb data although the SAR values are not in close agreement (Table 3-1). The observed reduction in SAR at sites WHG-1 and WHG-2 can be explained in terms of a reduction in sediment supply related to reduced catchment sediment inputs and/or reduced tidal inundation resulting from the vertical accretion of the intertidal flats over time. The timing of these observed changes in sedimentation rates do not coincide with the operation of the cement plant (1918-1982).

Core WHG-3 was collected from the intertidal flats north-east of the cement plant and on the opposite bank of the tidal channel. The initial log-linear regression fit to the <sup>210</sup>Pb<sub>ex</sub> data was reasonable ( $r^2 = 0.95$ ), however there was very poor agreement between the estimated <sup>210</sup>Pb and <sup>137</sup>Cs SARs of 9.4 mm/yr and 2.4 mm/yr (post-1950s) respectively (Fig 3-8). The X-radiographs indicates a muddy-sand layer (0–20-cm depth) deposited on an underlying

sandy-mud. This difference in sediment texture below 20-cm depth is likely to increase  $^{210}$ Pb<sub>ex</sub> activity in the bottom layer because radioisotopes bind to the finest clay particles, which will influence the slope of the log-linear regression fit to the  $^{210}$ Pb<sub>ex</sub> data. Furthermore, the top sandy layer has a different composition that reflect environmental differences, most likely due to winnowing of fines by waves. As a result, SAR are likely to decline over time as the intertidal flat accretes as note at sites WHG-1 and WHG-2. The  $^{210}$ Pb<sub>ex</sub> data were subsequently reanalysed for the top-most 20-cm layer, which yielded a  $^{210}$ Pb SAR of 3 mm/yr (r<sup>2</sup> = 0.52). Although the model fit is relatively poor, it more accurately reflect the stratigraphy at this core site.

The residence time of sediment in the <sup>7</sup>Be surface-mixed layer (SML) prior to removal by sedimentation in WHG-1, WHG-2 and WHG-3 are 6.1, 6.7 and 3.3 years respectively.



# Excess <sup>210</sup>Pb Activity (Bq/kg)

**Figure 3-8: Mangapai Arm: sediment accumulation rates (SAR) at core sites WHG-1, WHG-2 and WHG-3.** Excess <sup>210</sup>Pb activity profiles with 95% confidence intervals show. Time-averaged SAR derived from regression fit to natural-log transformed data, with estimated ages of key depth horizons (red text). The berylium-7 (<sup>7</sup>Be) surface mixed layer (SML) and maximum depth of caesium-137 (<sup>137</sup>Cs max) in each sediment core is also shown. Sediments below the <sup>137</sup>Cs max depth were deposited before the 1950s. Radioisotope activities are expressed in S.I. units of Becquerel's (Bq), which is equivalent to one radioactive disintegration per second.

## 3.3.2 Hātea arm

Sediment cores were initially collected at three sites in the Hātea Arm (WHG-4, -5, -6), although of these only WHG-6 yielded radioisotope data for determining sediment accumulation rates. The sediment composition for WHG-6 and the additional core site

WHG-14 (east of Hātea channel), is described here based on x-radiographs and dry-bulk density profiles.

The x-radiographs for core WHG-6 display a transition from a surface sandy layer, with a general increase in mud and/or pore-water with depth in the sediment column (Fig. 3-9). A finely-laminated sand layer extends to 18-cm depth and containing abundant Macamona valves at 8–18-cm depth. Small shell fragments also commonly occur throughout the core, with rare complete valves and gastropods. A notable feature of the sediments below the surface sand layer are abundant traces of mm-scale worm burrows infilled with mud and/or porewater. These appear as dark curving lines in the sediment fabric. These sediments also have a mottled appearance with bedding not well developed, which is consisted with mixing of the deposit by infauna. The down-core changes in sediment composition indicated by the x-radiographs are reflected in the sediment bulk density profile, with  $\rho_b$  values generally reducing from 1.1± 0.1 g/cm<sup>3</sup> in the surface sand unit to 0.8 ± 0.1 g/cm<sup>3</sup> near the base of the core (Fig. 3-8).



Figure 3-9: Core WHG-6 X-radiographs (0–165 cm). (Format: 8bit tiff inverted; export: 256 greyscale, scale 400%, png).

Radioisotope analysis of near-surface (0–3 cm) sediments showed that <sup>7</sup>Be and <sup>137</sup>Cs is absent at WHG-4 and WHG-5. <sup>210</sup>Pb<sub>ex</sub> was also confined to this surface mixed layer at these two core sites. These data are consistent with frequent physical reworking of bed sediments by waves such that muds presently do not accumulate. At high tide, both sites have substantially longer wave fetches to the east (~ 6 km) in comparison to other fetch directions. By comparison WHG-6, located immediately west of the Port Whangarei, is relatively sheltered from wave action. Cores collected at WHG-6 and at WHG-14, located on intertidal

flats east of the port and main channel, preserve records of sedimentation in the Hātea arm of the harbour.

At WHG-6, deep mixing in the surface layer is indicated by relatively uniform  $^{210}Pb_{ex}$  activities to ~20-cm depth (Fig. 3-10). This  $^{210}Pb_{ex}$  SML also coincides with the maximum depth of  $^{137}Cs$  in the core, which suggests that the  $^{137}Cs$  penetration at this site reflects an in situ rapid mixing event rather than a gradual sedimentation process. The  $^{210}Pb_{ex}$  profile in WHG-6 extends to 50-cm, with sediments at this depth dated to c.1830. The residence time of sediment in the <sup>7</sup>Be SML is 7.1 years.

At WHG-14, located east of the port and the Hātea channel, the <sup>210</sup>Pb<sub>ex</sub> profile extends to 25cm depth, with sediments at this horizon dated to c. 1974. The <sup>210</sup>Pb<sub>ex</sub> SAR of 6.5 mm/yr is substantially higher than at WHG-6.



# Excess <sup>210</sup>Pb Activity (Bq/kg)

**Figure 3-10:** Hātea Arm: sediment accumulation rates (SAR) at core sites WHG-6 and WHG-14. Excess <sup>210</sup>Pb activity profiles with 95% confidence intervals show. Time-averaged SAR derived from regression fit to natural-log transformed data, with estimated ages of key depth horizons (red text). The berylium-7 (<sup>7</sup>Be) surface mixed layer (SML) and maximum depth of caesium-137 (<sup>137</sup>Cs max) in each sediment core is also shown. Sediments below the <sup>137</sup>Cs max depth were deposited before the 1950s. Radioisotope activities are expressed in S.I. units of Becquerel's (Bq), which is equivalent to one radioactive disintegration per second.

## 3.3.3 Parua Bay

Sediment cores were collected at three sites in Parua Bay in subtidal (WHG-10, WHG-13) and intertidal habitats (WHG-11) (Fig. 2-1). Cores from sites WHG-10 and WHG-11 were selected for radioisotope dating.

The x-radiographs for core WHG-10 indicate that sediments at this site are composed of shell-rich sands and muddy sands (Fig. 3-11). Sands in the top 4 cm of the core display fine lamination and overlay a layer of shell valves and fragments to 12-cm depth. Below this shell layer, muddy sands containing shell valves extend to 50-cm depth and overlay another shell layer (50–65 cm). Muddy sands occur below this layer to the base of the core at 108-cm. Turret shells (*Maoriculpus roseus*) are abundant below 80-cm depth. The turret shell is a deposit-feeding gastropod found in subtidal estuarine and shelf environments in water depths up to 100 m (Powell 1979). The sediment bulk density profile shows that sands in the top ~20-cm of the core have  $\rho_b$  values of  $1.2 \pm 0.1$  g/cm<sup>3</sup> that are higher than in the underlying muddy sands  $1 \pm 0.1$  g/cm<sup>3</sup> (Fig. 3-7).





On the intertidal flats at WHG-11, the x-radiographs show a range of sediment fabric, with the muddy-sand matrix containing traces of animal burrows. Bedding is poorly preserved with the sediment fabric having a mottled appearance indicative of mixing by infauna (Fig. 3-12). The burrows appear as darker diagonal to near vertical tubes of mm to cm diameter. Disarticulated shell valves up to 3-cm diameter and occasional gastropods first occur at ~20-cm depth and occasionally to the base of the core at 157-cm depth. The sediment bulk density profile shows no apparent trend with depth in the sediment core, with  $\rho_b$  averaging 1.3 g/cm<sup>3</sup> with relatively small variations (± 0.1 g/cm<sup>3</sup>) (Fig. 3-7).



Figure 3-11: Core WHG-11 X-radiographs (0–157 cm). (Format: 8bit tiff inverted; export:256 greyscale, scale 400%, png).

Sediment accumulation rates in Parua Bay are generally lower and more similar than in the Mangapai and Hātea arms west of Limestone Island, where the largest sub-catchment discharge to the harbour. The <sup>210</sup>Pb<sub>ex</sub> profile at the subtidal WHG-10 core site extends to 17-cm depth, which corresponds to the mid-1930s. The <sup>210</sup>Pb<sub>ex</sub> SAR has averaged 2.2 mm/yr since that time (Fig. 3-13). On the intertidal flats, the WHG-11 <sup>210</sup>Pb<sub>ex</sub> profile dates sediments back to the mid-1920s (50-cm depth). An apparent reduction in sedimentation rate occurred in the early 1950s (Fig. 3-14), with <sup>210</sup>Pb<sub>ex</sub> SAR prior to the 1950s averaging 12 mm/yr reducing to 2.9 mm/yr since that time. As described in section 3.3.1 (Mangapai arm), this apparent reduction in historical SAR can be explained in terms of a reduction in sediment supply, either related to reduced catchment sediment inputs and/or reduced tidal inundation resulting from the vertical accretion of the intertidal flats over time. There is very good agreement between the <sup>210</sup>Pb<sub>ex</sub> and <sup>137</sup>Cs derived SAR values in WHG-11 (Table 3-1).



**Figure 3-12:** Parua Bay: sediment accumulation rates (SAR) at core sites WHG-10 and WHG-11. Excess <sup>210</sup>Pb activity profiles with 95% confidence intervals show. Time-averaged SAR derived from regression fit to natural-log transformed data, with estimated ages of key depth horizons (red text). The berylium-7 (<sup>7</sup>Be) surface mixed layer (SML) and maximum depth of caesium-137 (<sup>137</sup>Cs max) in each sediment core is also shown. Sediments below the <sup>137</sup>Cs max depth were deposited before the 1950s. Radioisotope activities are expressed in S.I. units of Becquerel's (Bq), which is equivalent to one radioactive disintegration per second.

## 3.3.4 Munro Bay and Takihiwai

The sediment cores collected in Munro Bay (WHG-7), east of Parua Bay, and at Takihiwai (WHG-8) are located in lower-harbour at sites remote from the major catchment sediment sources (Fig. 2-1). At Munro Bay, sediment cores were collected from a shallow subtidal habitat whereas at Takahiwai sediment cores were collected from an intertidal sea-grass meadow. Although not dated, sediment cores were also collected from intertidal sand flats in Blacksmith Bay (WHG-12), immediately west of Marsden Point wharf. The x-radiograph for WHG-12 is also described in this section.

The x-radiograph of WHG-7 show a general trend of increasing sediment density from muddy sands to shell-rich sands below a 1-cm thick SML with finely laminated muddy sands (Fig. 3-14). The apparent high pore-water content and fine laminations are consistent with recent resuspension of the SML. A sharp contact occurs with the underlying sand unit below. Another transition in sediment composition occurs at 26-cm depth, with a dense layer of shell valves and fragments occurring to the base of the core (48 cm). Apart from the SML, sediment stratigraphy is poorly preserved. The sediment bulk density profile is consistent with the observed sediment fabric. The  $\rho_b$  in the cm-thick SML is close to unity, which

indicates high porewater content. Below the SML,  $\rho_b$  values vary from 1.2 to 1.5 g/cm<sup>3</sup> (Fig. 3-7).

At Takahiwai, sediments within the seagrass meadow are composed of sands. In the top 10cm of core WHG-12, sediments have a mottled appearance indicative of mixing processes. A low density layer occurs at 8-cm depth composed of organic material composed of seagrass blades (Fig. 3-14). Below 12-cm depth these sandy sediments have a more homogeneous appearance although with cm-thick layers of organic material at intervals to the base of the core at 54-cm depth. Fine (mm scale) laminations are also evident in this sediment unit below the mixed surface layer. The sediment bulk density profile for WHG-8 shows no clear down-core trend, with  $\rho_b$  averaging 1.5 g/cm<sup>3</sup> (range 1.25–1.7 g/cm<sup>3</sup>) (Fig. 3-7).



**Figure 3-13:** Munro Bay (WHG-7) and Takahiwai (WHG-8): sediment accumulation rates (SAR) at core sites. Excess 210Pb activity profiles with 95% confidence intervals show. Time-averaged SAR derived from regression fit to natural-log transformed data, with estimated ages of key depth horizons (red text). The berylium-7 (7Be) surface mixed layer (SML) and maximum depth of caesium-137 (137Cs max) in each sediment core is also shown. Sediments below the 137Cs max depth were deposited before the 1950s. Radioisotope activities are expressed in S.I. units of Becquerel's (Bq), which is equivalent to one radioactive disintegration per second.

The <sup>210</sup>Pb<sub>ex</sub> profile in WHG-7 extends to 17-cm depth and dates to the mid-1950s, with SAR averaging 3.1 mm/yr since that time (Fig. 3-15). There is good agreement between the <sup>210</sup>Pb<sub>ex</sub> and <sup>137</sup>Cs derived SAR (Table 3-1). At Takahiwai (WHG-8), sedimentation rates are substantially lower, with <sup>210</sup>Pb<sub>ex</sub> SAR averaging 1.9 mm/yr being the lowest observed in Whangarei Harbour. <sup>137</sup>Cs was not detected at WHG-8.





## 3.3.5 Marsden Bay

Sediments at Marsen Bay are composed of sands, which have a mottled appearance, indicative of partial mixing over time by infauna (Fig. 3-16). Numerous voids in the sand appear as narrow dark bands. A shell layer occurs at 18–20-cm depth. A thin surface mixed layer (0-1 cm depth) can be seen in the x-radiograph, composed of finely laminated sands and silts, which is consistent with sediment resuspension on the intertidal flat by waves.