Sedimentation in the Avon-Heathcote Estuary/Ihutai – an analysis of past and present studies

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January 2007

Executive Summary

In order to determine where future studies of sedimentation in the Avon-Heathcote Estuary/Ihutai (the Estuary) should be directed the Avon-Heathcote Estuary/Ihutai Trust and Environment Canterbury initiated a review of the literature examining sedimentation in the Estuary. This review was undertaken over the summer of 2006-2007 and focuses on summarising and critiquing studies of sedimentation in the Estuary since the last major review on the topic from the early 1990s (Hicks, 1993). Following a general introduction to this project (Section 1) this review deals with three main areas of sedimentation.

Section 2 reviews studies of sediment size distribution across the Estuary and the pattern of erosion and deposition. It is apparent that significant work was undertaken in the 1980s and early 1990s. This produced good data on sediment distribution and the pattern of deposition and erosion. Studies since then, however, have only provided qualitative data or have been of narrow scope. This means that they are of limited usefulness when discussing the Estuary as a whole and the best data remains that obtained in the mid 1980s.

Section 3 examines studies of nutrient enrichment, organic matter concentrations, and the levels of heavy metals and organic contaminants within the sediments of the Estuary. Robust studies of heavy metals concentrations were undertaken in the 1980s, however, studies of nutrient enrichment and organic contamination are less common and, in some cases, of limited use to workers due to the lack of sampling information in the reports. Current information on the levels of contaminants in the Estuary sediments is therefore poor.

Section 4 of this review examines the input of sediment and sediment contaminants (such as heavy metals and nutrients) from the major sources of terrestrial input; the Avon and Heathcote Rivers and the Christchurch Wastewater Treatment Plant (CWTP). It is apparent from the existing literature that the major suppliers of sediment to the Estuary are the Avon and Heathcote rivers, however, while routine monitoring of the rivers occurs the actual estimates of sediment supply from these sources are poor. This is due to a lack of sampling of suspended sediment levels during storm events which are responsible for the majority of sediment input to the Estuary from the rivers. The estimates of contaminant input from the rivers to the Estuary are poor for the same reason. The input of suspended solids, nutrients and contaminants from the CWTP is better constrained as the discharge is controlled and the routine monitoring can be used to calculate robust estimates of input. There is not enough robust data from all the inputs, however, to produce reliable estimates of the long-term input of sediment and contaminants to the Estuary.

The final section of this review briefly summarises the findings and prioritises the recommendations for future study on sedimentation in the Estuary. The two immediate requirements for study are;

1. A comprehensive, quantitative survey of the Estuary in order to establish changes in the sediment size distribution and the areas of erosion and deposition within the Estuary since the mid 1980s.

2. A multi-year study of storm events on the Avon and Heathcote rivers in order to accurately calculate long-term sediment input to the Estuary.

Addition work that should be undertaken in the longer term includes;

3. An extensive quantitative study of sediment size distribution across the Estuary to establish the current composition of the sediment and to identify the best sites for long-term monitoring.

4. A study of sediment contaminants and nutrients with sampling sites chosen in order to represent all available habitats within the Estuary.

5. A study of contaminants in the Avon and Heathcote Rivers over multiple storm events to enable the calculation of the long term contribution of these contaminants to the Estuary.

6. The sampling (over multiple years) of the sediment, nutrient and heavy metal input of sub-catchments to the rivers in order to determine the relative contribution of the individual sub-catchments to the Estuary.

7. The sampling of the six major drains during storm events in order to calculate a more accurate measure of their relative contribution.

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Section 1 – Introduction

1.1. Purpose of this review

The Avon-Heathcote Estuary/Ihutai (the Estuary) has been subject to human activity in its environs for 600-700 years (Robertson et al., 2002) and has been subject to increasing urbanisation since European arrival in ca. 1850 (Hicks, 1993). The highly urbanised nature of the Estuary has made it the focus of substantial scientific investigation (Hicks, 1993) with the Zoology Department at the University of Canterbury (now part of the School of Biological Sciences) alone producing more than 80 unpublished reports and theses on the Estuary's ecology since the 1920s (Knox, 1992)! Additional studies were initiated by the Christchurch Drainage Board during the 1950s to 1970s culminating in a definative report on the ecology of the Estuary by Knox and Kilner (1973). While the history of scientific investigation on the Estuary has therefore been long and prolific most of the investigations have concentrated on the biology of the Estuary (Hicks, 1993) and studies of sedimentation in the Estuary are rare (e.g. Macpherson, 1978; Deely, 1991).

The existing information and the history of sedimentation in the Estuary prior to the early 1990s was summarised and supplemented with additional work by Murray Hicks in 1993 (Hicks, 1993). This report is, to date, the most comprehensive single reference regarding sedimentation in the Estuary. Since the Hicks report, however, information on sedimentation in the Estuary has continued to accumulate although these studies have generally focused on only one or two aspects of sedimentation (e.g. heavy metal and organic contamination of sediments (Mills & Williamson, 1999)). Furthermore, these studies have been undertaken by a number of different parties with differing agendas and thus different priorities. Information on sedimentation in the Estuary is scattered throughout numerous reports on a variety of topics held by a number of different organisations. This makes establishing the current state of knowledge regarding sedimentation in the Estuary difficult.

To help resolve this problem, and determine where future studies on sedimentation in the Estuary should be directed, Environment Canterbury and the Avon-Heathcote Estuary/Ihutai Trust initiated this project to gather together the various sources of information on sedimentation in the Estuary. Due to the time constraint on the production of this report, and the extremely broad subject to be reviewed, it concentrates primarily on reviewing work not included in the Hicks report (Hicks, 1993). This review focuses on the distribution of sediments (and their associated contaminants), their deposition and erosion within the Estuary, and on the input of sediments (and their associated contaminants) to the Estuary. Finally this review provides recommendations on where future projects on sedimentation in the Estuary should be directed.

1.2. Physical description of the Avon-Heathcote Estuary/Ihutai

The Estuary is a shallow (1.4m deep at mean high water springs (Robertson et al., 2002)), triangular bar built estuary of ca. 8km^2 (Knox & Kilner, 1973). To the south rise the volcanic basalt Port Hills of Banks Peninsula (Robertson et al., 2002) while the northern and western bounds of the Estuary are the low lying sequences of sand, drained swamp and alluvial gravels that comprise the Canterbury Plains

(Robertson et al. 2002). The eastern boundary of the Estuary is formed by the ca. 4km long Brighton Spit which divides the Estuary from the Pacific Ocean (Fig. 1.1).

Figure 1.1. Aerial photograph of the Avon-Heathcote Estuary/Ihutai showing the locations of the major inputs (the Avon and Heathcote Rivers, the Christchurch Wastewater Treatment Plant (CWTP) as well as the ocean inlet. Also shown are the Brighton Spit and McCormacks Bay. Aerial photograph is from Intergrated Mapping (1997-2004).

The Estuary hydrology is dominated by saltwater input from the Pacific Ocean, via the mouth of the Estuary in the southeast corner, and by the freshwater input of the Avon River in the north and the Heathcote River in the southwest (Fig. 1.1) (Robertson et al., 2002). Most of this combined input (ca. 8.3×10^6 m^3) drains to the Pacific Ocean each day through the mouth of the Estuary although 44% of the freshwater water drained returns on the next high tide (Knox & Kilner, 1973; Robertson et al., 2002). The fresh and saline water within the Estuary is generally well mixed due to the its shallow nature and the combined action of winds and tides but some stratification does occur (Roberston et al.,

2002) and saline water can reach ca. 10km up the Avon and Heathcote rivers (Knox & Kilner, 1973; Robertson et al., 2002).

The Avon and Heathcote Rivers are the primary suppliers of freshwater and sediment to the Estuary. Both rivers are dominated by ground water flow and are generally slow and meandering (Royds Garden Environmental Services, 1993; McKerchar, 2001). The Avon River flows through a combination of flat (maximum elevation of 30m a.m.s.l. (Royds Garden Environmental Services, 1993)), rural and residential areas in the northwestern suburbs of Christchurch. It drains a catchment of 84.3km^2 (Pratt, 2000). The Heathcote River and its tributaries drain a larger catchment (103.4 km^2 (Pratt, 2000)) which includes parts of the Port Hills (ca. 30% of the catchment (Royds Garden Environmental Services, 1993)) as well as the low lying land to the southwest of the Estuary. The Heathcote catchment includes rural, residential and industrial areas.

A third noteworthy supplier of water and contaminants to the Estuary is the Christchurch Wastewater Treatment Plant (CWTP) (Fig. 1.1). While the CWTP is currently planning to pipe effluent 3km out into the Pacific Ocean by 2009 (Thompson, 2005) it currently releases ca. 170,000m^3 of treated effluent (Christchurch City Council http://www.ccc.govt.nz/WasteWater/TreatmentPlant/ 15th January 2007) directly into the Estuary. This is done on the ebb tide, so as to facilitate the removal of effluent from the Estuary, however much of it (ca. 40%) still returns with the following incoming tide (Thompson, 2005).

1.3 Review Layout

Following this introduction this report is divided into four sections.

The first section (Section 2) deals with the sediments within the Estuary itself. It reviews the available information examining the recent (1970s-present) distribution of sediment within the Estuary and also examines current information regarding the pattern of erosion and deposition within the Estuary. Recommendations of future research are provided at the end of this section.

Section 3 provides a review of the available information on the distribution of nutrients and contaminants that occur in association with the sediments of the Estuary. General recommendations for future work in these areas are again provided at the end of this section.

The third part of this review (Section 4) reviews the existing information on the input of sediment, and associated contaminants and nutrients, to the Estuary. This includes reviews of sediment and contaminant input from the Avon and Heathcote rivers, the CWTP and the six major drains that empty into the Estuary. As for the previous sections recommendations for future work are made at the end of the section.

The final section of this review (Section 5) provides a brief summary of the overall findings of this review and prioritises the suggested recommendations for future study.

Section 2 – The pattern of sediment distribution, deposition and erosion within the Avon-Heathcote Estuary/Ihutai

A number of studies on the history and pattern of sedimentation within the Estuary have been undertaken since the mid 1940s. This body of work was extensively reviewed by Hicks (1993) and the long-term history of sedimentation in the Estuary is not discussed in this section which instead focuses on the current state of knowledge regarding surface sediment distribution and the rate and pattern of deposition and erosion.

2.1. Patterns of sediment distribution

It appears from the, often brief, descriptions of the methods used in the various studies of sediment distribution that methodologies have often varied. Knox & Kilner (1973), for example, state that most of the studies undertaken by the Zoology Department at the University of Canterbury removed soluble salts and organic matter prior to wet sieving (with a dispersal agent) to separate the sand and silt/clay fractions. The silt/clay fraction was then analysed using the pipette method (Knox & Kilner, 1973). On the other hand the most recent quantitative study of 330 samples from 17 transects was undertaken by Rodrigo (1985) using the methods outlined by the Christchurch Drainage Board (1988). This method used dry sieving of sediments down to the silt/clay fraction and then analysed these fractions using wet sieving and hydrophotometry rather than the pipette method (Christchurch Drainage Board, 1988). The most recent study of sediment distribution in the Estuary (Robertson et al., 2002) was based on mapping of aerial photographs and therefore only provides qualitative descriptions of sediment distribution rather than an analysis based on quantitative grain size analysis. Direct comparisons between these surveys are consequently fraught with difficulty.

Despite the different methods used a number of common trends can be distinguished indicating that patterns of sedimentation in the Estuary have remained relatively constant since the 1970s (Knox & Kilner, 1973; Deely, 1991; Knox, 1992). The muddiest sediments (i.e. the sediments with the highest silt and clay content) are situated close to the entrance of the rivers to the Estuary (Knox & Kilner, 1973; Macpherson, 1978; Rodrigo, 1985; Deely, 1991; Robertson et al., 2002) with a decreasing proportion of mud, and a corresponding increasing proportion of sand, closer to the mouth of the Estuary (Fig. 2.1). Knox & Kilner (1973) suggest that the reason for this trend is due to the generally sluggish flow of the Avon and Heathcote rivers which, while capable of carrying finer grades of sediment (i.e. clay and silt), are too weak to carry large amounts of suspended sand. This hypothesis is supported by the lack of suspended sediments coarser than 0.063mm (sand) in the base flow of the Avon and Heathcote rivers (Hicks, 1993). The input of sand to the Estuary is therefore thought to be derived from the coastal beaches and carried in by the incoming tide (Knox & Kilner, 1973).

The reason why fine sediment is deposited around the river mouths, rather than simply being carried through the Estuary and out to sea, relates to the interaction of fresh water from the rivers with the

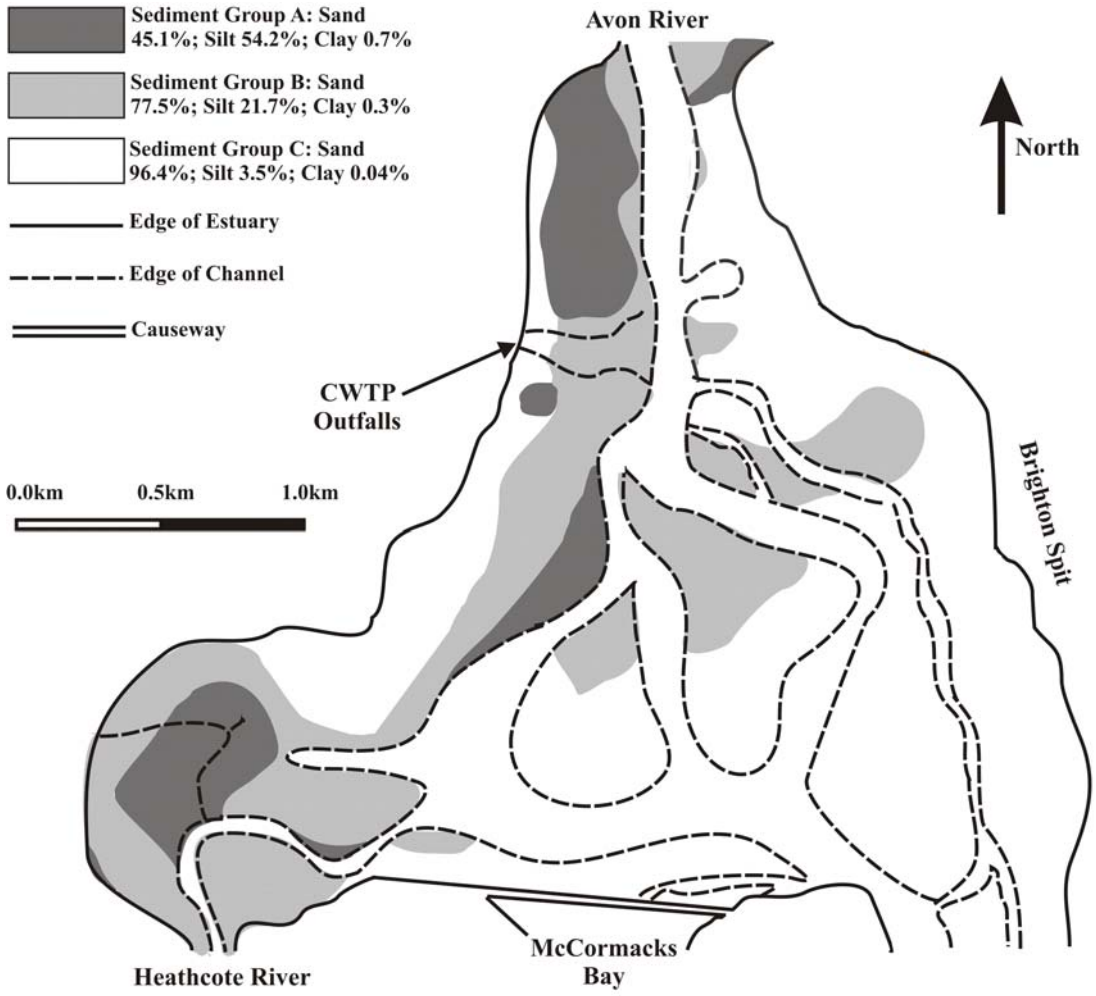

Figure 2.1. Distribution of sediment in the Avon-Heathcote Estuary/Ihutai according to the mean concentration of sediment types (sand, silt, clay). Distribution of sediment is based on the last extensive, quantitative examination of sediment distribution in the Estuary (Rodrigo, 1985; Christchurch Drainage Board, 1988). Figure is adapted from Figure 3, Rodrigo (1985).

saline water of the Estuary. The interaction between these different bodies of water causes flocculation (i.e. the clumping together) of the fine sediment particles which, due to their increased density, then sink (Knox & Kilner, 1973; Knox, 1992). This results in muddy areas of sediment around the river mouths with a mean composition of around 55-60% silt and clay with levels rising as high as 90% at some sites (Knox & Kilner, 1973; Macpherson, 1978; Rodrigo, 1985). The greatest concentration of fine sediments is near the mouth of the Heathcote River (Knox & Kilner, 1973; Macpherson, 1978; Rodrigo, 1985) and has been attributed to the higher concentration of suspended sediment carried in the Heathcote River relative to the Avon (Knox & Kilner, 1973; Macpherson, 1978) (and see section 4.1.1.).

Mud-rich sediments are also found along the western edge of the Avon channel (Fig. 2.1) (Knox & Kilner, 1973; Rodrigo, 1985) up to the "medium" tide level on the western slopes of the Estuary (Deely, 1991). The eastern slopes of the Estuary are comparatively poor in finer sediments (less than 20% silt and clay (Knox & Kilner, 1973; Rodrigo, 1985; Christchurch Drainage Board, 1988)). The reasons for this differential deposition of sediment on the western slopes of the Estuary appears to

relate to a combination of the outflow from the Christchurch Wastewater Treatment Plant and the flow of the Avon River which is driven towards the western edge of the Estuary by the dominantly easterly winds (Macpherson, 1978; Deely, 1991). Macpherson (1978) suggests that the reason the areas of the Estuary situated above the medium tide mark are not subject to this differential deposition of fine sediments is because wave energy exerts the principle control on deposition above this point stopping the sedimentation of finer particles due to water turbulence.

Other localised areas of fine sediment can also be observed with the Estuary. Some areas, like McCormacks Bay, are the result of a lack of flushing by currents due to the presence of barriers. The causeway across the mouth of McCormacks Bay has resulted in sluggish water movement within the bay except directly around the culvert. This has resulted in the deposition of muddy sediments in much of the bay (Knox & Kilner, 1973; Christchurch City Council, 1990). Other localised areas of muddy sediments in the Estuary are more temporal in natural being caused by biotic factors such as algae, causing the deposition of fine sediment through a reduction in current velocity (Knox & Kilner, 1973), or the presence of sea-grasses stabilising sediment and reducing erosion (Green, 2006). When these areas of algae or sea-grass move, or disappear entirely, the sediments are re-exposed to the full force of estuarine currents and eroded (Knox & Kilner, 1973).

2.2. Deposition and erosion of sediment

In his review of the history and patterns of sediment distribution within the Estuary Hicks (1993) examined a series of cross sectional surveys in order to establish changes in erosion and deposition within the Estuary over time. A similar study had been previously conducted by Macpherson (1978) and both studies used all but one of the same surveys of bed elevations across the Estuary. The first survey was undertaken by the Lyttleton Harbour Board and the Christchurch Drainage Board in 1920 and used a series of 10 west-north-west to east-south-east orientated transects situated north of Sandy Point (Fig. 2.2) (Hicks, 1993). The later surveys were undertaken by the Christchurch consultant firm Royds Garden in 1962 and the Christchurch Drainage Board in 1975-77 and 1988 (Macpherson, 1978; Hicks, 1993). These later surveys all used the same series of 20 west-east transects, separated by 200 metres, originally established by Royds Garden in 1962 and marked at either end by the presence of permanent stations (Fig. 2.2) (Macpherson, 1978; Hicks, 1993).

Macpherson (1978) calculated patterns of sedimentation and erosion in the Estuary based on the 1920, 1962 and 1975-77 surveys. The changes in sediment volume were calculated by dividing each of the survey lines into 40m sections, taking the vertical difference in elevation between surveys from the midpoint of each of those sections and multiplying the vertical differences by 40^2 to obtain the net change within a $40m^2$ area (Macpherson, 1978). This was then expanded to the entire Estuary by extrapolating the proportion of $40m^2$ cells showing deposition, erosion or no change between surveys out to a distance of 100m on either side of the line (i.e. each survey line was used to calculate the net erosion or deposition of an area of the Estuary 200m wide) (Macpherson, 1978). The value of each cell within the 200m wide strip was then totalled to provide a final measure of the change in sediment

volume of the entire Estuary between surveys. This result is presented alongside the equivalent results of the Hicks (1993) report in Table 2.1.

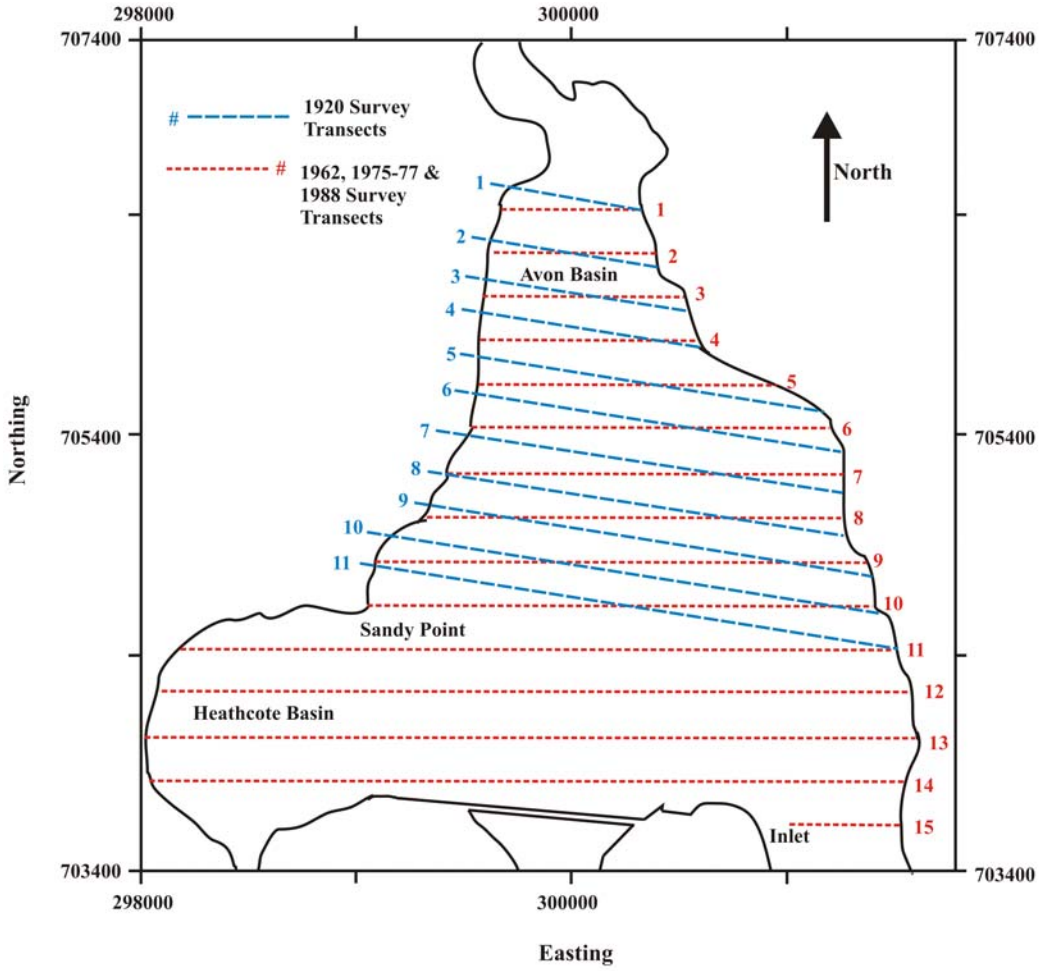

Figure 2.2. Cross sectional transects surveyed in the Avon-Heathcote Estuary/Ihutai in 1920 (blue WNW-ESE lines) and in 1962, 1975-77 and 1988 (red W-E lines). Figure adapted from Figure 3.4 in Hicks (1993).

Entire Estuary (Area = 5.53 x $10^6 m^2$) **Change in Volume ($1000m^3$)**			
	1920-1962	**1962-1975**	**1975-1988**
Macpherson (1978)	-	-170	-
Hicks (1993) DTM	-	-150 ± 60	220 ± 40
Hicks (1993) End Area Method	-	-183	71
Estuary north of Sandy Point (Area = 2.73 x $10^6 m^2$) **Change in Volume ($1000m^3$)**			
	1920-1962	**1962-1975**	**1975-1988**
Macpherson (1978)	-1012	-	-
Hicks (1993) DTM	-1040 ± 50	-70 ± 30	130 ± 30
Hicks (1993) End Area Method	-1061	-71	24

Table 2.1. Comparison of the change in sediment volume within the Avon-Heathcote Estuary/Ihutai between different surveys as calculated by Macpherson (1978) and Hicks (1993). Values are given for both the entire Estuary and the Estuary north of Sandy Point. Table adapted from Hicks (1993)

Unlike the Macpherson (1978) study the Hicks (1993) report used two different methods to analyse changes in sedimentation across the Estuary. The first method extrapolated a 50m grid digital terrain model (DTM) of the Estuary floor for each of the surveys (i.e. the 1920 survey, the 1967 survey etc.) based on the measured survey points (see Hicks (1993) for a full description of how this was done). The net sedimentation or erosion of the Estuary between each survey could then be calculated by subtracting the DTM for one survey from that of another (Table 2.1) (Hicks, 1993). The major benefit of this method was that it was able to model the elevation of any point in the Estuary, based on the known points, and could therefore easily compare the 1920s data to that of the later studies even though the transects were different (Hicks, 1993). The problem with this method was that while, in general, it provided a good match to the measured elevations across the Estuary it tended to smooth out abrupt changes in elevation leading to an error of about 50mm when calculating the mean elevation of an individual transect (Hicks, 1993). Hicks (1993) points out, however, that this systematic error becomes small (in the order of 4-5mm) when applied to the entire DTM grid for one survey and, due to its systematic nature, probably disappears when one grid surface is subtracted from the other.

The second method used by Hicks (1993) was the more traditional "end-area method" which involves calculating the change in area between the equivalent transects from different surveys. This is then extrapolated to provide a volume by multiplying the average change in area of adjacent transects by the distance between them (Table 2.1) (Hicks, 1993). This method also had problems as the 1920 survey did not fall along the same transect lines as the later studies. This was resolved by using the DTM elevations calculated for the 1920 survey to create equivalent east-west transects across the north of the Estuary to compare with the transects from the more recent studies (Hicks, 1993). In addition to the problem of the 1920s data some of the survey data across the low tide channels was missing from the 1988 data set effectively making the beds of channels high and flat (Hicks, 1993). To resolve this problem these parts of the transects were excluded when calculating the change in sediment volume.

While each method had problems they appear to have had a minor effect on the results as a comparison of the three methods used (Table 2.1) indicate similar results for those time periods with comparable data. This means that the average annual sedimentation rates for the entire Estuary, calculated by dividing the volume of sediment change by the area of the Estuary studied (Hicks, 1993) (Table 2.2), are probably reliable, at least for the period since 1962. The period between 1920 and 1962 remains less well constrained due to the differences between the later survey data and that obtained in the initial 1920 study (Hicks, 1993). This data not only suffered from lying on a different bearing to that of the later studies but also has a greater distance between sounding points (60m vs. 17m) and confusion about how the data was corrected to a datum (Hicks, 1993).

The results in Table 2.2 indicate that the average amount sediment moving in and out of the Estuary has almost reached equilibrium since the mid 1970s with the rate of sedimentation over the entire estuary at a level of less than 1mm per year between 1975 and 1988 (Hicks, 1993). This figure is,

Entire Estuary	1920-1962	1962-1975	1975-1988
Change in Volume (x $10^6 m^3$)		-0.18	0.07
Surface Area (x $10^6 m^2$)		5.53	5.53
Deposition (m)		-0.03	0.01
Deposition (mm)		-33.09	12.84
Average Annual Deposition (mm/yr)		-2.55	0.99
Northern Estuary	**1920-1962**	**1962-1975**	**1975-1988**
Change in Volume (x $10^6 m^3$)	-1.06	-0.07	0.02
Surface Area (x $10^6 m^2$)	2.73	2.73	2.73
Deposition (m)	-0.39	-0.03	0.01
Deposition (mm)	-388.64	-26.01	8.79
Average Annual Deposition (mm/yr)	-9.25	-2.00	0.68

Table 2.2. Calculation of average sedimentation rate over both the entire Avon-Heathcote Estuary/Ihuta and north of Sandy Point (Fig. Y.2) based on the "End Area Method" figures of Hicks (1993). Shaded values indicate the average amount of sediment deposited per m^2 per year.

however, averaged over the entire Estuary and a comparison of cross sections undertaken by Hicks (1993) indicates that the mudflats at the Estuary margins actually eroded ca. 50-150 mm between 1962 and 1988. This data is supported by evidence of erosion on the eastern shores of the Estuary (Walter, 1995) and anecdotal statements made by George Knox who observed a continuing change in the marginal mudflats to include a greater proportion of sand (Knox, 1992; Knox, 2001). Hicks (1993), as previously suggested by Macpherson (1978), interpreted the changes to the mud flats since 1965 as indicating the erosion of finer sediments from the mud-flats by a combination of bioturbation by burrowing organisms, waves and currents. This loss of fine sediments appears to have waned since 1975 with the mudflats approaching an equilibrium (Hicks, 1993). Hicks (1993) goes on to calculate, based on his estimates of annual sediment input by the Avon and Heathcote rivers (ca. 2,600 t/yr and ca. 4,500 t/yr respectively), an additional input of sediment from the City Outfall drain (ca. 170 t/yr), and some removal of sediment by the channel dredging programme, that the input of sediment from these sources roughly agree with the overall rate of deposition (Hicks, 1993). These calculations are problematic, however, as the sediment loads of the Avon and Heathcote are not well constrained due to the influence of storm events (see section 4.1.1.). There is no way to be sure, from the current information available, whether the input of sediment to the Estuary is indeed balanced with the loss of sediment as indicated by Hicks (1993).

2.3 Synthesis of sediment distribution, deposition and erosion

The studies discussed in this section indicate that the distribution of sediment and the sedimentation rate appear to have reached a virtual equilibrium since the 1970s. However, the most recent study of surface sediments in the Estuary, Robertson et al. (2002), was based on aerial photographs and produced only a qualitative description of sediment types in the different parts of the Estuary. The last quantitative survey was conducted in the mid 1980s (Rodrigo, 1985; Christchurch Drainage Board, 1988), about the same time as the last survey of Estuary bed levels (Hicks, 1993). While this survey was extremely detailed there has been no quantitative update to patterns of sediment distribution, accumulation and erosion in the Estuary for nearly two decades. Considering that the input of sediment

to the Estuary is not as well understood as previously thought (see section 4.1.1.) and the anecdotal (e.g. Knox, 2001) and site specific evidence of continuing erosion within the Estuary (e.g. Walter, 1995) it appears that changes in the distribution of sediments across the Estuary may still be occurring. It is therefore important that a new survey of the bed levels and surface sediments is undertaken to determine how patterns of sediment distribution have changed over the past 18 years.

Future work on the sediments within the Estuary should therefore include:

1. A survey of Estuary bed levels using, if possible, the transects used in the 1962, 1975-77 and 1988 studies as this will provide the most accurate evaluation of changes since the last studies undertaken in the Estuary.

2. The survey should also undertake to gather samples of surface sediments in order to evaluate changes in the composition of surface sediments across the Estuary.

Section 3 – Contaminants and nutrients in the sediments of the Avon-Heathcote Esturay/Ihutai

Estuarine sediments can act as a sink for contaminants, such as heavy metals, and nutrients such as phosphorous and nitrogen. When these nutrients and contaminants reach too high a level within the sediment they may adversely affect the estuarine ecosystem (Gillespie, 1993; Green, 2006). This section reviews the existing data on the levels of the primary contaminants and nutrients within the Avon-Heathcote Estuary/Ihutai.

3.1 Heavy metal contamination of Estuary sediments

Heavy metals – copper (Cu), chromium (Cr), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn) – are a natural component of aquatic environments being primarily derived, in unmodified environments, from the rocks and sediments of the local catchment (Christchurch Drainage Board, 1988). These natural levels are often modified by anthropogenic inputs. In particular the urbanisation of catchment areas can lead to increased concentrations of heavy metals. This can be due to inputs from industrial discharges (Mills & Williamson, 1999) and urban storm-water run off containing elevated levels of heavy metals such as zinc (from galvanised roofs and plumbing), lead (from lead-based petrol) and copper (from brake pads) (Mills & Williamson, 1999; Green, 2006). These anthropogenic sources of heavy metals can often exceed natural inputs (Deely, 1987 *in* Christchurch Drainage Board, 1988) and high levels of heavy metals can adversely affect aquatic ecosystems (Mills & Williamson, 1999). While heavy metal concentrations can fluctuate widely in water over the short term they tend to accumulate in sediments (Mills & Williamson, 1999) and therefore analysis of heavy metal concentrations in the sediments of the Estuary can determine long term changes.

Up until the early 1980s data on heavy metal concentrations in the sediments of the Avon-Heathcote Estuary/Ihutai were poorly known (Christchurch Drainage Board, 1988). To resolve this lack of information the Christchurch Drainage Board (CDB) undertook an intensive survey of heavy metal concentrations across the Estuary. This survey examined the top 10mm of sediment from 330 samples taken along a series of 17 west-east transacts across the Estuary (Rodrigo, 1985; Christchurch Drainage Board, 1988). The results of this survey were compared with the results of a similar study (undertaken around the same time) from the Saltwater Creek Estuary north of Christchurch (Christchurch Drainage Board, 1988). The Salt Water Creek Estuary was recognised by the North Canterbury Catchment Board as “the least modified large estuary in Canterbury” (Christchurch Drainage Board, 1988) and was used as a base line to determine deviation of heavy metal concentration in the Avon-Heathcote Estuary/Ihutai from the natural background concentration of heavy metals in an ‘unmodified’ Canterbury estuary. The comparison identified that mean levels of anthropogenic heavy metals (e.g. chromium, lead and zinc) were higher in the Avon-Heathcote Estuary/Ihutai than in Salt Water Creek Estuary (Table 3.1) indicating that the urbanisation of the Avon-Heathcote Estuary/Ihutai had resulted in heavy metal contamination. These mean levels were low, falling below the “low-trigger limit of potential ecological harm” established by the Australian and New Zealand Environment Conservation

	Avon-Heathcote Estuary (n = 330)			Salt Water Creek Estuary (n = 219)		
Heavy Metals	**Range**	**Mean**	**Std Dev**	**Range**	**Mean**	**Std Dev**
Chromium (mg/kg) *80 mg/kg dry*	6.2 - 43.2	11.66	4.93	3.8 - 11.6	7.65	1.56
Copper (mg/kg) *65 mg/kg dry*	1.4 - 37.0	6.39	4.64	2.0 - 12.0	6.12	2.27
Lead (mg/kg) *50 mg/kg dry*	3.2 - 86.4	13.59	9.99	2.6 - 15.2	8.06	2.81
Nickel (mg/kg) *21 mg/kg dry)*	4.4 - 13.8	7.43	1.65	4.0 - 13.6	8.28	2.16
Zinc (mg/kg) *200 mg/kg dry*	21.0 - 194.8	54.60	26.62	14.0 - 64.0	35.41	11.60

Table 3.1. Comparison of heavy metal levels in the Avon-Heathcote Estuary/Ihutai and Salt Water Creek Estuary from the Christchurch Drainage Board study (Christchurch Drainage Board, 1988). ANZECC ISCG-low trigger concentrations (ANZECC, 2000) are given in italics in the left column.

Council (ANZECC, 2000) (Table 3.1), and were interpreted at the time as having had no adverse effect on the estuarine fauna (Christchurch Drainage Board, 1988). A more recent examination of Avon-Heathcote sediment toxicity by Nipper et al. (1997) found, however, that sediments from the mouths of the Avon and Heathcote rivers were toxic to the estuarine amphipod *Chaetocorophium* cf. *lucasi* indicating that at least some estuarine fauna are affected by the presence of contaminants in parts of the Estuary.

In addition to identifying the heavy metal contamination of the Estuary the CDB study identified that the greatest concentrations of heavy metals were associated with the finer sediments in a bimodal relationship (Christchurch Drainage Board, 1988; Rodrigo, 1989). This relationship between sediment size and heavy metal enrichment lead the CDB to identify not only the overall range and mean concentrations of heavy metals over the entire Estuary (Table 3.1) but also the levels within four different ‘zones of deposition’ within the Estuary (Fig. 3.1) (Christchurch Drainage Board, 1988).

The four deposition zones were based on the CDB’s understanding of the hydrological and sedimentary patterns within the Estuary and tend to follow the deposition patterns illustrated by Rodrigo (1985) (Fig. 3.1). The four zones were further defined as follows:

- “Area A: Influenced greatly by deposition from the Avon River. Subject to discharges from the Christchurch Treatment Works.” (Christchurch Drainage Board, 1988).

- “Area B: An area of uncertain affinities but a little influence from one or other of the rivers likely. Possibly a slight influence in places from other discharges including the Christchurch Treatment Works outfalls in the north. Probably much more closely related to Area C than the others.” (Christchurch Drainage Board, 1988).

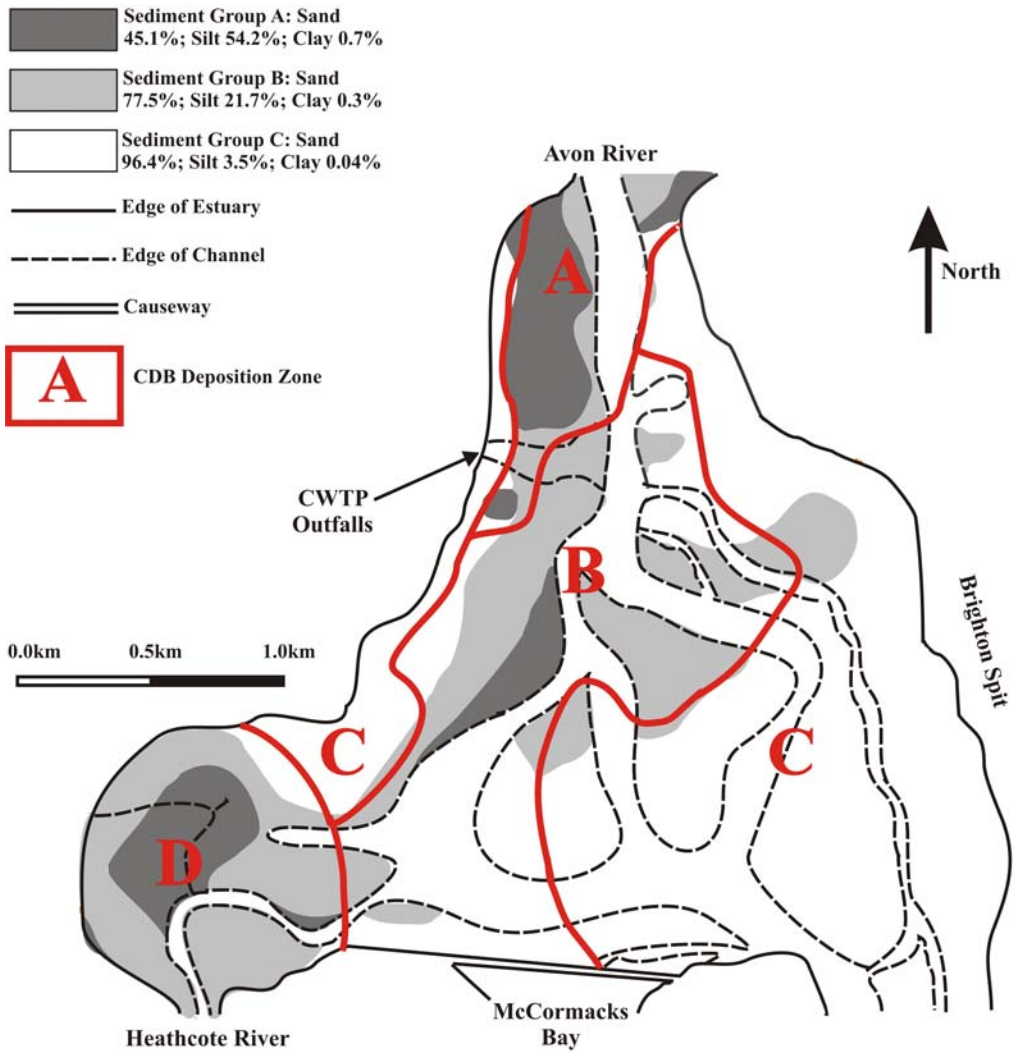

Figure 3.1. The four deposition zones recognised by the Christchurch Drainage Board (Christchurch Drainage Board, 1988) for the Avon-Heathcote Estuary/Ihutai are marked in red on the sediment distribution map of Rodrigo (1985). The borders of the deposition zones were obtained from a report on heavy metal concentrations in Estuary sediments by the Christchurch City Council (1988) and are based on the same data used by Rodrigo (1985) to map the distribution of sediments.

- "Area C: No influence expected from either river or other discharges. Predominantly sandy and includes marginal areas where bank erosion and sand outwash is or has recently been prominent." (Christchurch Drainage Board, 1988).

- "Area D: Heathcote depository. Some influence from the City Outfall Drain too." (Christchurch Drainage Board, 1988).

These zones exhibited different concentrations of heavy metals from one another (Table 3.2) with the two river influenced zones (Area A and Area D) showing enrichment of chromium, copper, lead and zinc when compared to the other two zones (Christchurch Drainage Board, 1988). This implies that the rivers were the primary suppliers of heavy metals to the Estuary at the time of the CDBs study although

	Area A				Area B				Area C				Area D			
	CDB, 1988	**Robb, 1992**	**Milne, 1998 *in* Mills & Williamson, 1999**	**Thompson, 2005**	**CDB, 1988**	**Robb, 1992**	**Milne, 1998 *in* Mills & Williamson, 1999**	**Thompson, 2005**	**CDB, 1988**	**Robb, 1992**	**Milne, 1998 *in* Mills & Williamson, 1999**	**Thompson, 2005**	**CDB, 1988**	**Robb, 1992**	**Milne, 1998 *in* Mills & Williamson, 1999**	**Thompson, 2005**
	n = 39	n = 1	n = 4 ?	n = 10	n = 86	n = 4	n = 4 ?	n = 10	n = 159	n = 6	n = 4 ?	n = 10	n =46	n = 2	n = 4 ?	n = 10
Cadium (mg/kg)																
1.5 mg/kg dry		**0.30**		**<0.1**		**0.34**		**<0.1**		**0.23**		**<0.1**		**0.55**		<0.1
Chromium (mg/kg)																
80 mg/kg dry	**17.50**	**17.00**	**15.10**	**11.70**	**12.90**	**15.25**	**14.60**	**22.80**	**8.40**	**10.67**	**7.20**	**13.35**	**15.50**	**24.50**	**11.30**	**10.90**
	10.8 – 35.2				***8.8-23.4***				***6.2-17.0***				***6.4-43.2***			
Copper (mg/kg)																
65 mg/kg dry	**13.87**	**9.00**	**9.30**	**2.78**	**6.30**	**7.25**	**5.80**	**6.72**	**3.60**	**2.67**	**2.50**	**3.18**	**9.90**	**13.00**	**5.40**	**5.52**
	6.0-25.0				***2.6-14.4***				***1.4-11.4***				***3.4-37.0***			
Lead (mg/kg)																
50 mg/kg dry	**24.60**	**21.00**	**14.50**	**8.14**	**13.50**	**18.25**	**10.60**	**12.30**	**7.20**	**11.50**	**6.60**	**10.34**	**26.60**	**66.50**	**14.80**	**11.10**
	13.0-40.2				***6.8-24.6***				***3.2-25.6***				***6.2-86.4***			
Nickel (mg/kg)																
21 mg/kg dry	**9.70**	**12.00**	**9.00**	**9.10**	**8.00**	**12.00**	**9.20**	**10.70**	**6.50**	**12.00**	**5.30**	**8.20**	**7.70**	**14.50**	**7.00**	**7.00**
	7.4-13.4				***6.0-11.2***				***4.4-9.6***				***4.4-13.8***			
Zinc (mg/kg)																
200 mg/kg dry	**90.60**	**81.00**	**79.50**	**25.60**	**57.70**	**69.75**	**59.50**	**68.40**	**36.20**	**42.00**	**39.10**	**38.25**	**82.40**	**157.50**	**71.90**	**38.80**
	54.0-150.0				*36.4-103*				*21.0-84.2*				*31.2-195*			

Table 3.2. Summary of sediment heavy metal concentrations in mg/kg of the four areas of the Avon-Heathcote Estuary/Ihutai from 1988 to 2005. Bolded values are mean concentrations for each area. Italicised values are the range of values observed in the 1982 study undertaken by the Christchurch Drainage Board (Christchurch Drainage Board, 1988). Note that the Area C values from Thompson, 2005 are from two sets of samples on different sides of the Estuary within the area defined, by the Christchurch Drainage Board, as Zone C. These values have been averaged to bring them in line with the other studies. ANZECC ISCG-low trigger concentrations (ANZECC, 2000) are given in italics in the left column. Note also that the Thompson (2005) samples for Area A and B (shaded columns) are actually located close to the border of other depositional areas as defined by the Christchurch Drainage Board (Christchurch Drainage Board, 1988) (see Fig. Y.6) and comparisons between these results and those of previous studies should be made with care.

no robust estimates of the amount of heavy metals input by the rivers currently exist (see section 4.1.2 below).

Since the CDB study was completed additional work has been undertaken to monitor levels of heavy metals (e.g. Robb, 1992; Milne, 1998 *in* Mills & Williamson, 1999; Thompson, 2005). Typically the four zones identified by the CDB have been used to constrain the sampling of these studies with comparisons made within the zones between studies (Table 3.2). The exception to this method of sampling was the study of Robb (1992) who did not distribute samples within the four deposition zones although he did otherwise follow the sampling method detailed by the CDB (Christchurch Drainage Board, 1988). In total Robb (1992) sampled 13 sites (Fig. 3.2) of which eight correspond to those previously sampled by the CDB. The remaining five of the sites can also be placed within one of the four zones identified in the CDB study although the sites are not evenly spread with only one site in Area A and six sites in Area C (Fig. 3.2). To enable comparisons to be easily made between studies the average heavy metal concentrations of the Robb (1992) sampling sites falling within one of the four zones are provided in Table 3.2. Many of these average results appear high when compared to those of the preceding CDB study (Christchurch Drainage Board, 1988) and those that have followed subsequently (Mills & Williamson, 1999; Thompson, 2005) (Table 3.2). Robb (1992), however, determined that the concentrations of heavy metals in the sites corresponding to sites previously sampled by the CDB fell within the range of concentrations observed in the CDB study (Christchurch Drainage Board, 1988) and argued that the differences are due to spatial variability rather than long-term change.

A recent review (Mills & Williamson, 1999) discussed trends in heavy metal concentrations in the Estuary over time comparing the original study of the CDB (Christchurch Drainage Board, 1988) with a set of analysis undertaken in 1998 (Milne, 1998 *in* Mills & Williamson, 1999) (Table 3.2). The methodology used by Milne for the 1998 study was slightly different from that used by the CDB with glass fibre filtration excluded from the process as it has the potential for contamination of filtrates with additional heavy metals from the glass fibres (Mills & Williamson, 1999). While it is therefore possible that the heavy metal concentrations from the CDB study (Christchurch Drainage Board, 1988) were anomalously high Mills & Williamson (1999) considered that the studies could be compared to determine trends over time. From the summary data Mills & Williamson (1999) determined that, on a straight comparison, there appeared to have been little change in heavy metal concentrations over time as the values of the Milne (1998) (*in* Mills & Williamson, 1999) study fell within the ranges recorded by the Christchurch Drainage Board (1988) (Table 3.2). Under a closer examination of the Milne sites corresponding to those of the Christchurch Drainage Board study Mills & Williamson (1999) determined that levels of organic carbon between sites had changed significantly between samplings. These changes were thought to reflect changes in sediment composition and normalization of the data for organic carbon levels revealed apparent decreases in chromium, copper, lead and zinc levels between 1988 and 1998 (Mills & Williamson, 1999). These changes were determined as real by a

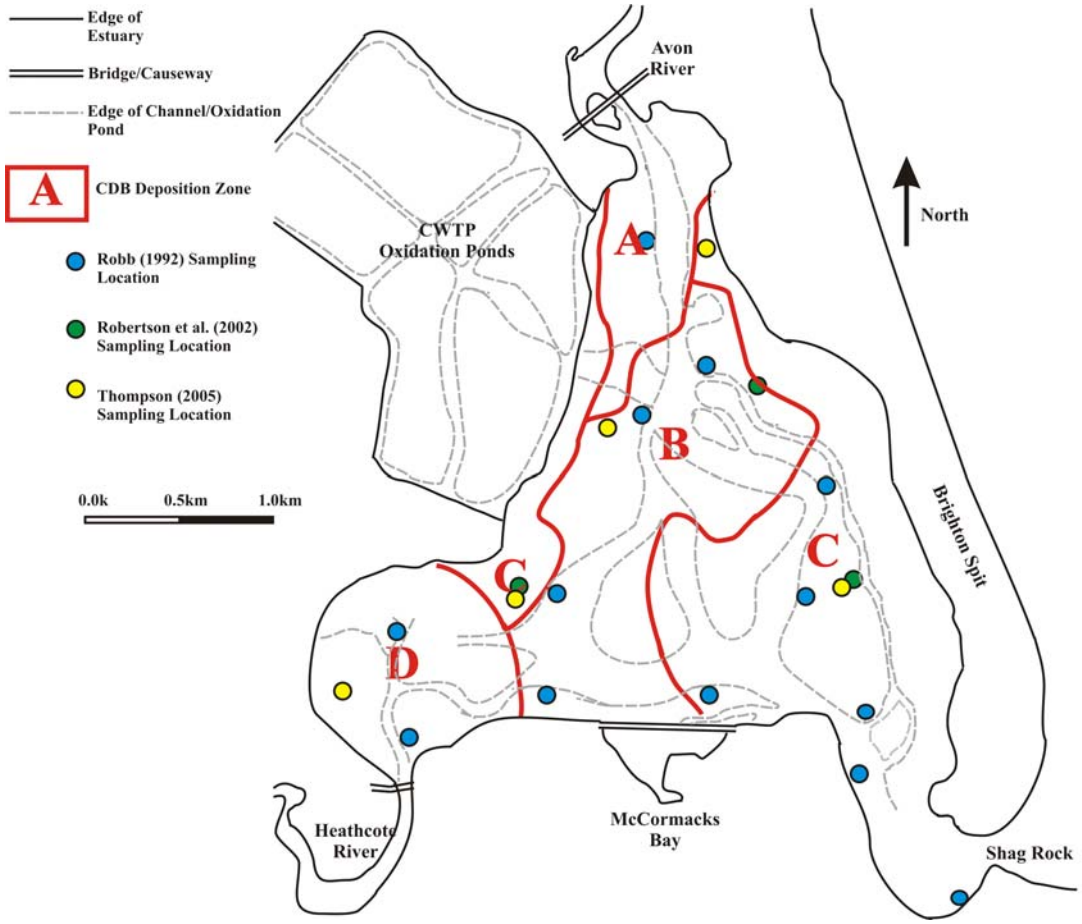

Fig. 3.2. Map of the Avon-Heathcote Estuary/Ihutai illustrating the four depositional zones of the Christchurch Drain Board (1988) in red and the locations sampled by Robb (1992) (blue circles), Robertson et al. (2002) (green circles), and Thompson (2005) (yellow circles). Figure adapted from Robb (1992).

re-examination of the Salt Water Creek Estuary which showed no equivalent change in heavy metal concentration since its sampling in 1988 (Mills & Williamson, 1999).

Robertson et al. (2002) sampled the Estuary in three locations while establishing a national protocol for monitoring estuaries. These results are not provided in Table 3.2, as they do not cover all four of the deposition areas, but a more recent study, Thompson (2005), deliberately re-sampled near the Robertson et al. (2002) sites (Fig. 3.2) and obtained similar results. Thompson (2005) also increased the number of sampling sites to include all of the depositional areas recognised by the Christchurch Drainage Board (1988). Care should be taken when comparing the Thompson (2005) results with those from earlier studies, however, as when the sampling locations of Thompson (2005) are plotted alongside the deposition zones defined by the CDB report (Christchurch Drainage Board, 1988), the supposed sample for Area A actually lies within the eastern Area C (Fig. 3.2). Furthermore the Thompson (2005) study followed the sampling guidelines outlined by Robertson et al. (2002) and thus deviated from the earlier studies in the Estuary by measuring heavy metal concentrations in the top 20mm of sediment. While this is unlikely to have affected the average heavy metal concentrations, as the top 100-250mm of Estuary sediment appear to be well mixed by burrowing fauna (Macpherson, 1978; Hicks, 1993), the study also restricted its sampling to only one location (with 10 replicates at

each location) within each of the four zones. The exception to this is Area C where two sampling areas were chosen, one on the eastern and one on the western sides of the Estuary. The lack of widespread sampling *within* the different deposition zones means that little of the within-zone variation in heavy metal concentrations (due to localised differences in sediment composition) was sampled. While Thompson (2005) concluded from his data that the concentration of heavy metals had decreased since 1988 the new values (Table 3.2) remain within the original ranges observed by the Christchurch Drainage Board (1988). As no normalisation of the data was undertaken to account for differences in sediment composition between the new and original sampling sites the apparent variation may simply be the result of localised differences in sediment composition although in light of the normalised data of Mills & Williamson (1999) the apparent reduction in heavy metal concentrations may be real.

While there are some problems with differences in sampling methodology between the various studies on heavy metal concentrations in the Estuary it does appear, from the collective information available, that the concentration of heavy metals in the Estuary has decreased since 1988. This reduction in the concentration of heavy metals has been linked to changes in land use and waste management practices (Mills & Williamson, 1999), the removal of lead from petrol (Thompson, 2005), and the input of less contaminated sediments from the rivers, stormwater and treatment plant burying and diluting the contaminated sediments already present in the Estuary (Mills & Williamson, 1999).

3.2. Organic contaminants of Estuary sediments

While the concentration of heavy metals in Estuary sediments has been the subject of extensive research the levels of organic contaminants, such as organic insecticides, have received far less attention with the first apparent sampling of organic contaminants in the Estuary undertaken in December of 1991 (Holland & Trower, 1992). A total of 13 sites were sampled from around the Estuary and analysed for Total Hydrocarbons, Organochlorine insecticides, Polychlorinated Biphenyls (PCBs), Chlorophenol and Polynuclear Aromatic Hydrocarbons (PAHs). The raw data for these samples appears in Holland & Trower (1992) but was analysed by Thompson & Davies (1993) who concluded that most organic contaminants were either low or undetectable at most of the 13 sites examined. Due to the sheer size of this data set it is not reproduced here although low-level contamination with insecticides, such as Dieldrin, DDT and Chlordane, was evident at some sites, particularly near the Avon River mouth, the City Outfall Drains at Humphreys Drive, the mouth of the Heathcote River and in three sites towards the mouth of the Estuary (Thompson & Davies, 1993).

A second study examined a further two sites within the Estuary (at Pleasant Point and the McCormacks Bay outlet) as part of a Ministry for the Environment study of organic contamination in 12 New Zealand estuaries (Scobie et al., 1998). Mills & Williamson (1999) have previous reviewed the results of both the Scobie et al. (1998) and Thompson & Davies (1993) studies determining that the samples obtained by the Ministry for the Environment study (Scobie et al., 1998) were consistent with that of the initial survey (Thompson & Davies, 1993). Due to the paucity of the data from the Scobie et al.

(1998) report and the fact that its results were consistent with those of Thompson & Davies (1993) they are not discussed further in this review.

Mills & Williamson (1999) grouped the results of the Thompson & Davies (1993) study into the four depositional areas recognised by the CDB (Christchurch Drainage Board, 1988) (Fig. 3.1) concluding that the distribution of organic contaminants at the time of the initial survey (1991) was similar to that of heavy metals in the Estuary, i.e. the greatest concentrations of organic contaminants is in the region of the Avon and Heathcote rivers (deposition Areas A and D respectively (Christchurch Drainage Board, 1988)), and related this to the muddier nature of the sediment in these zones. They further concluded that the levels of organic contamination in the Estuary were below or similar to those observed elsewhere in New Zealand (Mills & Williamson, 1999; Mills, 2001) and, based on draft Canadian Sediment Quality guidelines (Smith et al., 1996 *in* Mills, 2001), are below the level estimated to cause adverse affects in most sediment dwelling organisms (Mills, 2001) although sensitive organisms may be affected (Thompson & Davies, 1993; Elliot, 1997).

Due to the paucity of information Mills & Williamson (1999) were unable to determine whether levels of organic contaminants in the sediment had varied through time as while analysis of levels of organic contaminants in shellfish by Thompson & Davies (1993) and Scobie et al. (1998) indicated an apparent reduction between studies, this was considered to be related to differences in the methodology used between the studies (e.g. the time of year samples were collected and differing sampling depth etc.) rather than any temporal change (Mills & Williamson, 1999). The recent study by Thompson (2005), however, also implies a reduction in organic contaminant concentrations as examination of samples, from the sites analysed for heavy metals (see section 3.1 above), for a suite of 251 organic compounds (including PCBs, organonitrogen and organophosphorous pesticides, petroleum hydrocarbons and semi-volatile and volatile organic compounds (Thompson, 2005)) indicates that only Dicholoromethane (Methylene choride), a volatile organic compound, was above the analysis detection limit occurring at 0.8 mg/kg of dry weight sediment. While this general lack of detectable organic contaminants in the Thompson (2005) study may represent an actual reduction in organic contamination of sediments compared to the previous sampling by Holland & Trower (1992) it must be treated carefully as the available information is still poor and the variation may simply relate to site specific differences.

3.3. Nutrient enrichment in Estuary sediments

Nutrient levels in sediments are important factors in the biology of an estuary, for example nutrient distribution affects the distribution of plants such as sea-grasses (Short, 1988). Nutrients in sediments also act as a buffer on the wide fluctuations observed in nutrient levels in the water column and can therefore act to reduce the “feast or famine” situation that can sometimes arise in coastal areas due to fluctuating levels of nutrients in the water (Gillespie, 1993). While the presence of nutrients within estuary sediments is generally beneficial nutrient enrichment can also be harmful as high concentrations can result in a reduction in available oxygen to infaunal organisms and a build up of

toxic hydrogen sulphide resulting from decomposing organic materials within the sediment (Gillespie, 1993).

In light of the importance of nutrient enrichment to estuarine ecosystem health, studies in the Estuary have been extremely few. In fact only four studies (Knox & Kilner, 1973; Gillespie, 1993; Robertson et al., 2002; Thompson, 2005) appear to have been undertaken in the last three decades! This apparent lack of studies is unexpected as sediment nutrients are a better indication of nutrient enrichment within a coastal area, such as the Estuary, then are nutrient levels in the water column as they show far less short-term variability (Gillespie, 1993).

All four studies (Knox & Kilner, 1973; Gillespie, 1993; Robertson et al., 2002; Thompson, 2005) have measured slightly different groups of nutrients with the only common nutrients between all studies being total phosphorous (TP). Three of the studies also provided measurements of total nitrogen (TN) (Gillespie, 1993; Robertson et al., 2002; Thompson, 2005), however, and this review therefore deals primarily with these two variables when comparing between the different studies.

The best data available for the distribution of nutrients around the Estuary is from Knox & Kilner (1973). No methodology or raw numbers are provided in Knox & Kilner (1973) but the distribution of albuminoid nitrogen and total phosphorous per gram of sediment, and the level of ammoniacal nitrogen per millilitre of interstitial water (Knox & Kilner, 1973), are shown on maps of the Estuary. The distribution of nitrogen around the Estuary as mapped by Knox & Kilner (1973) is not able to be directly related to the more recent studies which have either measured different forms of nitrogen or measured their concentrations differently. The map of total phosphorous distribution, however, can be compared and is reproduced in Fig. 3.3 indicating that the highest concentrations of TP per gram of dry sediment (>500 µg/g and 350-500µg/g ranges) are found in the depositional basins of the Avon and Heathcote Rivers and along the western slopes of the Estuary. The concentration of TP decreases towards the mouth of the Estuary reaching a minimum concentration of between 200-250 µg/g of dry weight sediment near the tip of Brighton Spit (Fig. 3.3). This pattern of distribution is similar to that observed for the two different types of nitrogen measured and Knox & Kilner (1973) determined that the highest concentrations were correlated with high levels of organic matter, which in turn tends to be deposited in association with the finer sediments (Knox & Kilner, 1973). The pattern of nutrient deposition therefore roughly corresponds with the four depositional areas identified by the Christchurch Drainage Board (1988) (Fig. 3.1).

The Gillespie (1993) study is of limited use when establishing the distribution of nutrients around the Estuary as while samples from 13 sites within the Estuary were examined the actual location of the sites is not noted in the report as the data is meant to be part of a larger, unnamed, project coordinated by the Canterbury Regional Council (now Environment Canterbury). Gillespie (1993) does note, however, that there are strong correlations between the % of silt and clay in the samples and the

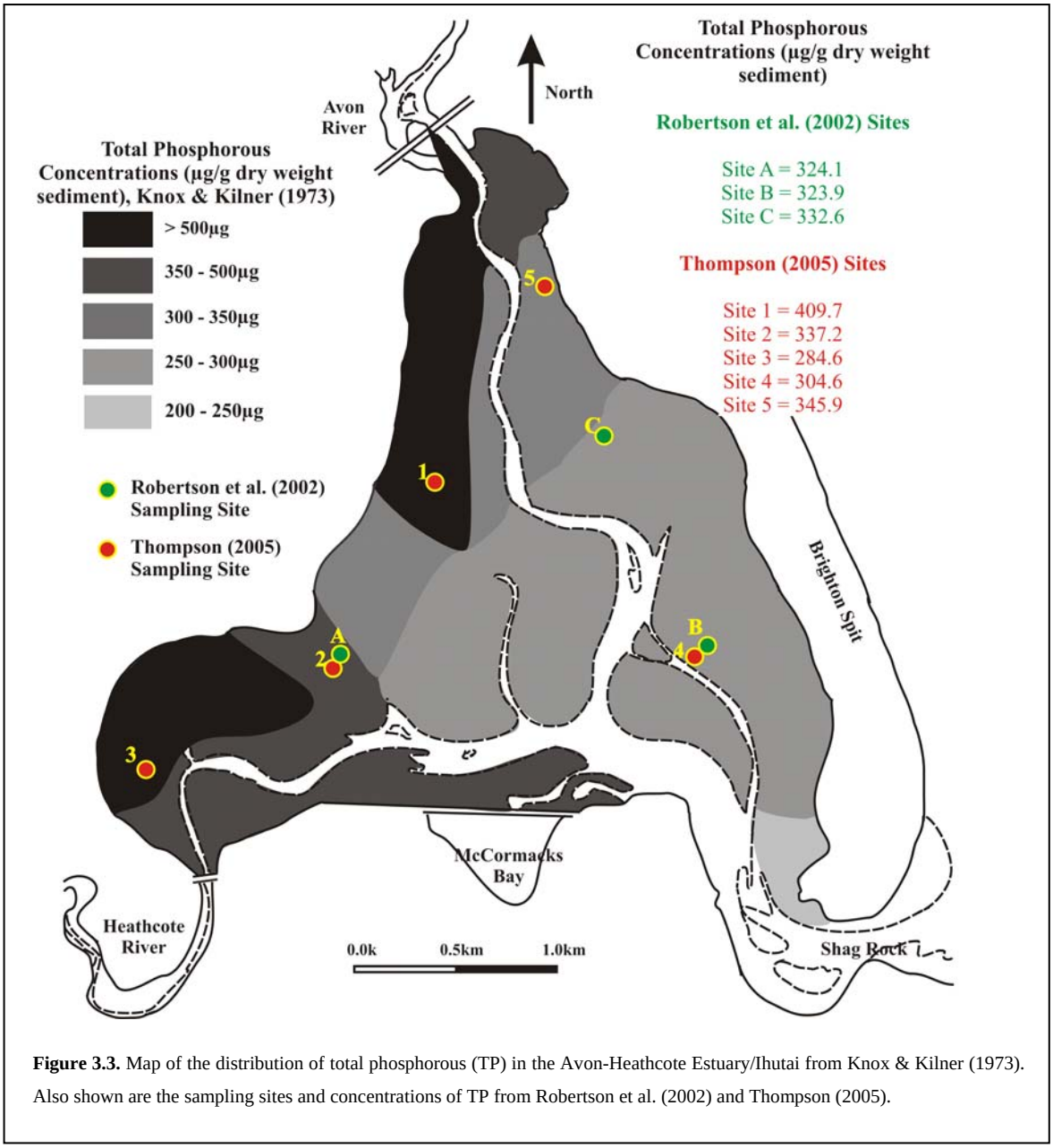

Figure 3.3. Map of the distribution of total phosphorous (TP) in the Avon-Heathcote Estuary/Ihutai from Knox & Kilner (1973). Also shown are the sampling sites and concentrations of TP from Robertson et al. (2002) and Thompson (2005).

concentrations of nutrients (except soluble reactive phosphorous). This agrees with the conclusion of Knox & Kilner (1973) which linked nutrient level, indirectly with sediment composition. The sampling sites used by Thompson (2005) were placed so as to be comparable to the locations used by Robertson et al. (2002) (12 samples per site) and the values of TP indicated for both the Robertson et al. (2002) and Thompson (2005) sampling locations generally appear to be within, or close to, the ranges indicated by Knox & Kilner (1973) for the same general areas (Fig. 3.3) implying that no significant change in the levels of TP have occurred within the Estuary at these sites. There are two exceptions. Thompson (2005) sites 1 and 3 show reductions in the order of 100 µg/g of dry sediment near the outfalls from the CWTP (site 1) and near the mouth of the Heathcote River (site 3) (Fig. 3.3). The reasons for these apparent reductions are unclear but may relate to the continuing erosion of fine sediments from the mudflats of the Estuary (Knox, 1992; Knox, 2001), and thus a continuous loss of

associated nutrients. Alternatively the apparent reduction may simply be due to differences in nutrient levels at different sampling sites.

While the location of the sites examined in the Gillespie (1993) report are unknown it is possible to compare estimates of the mean concentration of TN and TP across the entire estuary between the different studies that have provided actual numbers (i.e. Gillespie, 1993; Robertson et al., 2002 and Thompson, 2005). Gillespie (1993) presents his results in mmols per kg of sediment rather than mg/kg of sediment. The Gillespie (1993) concentrations were therefore converted to mg/kg to bring it in line with the studies of Robertson et al. (2002) and Thompson (2005). These results are presented in Table 3.3.

	Gillespie (1993)	**Gillespie (1993) – extreme high value excluded**	**Robertson et al. (2002)**	**Thompson (2005)**	**Robertson et al. (2002) Range**
TN (mg/kg)	563.04 ± 552.7	418.27 ± 189.7	301.4 ± 89	413.2 ± 11.06	250-600
TP (mg/kg)	201 ± 59.7	-	326.9 ± 5	336.4 ± 6.62	298-355

Table 3.3. Comparison of the mean concentration of total nitrogen (TN) and total phosphorous (TP) between the named studies. Note that the Gillespie concentrations were originally expressed as mmols per kg of sediment and were converted to mg/kg prior to calculating the mean and standard deviation. Also given is the range of values recorded by Robertston et al. (2002) for TN and TP.

The conversion of the Gillespie (1993) data produces a high TN concentration with an extremely high standard deviation, especially when compared to later studies, although the mean does fall within the range measured in the Robertson et al. (2002) study. This indicates that levels of TN in the Estuary may have been higher, and far more variable, during the 1990s. However, one sample within the Gillespie (1993) study had a concentration of TN more than twice that of other samples. Excluding that sample from the calculation of the mean produces a mean much closer to that of Thompson (2005) and with a smaller, although still large, standard deviation. This indicates that the high mean and standard deviation may simply be the result of differences associated with the, presumably, greater spread of sampling locations then those of Robertson et al. (2002) and Thompson (2005).

Due to the paucity of hard data from the Knox & Kilner (1973) study and the problem with the Gillespie (1993) data set interpretations made from the comparison of the studies presented here must be tentative. It appears that there has been no major change in the overall level of nutrients within the sediments of the Estuary over time and these concentrations are in line with those observed in similar, unpolluted estuaries from the Nelson region and are thus unlikely to cause any problems in the estuarine ecosystem (Gillespie, 1993).

3.4. Organic matter content of Estuary sediments

Like nutrient levels the level of organic matter in estuarine sediments is of great importance as it supports the Estuarine ecosystem forming the basis of the complicated food web of the estuarine biota (Knox & Kilner, 1973; Owen, 1992; Green, 2006). This organic matter is derived both directly from

the flora and fauna living within the estuary (e.g. benthic algae) and also from external sources such as organic matter carried by the rivers and the effluent outfall from the Christchurch Wastewater Treatment Plant (Knox & Kilner, 1973; Green, 2006). While the amount of organic matter supplied to the Estuary is thought to have changed by a factor of 10 to 20 since human settlement (Knox & Kilner, 1973) there has been very little work on establishing the level of organic matter in the sediments with the majority of sediment sampling instead concentrating on heavy metal and other forms of sediment contamination.

Knox & Kilner (1973) determined that the percentage of organic matter in the surface sediments of the Estuary closely correlates with the distribution of finer sediments (Fig. 3.4). Their study indicated, through an unspecified method, a concentration of between 3 and 7% in the Avon depositional basin and along the western edge of the Estuary with similar levels along the western edge of the Heathcote depositional basin (Fig. 3.4) (Knox & Kilner, 1973). The concentration of organic matter in the sediments then dropped towards the mouth of the Estuary reaching levels of 1 to 1.75% of the sediment samples on the central and eastern mudflats and near the mouth of the Estuary (Fig. 3.4) (Knox & Kilner, 1973). The concentration of organic matter has been associated with the size composition of the sediment (Knox & Kilner, 1973) and the higher level of organic matter in the deposition areas near the rivers is therefore to be expected. The higher concentrations at the mouth of the Avon relative to the concentrations near the mouth of the Heathcote, however, are probably due to the Avon River carrying, on average, more organic matter than does the Heathcote River (22% versus 13.5% respectively) (Hicks, 1993).

Since the Knox & Kilner (1973) review there has been little work on the levels of organic matter in the Estuary sediments. The Christchurch Drainage Board obtained levels of organic matter from the 330 samples used in their 1988 study of heavy metals using a modified version of the Walkley and Black technique (Christchurch Drainage Board, 1988). While they did not group the organic matter concentrations by deposition area they did provide both a mean (0.29%) and range of values. Of these the range is of more interest as it covers samples from across the entire Estuary indicating organic matter concentrations of between 0.03% and 1.69% (Christchurch Drainage Board, 1988). The upper end of this range is substantially less than the highest levels of organic matter (3-7%) given by Knox & Kilner (1973) indicating a potential reduction in organic matter levels. A more recent study by Gust et al. (2004), however, took a series of long (2.4-3.4m) sediment cores from the proposed outfall pipeline route across the northern end of the Estuary (Fig. 3.4) obtaining measures of organic matter through Loss on Ignition. Although the raw data was not provided in the report the results (Figures A1 – A6, Appendix 1 Gust et al. (2004)), indicate the levels of organic matter in the surface sediments of this part of the Estuary were at the lower end of the ranges recognised by Knox & Kilner (1973). For example the percentage organic matter in surface sediments from the western part of the Avon depositional basin were in the order of ca. 3% (Gust et al., 2004) compared to between 3% and 7% in 1973 (Fig 3.4) (Knox & Kilner, 1973). Sites in the eastern part of the basin had organic matter levels in the order of 1-2% compared to 1-1.75% in Knox & Kilner (1973) (Fig. 3.4). Thompson (2005) also

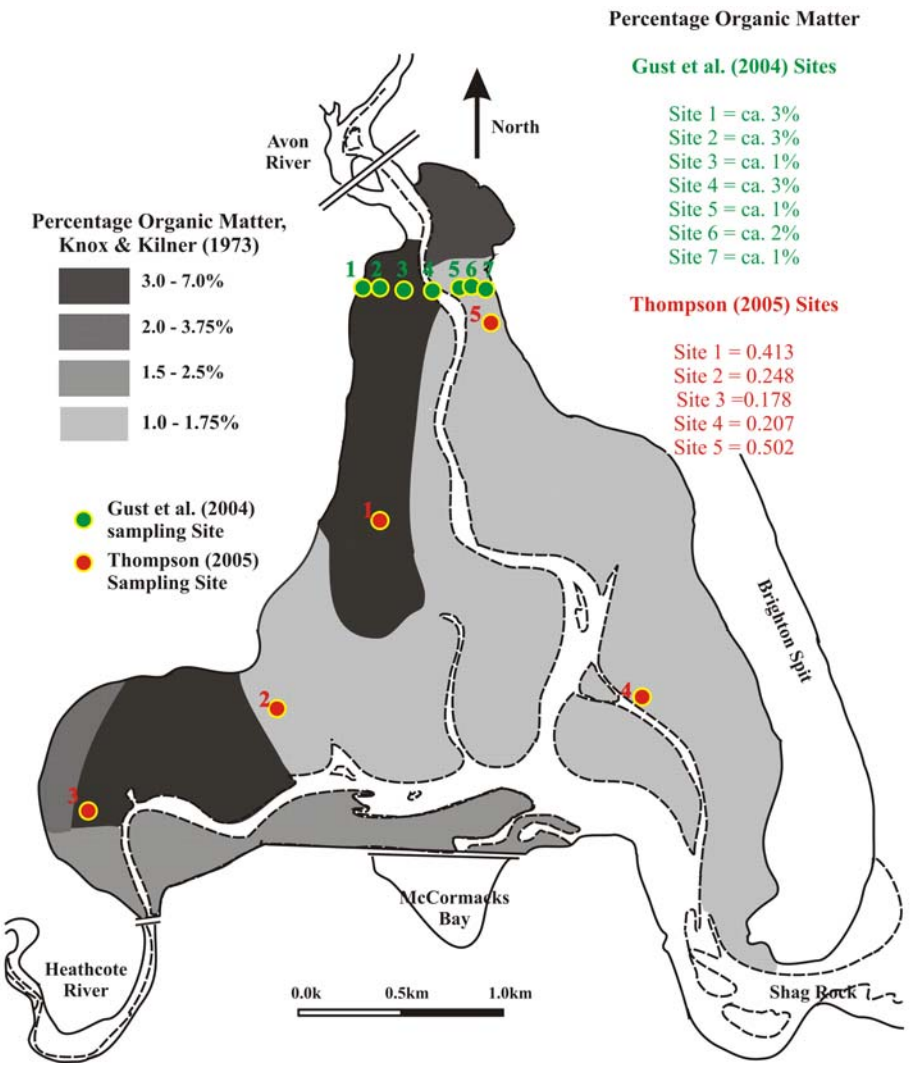

Figure 3.4. Map of the distribution of organic matter in the sediments of the Avon-Heathcote Estuary/Ihutai from Knox & Kilner (1973). Also shown are the sampling sites and percentage organic matter measured by Gust et al. (2004) and Thompson (2005).

examined organic matter content in their sediment samples from the around the Estuary with the results indicating an organic content of between 0.5% at the site near the edge of the Avon depositional basin (red site 5, Fig. 3.4) and 0.18% of the sample in the Heathcote depositional basin (red site 3, Fig. 3.4). These results are again substantially lower than the values observed by Knox & Kilner (1973). Taking the mean of the Thompson (2005) organic matter levels gives a result of 0.31% which is similar to the mean obtained by the Christchurch Drainage Board (0.29%) (Christchurch Drainage Board, 1988).

While few, these studies indicate that, outside the Avon depositional basin, the organic matter content of the Estuary sediments may not be as high as that indicated by Knox & Kilner (1973). This could represent a reduction in the overall level of organic matter in the Estuary since the 1970s, however, the similarity between the mean concentrations of organic matter across the entire Estuary between 1988 (Christchurch Drainage Board, 1988) and 2005 (Thompson, 2005) indicate that if this is the case the fall has not continued since the mid 1980s. Furthermore, if the apparent reduction in organic matter was real it should have had repercussions throughout the estuarine ecosystem. This appears not to have been

the case as no significant changes in the macroinvertebrate and algae flora have occurred since the 1970s (Maclaren & Marsden, 2005). It seems more likely that modern levels are actually similar to those of the 1970s and the large values reported by Knox & Kilner (1973) are an over estimation due to some samples having particularly high levels of organic matter and, perhaps, some methodological differences between the various studies that are not apparent from the available literature.

3.5 Synthesis of contaminant and nutrient concentrations in the sediments of the Estuary

This section focused on studies of sediment contaminants, organic content and nutrient levels. It is apparent from this review that the current level of understanding regarding the concentrations of these substances is mixed. While heavy metal levels have been well studied, and appear to have decreased since 1988, the concentrations of organic contaminants, such as pesticides, and the organic matter and nutrient levels which form the basis of the Estuary ecosystem are far less well constrained and require significantly more research. The recent development of a national protocol for accessing and monitoring estuarine environments (Robertson et al., 2002) has provided a standard methodology for sampling estuarine sediments which can be compared between different estuaries and these protocols should be adopted as the standard for future Estuary sampling. There are already five locations within the Estuary which have been sampled according to these methods (Thompson, 2005), and which should be used as part of any future monitoring, but they are not necessarily in the best locations. As the deposition of sediment contaminants tends to follow that of the finer sediments it is possible that a new survey of the surface sediments, as recommended in Section 2, may reveal better sampling locations which can be used to obtain samples that will lead to a more holistic understanding of contaminant and nutrient levels across the Estuary.

The following recommendation for future work is therefore proposed:

1. Based on an updated knowledge of sediment distribution additional sampling sites should be decided upon to monitor levels of heavy metals, organic contaminants and nutrients in the sediments. These sites should be monitored on a continuing basis using a standardised method (Robertson et al., 2002) to determine long term trends.

Section 4 – The supply of sediment and contaminants to the Avon-Heathcote Estuary/Ihutai

While surveys of the Estuary may provide a 'snap shot' of the state of the Estuary at a particular time additional information on the input of sediments and contaminants is required to predict how the sedimentation regime of the Estuary may change. This section reviews the current data available on the input of sediment, contaminants and nutrients to the Estuary.

4.1. Inputs from the Avon and Heathcote Rivers

4.1.1. Annual Sediment Loads

The Avon and Heathcote Rivers are the primary suppliers of sediment to the Estuary and are routinely sampled four times a year for a variety of contaminants including suspended solids. This routine monitoring is, however, not indicative of annual sediment loads to the Estuary as most of sediment appears to enter the Estuary from the rivers during storm events (Hicks, 1993; Pratt, 2000). Considering the importance of meaningful estimates of annual sediment loads for predicting the sediment supply to the Estuary, and for predicting sedimentation in the rivers themselves, the apparent lack of information on this subject is surprising.

The first study to provide quantitative information on sediment flows in the rivers was the Wallingford Study of the mid 1960s (Hicks, 1993). This report, for which the original data is lost (Hicks, 1993), used turbidity measurements to provide estimates of the suspended sediment load of the Avon River at Gloucester Street and of the Heathcote River at Buxton Terrace for the 12 months between 1964 and 1965. The results of this study indicated that the Avon carried ca. 900 tonnes of sediment per year past Gloucester Street (Wallingford, 1970 *in* Hicks, 1993). The sediment load of the Heathcote at Buxton Terrace between 1964 and 1965 was estimated at ca. 11,000 tonnes per year (Wallingford, 1970 *in* Hicks, 1993) although the turbidity meter used to estimate the suspended sediment load apparently malfunctioned (Hicks, 1993) and the reliability of this estimate is therefore low.

These sediment load estimates are for only a fraction of the catchments drained by the rivers. The Avon River at Gloucester Street, for example, has only drained ca. 45% of the 84.3km^2 that make up its catchment (Hicks, 1993; Pratt, 2000). To keep the results of the Wallingford study in line with those of the other studies the estimated sediment loads from the Wallingford study were modified by applying the assumption used by both Hicks (1993) and Pratt (2000), namely that the sediment loads at Gloucester Street and Buxton Terrace are proportional to the catchment size. This extrapolation increases the 900 tonnes of sediment per year passing Gloucester Street to an estimate of 2,000 t/yr of sediment at the entry of the Avon River to the Estuary (Table 4.1). Applying the same assumption to the Heathcote at Buxton Terrace (which has drained ca. 62% of the entire 103.4 km^2 of Heathcote catchment (Hicks, 1993; Pratt, 2000)) an estimated sediment load at the mouth of the Heathcote of ca. 17,000 t/yr is indicated (Table 4.1).

	Average Annual Sediment Load (t/yr)		
	Wallingford (1970)	**Hicks (1993)**	**Pratt (2000)**
Avon River	2,000	3,198	5,664
Heathcote River	17,000	5,220	18,214

Table 4.1. Comparison of the average estimated annual sediment loads for the Avon and Heathcote Rivers to the Estuary. To enable all three studies to be compared with one another the estimated sediment load has been extrapolated to cover the entire catchment of each river. A discussion of this extrapolation is provided in the text. The original data from Wallingford (1970) was unavailable and the non-extrapolated data was instead obtained from Hicks (1993). The numbers provided for Hicks (1993) are corrected for the underestimation of the sediment yield (23% for the Avon and 16% for the Heathcote) indicated by Hicks in his report. The average annual sediment load indicated for the Pratt (2000) study is the mean of the two years (1997-98 and 1998-99) of suspended solids data provided.

The second study to provide information on long-term average sediment loads of the Avon and Heathcote Rivers was Hicks (1993) using the sediment rating technique. This is a common and widespread technique although some studies (e.g. Walling, 1977; Fenn et al., 1985) have indicated that the use of this technique can significantly underestimate sediment loads. A detailed breakdown of the methodology used in this study is provided in Hicks (1993) and only a summary is provided here. Pooled sediment concentration data from a series of storm events (collected using ISCO auto-samplers operated by the Canterbury Regional Council) was used to relate the suspended sediment (actually suspended solids (Murray Hicks pers. comm., 2007)) at the time of sampling to the water flow at the time of sampling (Hicks, 1993). This data was converted to cross-section mean concentrations and calibrated using manually collected samples from the same storm events in order to remove sampling bias resulting from the position of the auto-samplers in the rivers. This data was combined with long term records of river flow to provide annual yields of sediment using linear regression of the log transformed data (Hicks, 1993). The break down of these calculations can be found in Hicks (1993) and is not repeated here but indicate, based on the entire catchment size, that the average annual sediment load from the Avon River to the Estuary is 2,600 t/yr and that of the Heathcote is 4,500 t/yr (Hicks, 1993). Based on the size of the respective catchments this indicates an average sediment yield for the Avon of ca. 35 t/km^2/yr and of ca. 43 t/km^2/yr for the Heathcote which are values considered typical for mature urban catchments (Hicks, 1993). Hicks (1993) tested his estimates of average annual input by comparison to three storm events (the 7th to 8th of June 1992, the 7th to 9th of July 1992 and the 28th to 29th of August 1992) and determined that the calculated sediment loads were, on average, 23% too low for the Avon River (at Gloucester Street) and 16% too low for the Heathcote River (at Buxton Terrace). Correcting for these underestimations the average annual sediment loads are ca. 3,200 t/yr and ca. 5,220 t/yr for the Avon and Heathcote Rivers respectively (Table 4.1).

The most recent study detailing annual sediment load to the Estuary is that of Pratt (2000). Again only a summary of the methodology is given here and the reader is referred to Pratt (2000) for the full methodology. Pratt (2000) estimated the contaminant discharge of the Avon and Heathcote Rivers for the period of August 1997 to July 1998 and of August 1998 to July 1999. This was done by using a year of Christchurch City Council river flow data for each river where it entered the Estuary (Pratt,

2000). The median base flow levels of contaminants (including suspended solids) recorded between 1991 and 1997 for the Avon River (at Manchester Street) and between 1989 and 1997 for the Heathcote River (at Bowenvale Avenue) were used to provide an average concentration of the contaminants in the rivers when they entered the Estuary assuming base flow conditions (Table 4.2 (Pratt, 2000). Contaminant concentration data of two storm events on each river (Table 4.2) were then used to calculate the contaminant input from the rivers to the Estuary for storm days. This was done under the assumption that contaminant loads would be similar between different storm events regardless of their magnitude. The number of days-worth of storm events in each time period was identified (45 days for the Avon and 53 for the Heathcote for the 1998-99 year and 47 days for the Avon and 42 days for the Heathcote for the 1997-98 year (Pratt, 2000)) and the contaminant concentration for each of the storms was used to produce an estimate of sediment input for those storm days. The sediment input from these storm days was then added to a base level of input calculated using the remaining number of days in the time period analysed and the base flow concentration (Table 4.2). This method provided an estimated input of suspended solids to the Estuary from the Avon River of 5,581 t/yr between August 1997 and July 1998 and 5,747 t/yr between August 1998 and July 1999. The estimates for the Heathcote River put the annual input of suspended solids at 13,234 t/yr between August 1997 and July 1998 and 23,193 t/yr for the period of August 1998 and July 1999. Taking the average of these amounts as the average annual input to the Estuary gives the value of 5,664 t/yr for the Avon and 18,214 t/yr for the Heathcote (Table 4.1).

	Avon River			**Heathcote River**		
	Base Flow (1989-1997)	**17th July Storm Event 1999**	**28th July Storm Event 1999**	**Base Flow (1989-1997)**	**8th July Storm Event 1999**	**27th July Storm Event 1999**
Suspended Solids (g/m^3)	1.0	285	162	4.5	206	1,308

Table 4.2. Base flow and storm sediment loads (g/m^3) used to calculate the average annual sediment input from the Avon and Heathcote Rivers to the Estuary by Pratt (2000). Base flow suspended solid concentrations are from Gilson & Mitchell (1999).

Each of the three studies of average annual sediment input to the Estuary has provided different results (Table 4.1). While an initial examination indicates similarity between the estimated annual sediment input to the Estuary of the Heathcote River in the Wallingford (1970) and Pratt (2000) studies (ca. 17-18,000 t/yr) and a trend of increasing sediment load to the Estuary from the Avon over the past 30 years (Table 4.1), possibly due to increased urbanisation, any interpretation of these results must be treated with caution.

Each of the different studies was undertaken using different methodologies with their own unique problems. The turbidity measurements of the Wallingford study, for example, can be affected by the colour of the suspended sediment (Ziegler, 2002). Considering that Avon sediment generally appears darker than that of the Heathcote (Hicks, 1993) this may affect the relative turbidity measurements of the different rivers. Particle size can also affect the turbidity measurement (Ziegler, 2002) and a study

of particle size data by Hicks (1993) indicates that the relative concentrations of different sized sediment can vary both between rivers and between different storm events. Other factors affecting turbidity results include the orientation of the turbidity meter, the standards used for calibration and the wave length of the light used to measure turbidity (Ziegler, 2002). These sources of uncertainty in the Wallingford data make a direct comparison to the other methods of measurement difficult. Furthermore the original Wallingford data appears to be lost (Hicks, 1993) and cannot be re-examined. Combined with the apparent malfunction of the Heathcote turbidity meter (Hicks, 1993) any results of this original study must be treated with extreme caution.

Issues also arise with the results of the Hicks (1993) report. While sediment rating is a common technique it is acknowledged to significantly underestimate sediment loads (Walling, 1977; Fenn et al., 1985). While Hicks (1993) provides an average estimate of the underestimation of his formulas the corrections are based on only three storm events. This is an extremely limited dataset but is especially problematic for the Heathcote River which shows substantial variation in its mass load between different storm events (Table 4.2) (Pratt, 2000). Hicks (1993) acknowledges this problem by stating that the Heathcote sediment yields may be substantially increased over his estimates of long-term yields in those years with large storm events (as these increase erosion in areas of the Port Hills and thus increase sediments entering the river) he provides no indication of the frequency of these events.

The problem of an extremely small dataset is also apparent in the Pratt (2000) study which bases its calculations on two storm events assuming that the concentration of contaminants in river water is similar during all storm events even though it is clearly apparent that sediment loads can vary significantly between different events (Table 4.2). For example, if the suspended solids data for the 8th July 1999 storm event are used in the calculation of the average annual mass load of the Heathcote River the result is ca. 4,980 t/yr (Pratt, 2000). This is remarkably similar to the Heathcote River suspended sediment estimate of Hicks (1993) at 4,500 t/yr (corrected for the underestimation of the sediment rating technique to 5,220 t/yr (Table 4.1)). On the other hand if the 27th July 1999 storm event is used in the calculations the Heathcote River's average annual mass load is ca. 31,400 t/yr! This is an order of magnitude larger than that calculated using the 8th July 1999 data and the Hicks (1993) estimate. It is also twice as large as the results of the Wallingford study (Table 4.1). While averaging of these results brings the average sediment load in line with that observed in the Wallingford study (Table 4.1) the relative proportion of small to large storm events was not applied in the calculations of annual sediment load and would have affected the average annual sediment input to the Estuary.

Additionally the Hicks (1993) and Pratt (2000) study both make the assumption that the mass loads of the Avon River at Gloucester Street and the Heathcote River at Buxton Terrace are proportional to the entire catchments and thus can be extrapolated to indicate the mass loads entering the Estuary. While this assumption simplifies the calculations needed to produce an estimate of annual sediment load Hicks (1993) demonstrates that this assumption is false with hill sub-catchments supplying significantly more sediment than the flat sub-catchments. The supply of sediment is also influenced by

the land-use of the sub-catchment with rural hill catchments supplying significantly more sediment than the other hill catchments (Hicks, 1993).

The various problems with all three of these studies means that while it is possible that all three of these studies are accurate measures of the sediment load to the Estuary, for the time at which the samples were obtained, extrapolation of each study's data to produce long term estimates of the annual sediment input to the Estuary exceeds the capabilities of the available data due to the paucity of storm events sampled. While this is less of a problem for the Avon River, which shows less variation in its flow regime (McKerchar, 2001) and sediment concentration than the Heathcote (Table 4.1) (Pratt, 2000), the dataset for the Avon is still limited. Furthermore, for accurate estimates to be calculated a number of factors other than simply the frequency of the storm events need to be considered. These factors include the scale of the event (i.e. the total mm of rain that fell within the entire catchment), the intensity of the event (i.e. how many mm of rain fell per hour of the event), and the antecedent conditions (e.g. whether the ground is saturated or dry, whether a previous storm has already removed most of the sediment). This data is currently unavailable and it is therefore impossible to draw any robust conclusions regarding long term sediment loads to the Estuary via the Heathcote and Avon rivers other than that the Heathcote is likely, on average, to supply more sediment to the Estuary.

4.1.2 Annual nutrient and heavy metal input from the Avon and Heathcote Rivers

In addition to their sediment load the Avon and Heathcote rivers supply nutrients and heavy metals to the Avon-Heathcote/Ihutai Estuary. These levels are routinely monitored by the Christchurch City Council using methods outlined in Gilson & Mitchell (1999). In general, sampling and analysis appear to follow standard methodologies, which are not discussed here, with the only recorded change in methodology having occurred in 1996 when the analysis of heavy metals changed from using flame atomic absorption spectrometry to graphite furnace atomic absorption spectrometry which is up to 50 times more sensitive than the old method (Gilson & Mitchell, 1999).

While this continuous monitoring has accumulated significant amounts of data (e.g. Robb, 1993; Robb, 1994; Gilson, 1996; Gilson & Mitchell, 1999) very little has been done with it and actual calculations of the amount of nutrients and heavy metals input to the Estuary are rare. The Monitoring and Research Team of the Christchurch City Council used the standard monitoring data to estimate the average daily input to the Estuary for dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorous (DRP) between 1989 and 2003 (Table 4.3) (Monitoring and Research Team Christchurch City Council, 2003). The data appears to indicate a general decrease in the relative daily input of nutrients to the Estuary and this has been interpreted as indicating a reduction in the amount of nutrients contributed to the Estuary over time (Monitoring and Research Team Christchurch City Council, 2003).

The Monitoring and Research Team also produced estimates of the daily input of heavy metals (Monitoring and Research Team Christchurch City Council, 2003). Unlike the apparent decrease observed in nutrient inputs to the Estuary, however, the routine monitoring of heavy metals indicates

	Avon		Heathcote	
	DIN	DRP	DIN	DRP
Historical Median (1989-1999)	178	7	142	8
Last 3-year Median (2000-2003)	140	7	141	7
2002/2003 (Median)	72	6.5	82	6

Table 4.3. Daily input of nutrients (kg/day) to the Estuary from the Avon and Heathcote Rivers. Data is from Monitoring and Research Team Christchurch City Council (2003). DIN = Dissolved inorganic nitrogen, DRP = Dissolved reactive phosphorous.

that while concentrations may fluctuate from year to year (Table 4.4) (Robb, 1993; Robb, 1994; Gilson,1996; Gilson & Mitchell, 1999) there has been no overall decrease in the concentrations of heavy metals contributed to the Estuary on a daily basis with the Avon River contributing a total of ca. 10kg of heavy metals to the Estuary per day compared to ca. 8kg per day from the Heathcote (Monitoring and Research Team Christchurch City Council, 2003).

Time Period	Avon River					Heathcote River				
	Copper	Chromium	Nickel	Zinc	Lead	Copper	Chromium	Nickel	Zinc	Lead
1989-1993	2	*	*	16.3	4	3.3	2.5	*	44.2	5.8
1992-1993	2	*	*	11.8	2.3	3.5	3.5	1.8	24.8	5.8
1993-1994	2	2	1	10	2.3	3.5	3	1.5	22.5	3.8
1994-1995	2	1.25	0.5	44	3.75	2.75	3	1.17	25.25	4.25
1995-1997	1.29	1.26	0.51	19.71	5.6	6.87	4.52	2.2	50.5	8.43
Long Term Mean 1986-1997	1.9	1.17	0.68	16	4.11	3.82	2.98	1.67	40.9	5.78

Table 4.4. Mean concentration (g/m^3) of heavy metals in the waters of the Avon River (at Bridge Street) and Heathcote River (Ferrymeade Bridge). Data is from the water quality records of the Christchurch City Council (Robb, 1993; Robb, 1994; Gilson, 1996; Gilson & Mitchell, 1999). A * indicates a lack data for that metal during that year.

The estimates of daily nutrient and heavy metal input to the Estuary presented in Tables 4.3 and 4.4 are acknowledged to be conservative estimates as they do not include inputs during storm events which are likely to affect the levels of input to the Estuary (Monitoring and Research Team Christchurch City Council, 2003). This is particularly true in the case of the Heathcote River due to is substantially increased storm flow relative to its base flow (McKerchar, 2001). It is likely, therefore, that the levels of metals and nutrients input to the Estuary will vary substantially from the conservative estimates presented in Tables 4.3 and 4.4 depending on the magnitude and frequency of storm events. Only one study, Pratt (2000), appears to have addressed this issue producing annual estimates of heavy metal and nutrient input.

As in his study of sediment input (see section 4.1.1 above) Pratt (2000) measured the concentrations of nutrients and heavy metals during two storm events on the Avon and Heathcote rivers in order to establish the amount of these contaminants added to the Estuary during storm events. These concentrations are presented in Table 4.5 alongside the long-term average base-flow nutrient

Nutrient/Heavy Metal	Avon River			Heathcote River		
	Base Flow (1989-1997)	17th July Storm Event 1999	28th July Storm Event 1999	Base Flow (1989-1997)	8th July Storm Event 1999	27th July Storm Event 1999
Ammonia	0.04	0.189	0.21	0.04	0.248	0.316
Nitrite	0.014	0.014	0.0087	0.019	0.019	0.021
Nitrate	1.2	0.704	0.587	1.8	0.78	0.93
Reactive Phosphorous	0.025	0.073	0.045	0.048	0.125	0.181
Copper	0.0026	0.063	0.0312	0.015	0.033	0.021
Lead	0.009	0.084	0.0096	0.0095	0.024	0.016
Zinc	0.018	0.527	0.184	0.1	0.323	0.129

Table 4.5. Mean concentration of nutrients and heavy metals (g/m^3) in base flow and during the two storm events on the Avon and Heathcote Rivers measured by Pratt (2000). Base flow concentrations of nutrients were calculated from the collated data presented in Gilson & Mitchell (1999) while the base flow concentrations of heavy metals are from studies undertaken in the mid-1980s by the Christchurch Drainage Board and Deely (see Appendix A, Pratt (2000)).

concentrations from the Christchurch City Council (Gilson & Mitchell, 1999) and the heavy metal concentrations used by Pratt (2000). It should be noted that the base flow heavy metal concentrations used by Pratt (2000) were not from the long term monitoring undertaken by the Christchurch City Council but rather from some unnamed studies by Deely and the Christchurch Drainage Board in the mid 1980s (see Appendix A, Pratt, 2000). This is surprising as the long term monitoring data of heavy metals appears in the same volume (i.e. Gilson & Mitchell, 1999) as the nutrient records reproduced in Appendix A of Pratt (2000). Regardless, these data indicate that, as expected, both nutrient and heavy metal concentrations vary between base flow and storm events. For example levels of ammonia and reactive phosphorous increase during storm events (in both the Avon and the Heathcote rivers) while the level of nitrates decrease (Table 4.5). Heavy metals also show (in general) greater concentrations during storm events (Table 4.5). This variation in nutrient and heavy concentrations emphasises the importance of including storm events when analysing the annual input of contaminants from the Avon and Heathcote Rivers to the Estuary.

Pratt (2000) used the data in Table 4.5 to calculate the annual input of nutrients and heavy metals for the period of August 1997 to July 1998 and for August 1998 to July 1999 using the same methods outlined in section 4.1.1 for the estimates of annual sediment input. The results of the analysis of nutrient and heavy metal inputs are provided in Table 4.6.

It appears from the results in Table 4.6 that the Avon River contributes significantly more nitrogen bearing nutrients (ammonia, nitrates and nitrites) to the Estuary per year. This is mainly in the form of an additional ca. 35 tonnes of nitrates (Table 4.6). The Avon also appears to contribute more heavy metals to the Estuary than does the Heathcote River although the variance is smaller. These results are not unexpected as it agrees with higher daily input of nutrients and heavy metals calculated by the Monitoring and Research Team Christchurch City Council (2003) and is likely to be a function of the fact that, except during storm events, the flow of the Avon River is generally higher than that of the Heathcote (McKerchar, 2001). The flow of the Avon River is fairly consistent with its flow ranging between 1,265 L/s and 2,805 L/s, with a median of ca. 1,722 L/s (McKerchar, 2001). This is due to the

Nutrient/Heavy Metal	Avon			Heathcote		
	1997-1998	1998-1999	Average	1997-1998	1998-199	Average
Ammonia	7.7	7.8	*7.75*	5.9	9.6	*7.75*
Nitrite	1.2	1.3	*1.25*	0.8	1.1	*0.95*
Nitrate	98	99	*98.5*	60	69	*64.5*
Reactive Phosphorous	3.2	3.2	*3.2*	3.8	5.8	*4.8*
Copper	1.3	1.4	*1.35*	0.8	1.2	*1.0*
Zinc	1.8	1.8	*1.8*	0.6	0.8	*0.7*
Lead	10.0	10.3	*10.15*	6.4	9.3	*7.85*

Table 4.6. Nutrient and heavy metal input (t/yr) to the Avon-Heathcote Estuary/Ihutai as calculated by Pratt (2000) for the period of August 1997 to July 1998 and August 1998 to July 1999. An average annual input is also provided.

fact that the Avon River is dominated by its base flow with increased storm flow ceasing soon after rain stops (McKerchar, 2001). The Heathcote's flow is more variable, ranging between 448 L/s and 3,330 L/s with a median flow of 753 L/s (McKerchar, 2001), and while carrying a greater concentration of contaminants, it actually contributes less contaminants to the Estuary overall.

These results must, however, be interpreted with caution as the method used by Pratt (2000) is flawed due to the assumption made in the calculations; namely that the concentration of contaminants is similar between different storm events regardless of their magnitude. While the problem with this assumption is far more obvious when calculating sediment loads (where the concentration of suspended solids in the Heathcote River during the July 27th storm event is ca. 635% of the concentration of suspended solids during the July 8th storm event (Table 4.2)) the concentration of nutrients and heavy metals still varies between storm events. For example the concentration of zinc during the 8th of July storm event on the Heathcote River is ca. 250% that observed during the 27th July storm event (Table 4.5). This means that the assumption made by Pratt (2000) is false and the results cannot be accepted as robust estimates although they may provide rough guidelines of annual inputs.

4.2 Inputs from the Christchurch Wastewater Treatment Plant

A third significant supplier of contaminants, and the major supplier of nutrients (Gilson, 2001), to the Estuary is the Christchurch Wastewater Treatment Plant at Bromley (CWTP). Like the base flow of the Avon and Heathcote rivers the effluent discharged from the treatment plant into the Estuary has been routinely monitored since 1986 (Gilson & Mitchell, 1999) with the time between measurements varying with the contaminant examined. Gilson (2001) states that suspended solids and ammonia levels are measured weekly, nitrate, nitrite and total phosphorous levels are measured fortnightly and heavy metal concentrations are measured three monthly. This is obviously a minimum number of measurements as the raw data available from the Christchurch City Council (www.ccc.govt.nz/wastewater/treatmentplant/DischargeConsentMonitoring.asp) indicates far more frequent monitoring of some contaminants and nutrients. The methods used to monitor the effluent from the CWTP are again detailed in Gilson & Mitchell (1999).

Table 4.7 gives a selection of mean concentration data obtained from the available published records (Robb, 1993; Gilson & Mitchell, 1999) and from the Christchurch City Council website (www.ccc.govt.nz/wastewater/treatmentplant/DischargeConsentMonitoring.asp). It appears from the concentration data presented that the level of most contaminants and nutrients in CWTP discharge has dropped significantly since the mid 1990s although some contaminants, such as lead and zinc, have remained the same or increased.

	Time Period (Year)		
	1992-1993	**1995-1997**	**2005-2006**
Contaminant/Nutrient (g/m3)			
Suspended Solids	43.35	50.75	18.49
Total Phosphorous	5.6	6.47	6.14
Dissolved Reactive Phosphorous	5.1	5.57	5.21
Kjeldahl Nitrogen (Total Nitrogen)	29	(37.95)	34.01 (33.95)
Ammoniacal Nitrogen	20.25	25.5	31.93
Nitrite	*	0.365	0.033
Nitrate	*	0.285	0.153
Copper	0.016	0.014	0.0084
Chromium	0.038	0.054	0.024
Nickel	0.026	0.026	0.010
Zinc	0.037	0.043	0.059
Lead	0.0045	0.0038	0.0037
Discharge (m^3/day)	154,000	153,000	170,000

Table 4.7. Three years of mean concentration (g/m^3) of contaminants in discharge from the Christchurch Wastewater Treatment Plant between 1992 and 2006. This data was derived from the surface water quality data published by the Christchurch City Council (Robb, 1993; Gilson & Mitchell, 1999) and published on the internet at www.ccc.govt.nz/wastewater/treatmentplant/DischargeConsentMonitoring.asp. Note that those values listed in the 2005-2006 as "< x.x" (e.g. <0.01) were treated as the value for calculating the mean. This means that the concentrations are conservatively high.

While this indicates that the concentration of heavy metals and nutrients entering the Estuary from the CWTP has decreased over time the data presented in Table 4.7 is not the best means of examining the longer term input of contaminants to the Estuary as the discharge from the CWTP differs from year to year and has been generally increasing. For example the discharge in 1992-1993 was 154,000 m^3/day (Robb, 1993), 160,000 m^3/day in 2001-2002 (Bolton-Ritchie & Main, 2005) and, as of 2005-2006 was 170,000 m^3/day (Christchurch City Council http://www.ccc.govt.nz/WasteWater/TreatmentPlant/ 15th January 2007). To produce a robust estimate of the actual contribution of the CWTP to the Estuary therefore requires an estimate of the annual input in order to take into account the effects of both the increased discharge and the reduced concentration. As the discharge from the CWTP is carefully controlled it is, unlike for the Avon and Heathcote rivers (see above), possible to produce relative robust estimates of the annual input of suspended solids, heavy metals and nutrients. Table 4.8 contains a summary of annual suspended solids, heavy metals and nutrients discharged from oxidation ponds 5 and 6 between 1992 and 2006.

Parameter (t/yr)	Time Period (Year)					
	1992-1993 (Robb, 1993)	1993-1994 (Robb, 1994)	1994-1995 (Gilson, 1996)	1995-1997 (Gilson & Mitchell, 1999)	2000-2001 (Gilson, 2001)	2005-2006 (website link above)
Suspended Solids	2436.70	2286.50	2738.81	2834.13	2190.00	1147.30
Total Phosphorous	314.78	373.83	377.60	361.32	*	380.99
Dissolved Reactive Phosphorous	286.67	320.06	330.33	311.06	584.00	323.38
Kjeldahl (Total Nitrogen)	1630.09	1705.28	(1748.63)	(2119.32)	(1460.00)	2110.32 (2106.60)
Ammoniacal Nitrogen	1138.25	1175.26	1202.49	1424.05	1460.00	1981.26
Nitrite	*	*	5.94	20.38	0.00	2.05
Nitrate	*	*	4.94	15.92	0.00	9.49
Copper	0.92	1.17	1.00	0.77	1.13	0.52
Chromium	2.12	2.50	2.49	3.00	*	1.50
Nickel	1.45	1.14	1.28	1.45	*	0.62
Zinc	2.06	1.61	2.83	2.38	2.47	3.64
Lead	0.25	0.22	0.36	0.21	0.40	0.23

Table 4.8. Annual contaminant and nutrient input (t/yr) to the Avon-Heathcote Estuary/Ihutai from the Christchurch Wastewater Treatment Plant at Bromley between 1992 and 2001. Annual input for the years 1992-1997 was calculated from the surface water quality data published by the Christchurch City Council (Robb, 1993; Robb, 1994; Gilson, 1996; Gilson & Mitchell, 1999) while the 2000-2001 data was from evidence presented for a resource consent hearing by Mike Gilson (Gilson, 2001). The 2005-2006 data was from www.ccc.govt.nz/wastewater/treatmentplant/DischargeConsentMonitoring.asp.

It is quite clear that the level of suspended sediments being discharged from the CWTP has been decreasing since the mid-1990s (Table 3.8). While 90% of these suspended solids are algal cells rather than actual sediment (Gilson, 2001), and thus contribute more to the organic content of the sediment rather than to the sediment itself, this reduction may partially explain the apparent decrease in muddiness of the western mudflats (Knox, 1992; Knox, 2001) as the rate of erosion of fine material from these areas is no longer being matched by an equivalent input from the CWTP and Avon Rivers.

While the concentration of heavy metals has also decreased (Table 4.7) the actual amount entering the Estuary has remained relatively constant over time with the lowered concentration being offset by the increased flow (Table 4.8). This constant level of input is not, however, stopping the apparent reduction in heavy metal concentrations within the Estuary over time (see section 3.1.2 above).

Bolton-Ritchie & Main (2005), in a study on nutrient water quality in the Estuary based on median concentrations, concluded that there had been an increase in the level of ammoniacal nitrogen, total nitrogen, dissolved reactive phosphorous (DRP) and total phosphorous entering the Estuary over time. They also concluded that the level of nitrates and nitrites had decreased. While the data in Table 4.8 supports their conclusions regarding the general increase in ammoniacal nitrogen and total nitrogen it does not support their conclusions regarding DRP and total phosphorous as while DRP increased in 2000-2001 it returned to a similar level of input in 2005-2006. Likewise the conclusions regarding the apparent decrease in nitrates and nitrites may not be robust as the high input of these nutrients observed between 1995 and 1997 (Table 4.8) is anomalously high when compared to both the 1994-1995 and 2005-2006 inputs. The 2000-2001 data from Gilson (2001) are of no help in resolving this trend (or the

lack thereof) as he reported values of 0.00 t/yr. This is an improbable result and it is considered more likely that this is an error in the reporting of the results. The large variability observed between the presented records (1994-1995, 1995-1997 and 2005-2006) indicates that there is insufficient data to draw robust conclusions regarding the concentration and input of nutrients over time.

4.3 Inputs from the Christchurch Outfall Drains

While the Avon and Heathcote rivers and the CWTP are the three primary contributors of sediment, nutrients and contaminants to the Estuary a series of 6 drains (Gilson, 2001), 67 stormwater outlets and 45 smaller outlets (Bolton-Ritchie & Main, 2005) also open into the Estuary. Of these additional sources of input the six major drains have been routinely monitored since 1989 (Gilson, 2001) and include the Charlesworth drain, the City Outfall Drain, Lovett's Drain, and the Estuary Drain which empty directly into the western edge of the Estuary in the Heathcote River deposition zone while the Northern and Southern Toe Drains drain the seepage from the CWTP into the Estuary.

Like the river and CWTP monitoring the methodology used for monitoring these drains is outlined in Gilson & Mitchell (1999) and not repeated here. Unlike the CWTP monitoring results, however, the data from the drains is less readily available on the Christchurch City Council website and any estimates of inputs must rely on published data (Robb, 1993; Robb, 1994; Gilson, 1996; Gilson & Mitchell, 1999). As the purpose of this review is to discuss sedimentation within the Estuary, rather than the differences between the contaminant concentrations within the drainage system, the six drains are considered a single input to the Estuary even though they show variability between them (e.g. the Northern and Southern Toe Drains contain elevated levels of ammonia relative to the other drains). Table 4.9 provides a summary of the mean concentrations of contaminants input to the Estuary from all six drains over time although prior to 1994-1995 the heavy metal measurements are such that they cannot be used to determine a mean value.

It can be seen from the data presented in Table 4.9 that, at least through the 1990s, there was little change in the concentration of contaminants and nutrients discharged into the Estuary from the drains. Estimates of average input are non-existent as there is a general impression that there is no published data on the discharge from these drains (e.g. Bolton-Ritchie & Main, 2005). This is not the case, however, with the published records from the Christchurch City Council giving measurements of their annual combined discharge of 15,085 m^3/day (Table 4.9) (Robb, 1993; Robb, 1994; Gilson, 1996; Gilson & Mitchell, 1999). This enables an estimate of annual discharge to be calculated (Table 4.10).

An examination of the results in Table 4.10 appears to indicate that, like the concentrations (Table 4.9), the contribution of the drains to the Estuary, while varying slightly from year to year, is fairly consistent. This result is probably misleading as unlike the discharge from the CWTP the discharge from the drains is not actively controlled. It is probable, therefore, that the flow estimates used in the

Parameter (g/m^3)	1992-1993 Mean	1992-1993 Range	1993-1994 Mean	1993-1994 Range	1994-1995 Mean	1994-1995 Range	1995-1997 Mean	1995-1997 Range	1992-1997 Mean
Suspended Solids	42.600	8.000 – 87.300	39.200	8.300 – 98.000	39.180	9.170 – 77.330	40.440	6.560 – 73.200	40.355
Dissolved Reactive Phosphorous	0.340	0.100 – 1.009	0.283	0.034 – 1.012	0.527	0.138 – 1.374	0.442	0.118 – 1.240	0.398
Ammonia Nitrogen	11.960	0.330 – 34.630	12.750	0.250 – 37.710	14.370	1.050 – 40.660	14.450	0.370 – 40.800	13.383
Nitrite	0.026	0.018 – 0.48	0.092	0.015 – 0.025	0.037	0.015 – 0.068	0.028	0.014 – 0.051	0.046
Nitrate	0.460	0.190 –0.740	0.220	0.160 – 0.330	0.280	0.020 – 0.500	0.270	*< 0.04 (treated as 0.04)* – 0.630	0.308
Copper	*	*	*	*	0.009	0.001 – 0.010	0.009	0.001 – 0.028	0.009
Chromium	*	*	*	*	0.008	0.001 – 0.010	0.004	0.001 – 0.008	0.006
Nickel	*	*	*	*	0.008	0.001 – 0.010	0.004	0.001 – 0.006	0.006
Zinc	*	*	*	*	0.037	0.013 – 0.083	0.130	*< 0.02 (treated as 0.02)* – 0.397	0.083
Lead	*	*	*	*	0.009	0.002 – 0.010	0.006	0.001 – 0.011	0.007
Combined Discharge (m^3/day)	15,085		15,085		15,085		15,085		15,085

Table 4.9. Mean concentration (g/m^3) of contaminants in discharge from the six drains discharging into the Estuary This data was derived from the surface water quality data published by the Christchurch City Council (Robb, 1993; Robb, 1994; Gilson, 1996; Gilson & Mitchell, 1999). The combined discharge value is from the published data of the Christchurch City Council (Robb, 1993; Robb, 1994; Gilson, 1996; Gilson & Mitchell, 1999).

Parameter (t/yr)	Time Period 1992-1993	1993-1994	1994-1995	1995-1997	Mean 1992-1997
Suspended Solids	234.557	215.836	215.726	222.664	222.196
Dissolved Reactive Phosphorous	1.872	1.558	2.902	2.434	2.191
Ammonia Nitrogen	65.852	70.202	79.122	79.562	73.684
Nitrite	0.143	0.507	0.204	0.154	0.252
Nitrate	2.533	1.211	1.542	1.487	1.693
Copper			0.050	0.050	0.05
Chromium			0.044	0.022	0.033
Nickel			0.044	0.022	0.033
Zinc			0.204	0.716	0.460
Lead			0.050	0.033	0.042

Table 4.10. Estimated annual contaminant and nutrient input (t/yr) to the Avon-Heathcote Estuary/Ihutai from the combined input of the six primary drains over the period of 1992-1997. Also provided is a mean for the entire period (1992-1997) although data for the heavy metal inputs is only available for 1994-1997.

calculations (Table 4.9), based on routine monitoring of the flow in the drains, can actually vary significantly depending on the size and frequency of storm events. As it is unlikely that the routine monitoring of the drains has sampled a useful number of storm events the estimates of annual input presented in Table 4.10 are likely to be extremely conservative.

4.4 Synthesis of sediment, nutrient and contaminant input to the Estuary

The preceding sections have attempted to establish, from the existing literature, the input of sediment, and sediment contaminants, to the Estuary. The mean annual contribution of the primary sources of input are summarised in Table 4.11.

	Avon River			Heathcote River			CWTP	Drains
	Wallingford (1970)	**Hicks (1993)**	**Pratt (2000)**	**Wallingford (1970)**	**Hicks (1993)**	**Pratt (2000)**	**(Mean 2005-2006)**	**(Mean 1992-1997)**
Mean Sediment Input								
Suspended Solids	2,000	3,198	5,664	17,000	5,220	18,214	1, 147.3	222.20
Mean Nutrient Input								
Ammoniacal Nitrogen	*	*	7.75	*	*	7.75	1981.26	73.68
Nitrite Nitrogen	*	*	1.25	*	*	0.95	2.05	0.25
Nitrate Nitrogen	*	*	98.5	*	*	64.5	9.49	1.69
Reactive Phosphorous	*	*	3.2	*	*	4.8	323.38	2.19
Mean Heavy Metal Input								
Copper	*	*	1.35	*	*	1	0.52	0.05
Zinc	*	*	1.8	*	*	0.7	3.64	0.46
Lead	*	*	10.15	*	*	7.85	0.23	0.04

Table 4.11. Estimated mean annual contaminant and nutrient input (t/yr) to the Avon-Heathcote Estuary/Ihutai from the primary suppliers of sediment, nutrients and contaminants to the Estuary. Estimates of inputs for all three of the sedimentation studies on the Avon and Heathcote Rivers (Wallingford (1970) *in* Hicks (1993); Hicks (1993) and Pratt (2000) are provided as well as the most recent available data from the CWTP and Drains. Note that the heavy metal concentrations for the Drains are the mean for only 1994-1997 as there is no measurable data prior to this.

It can be seen from the data in Table 4.11 that the primary source of sediments (in the form of suspended solids) is, regardless of the estimate used, the Heathcote River with the second largest supplier the Avon River. The accuracy of these estimates is, however, doubtful due to the flaws in the methods used. The most significant flaw in these studies is the lack of sampling during storm events which show large scale deviations from the base flow concentrations of contaminants. Hicks (1993), for example, followed a commonly used technique whose major flaw, the underestimation of sediment loads, was understood and taken into account. The comparatively low sediment load estimates for the Heathcote River relative to the other studies is therefore likely to be the result of the limited variation captured in his sampling of storm events which the Pratt (2000) study showed can vary substantially. The Pratt (2000) study has more problems as while the base idea behind the methodology seems sound all the calculations used were based on the flawed assumption that all storm events would be similar to the two measured. The Pratt (2000) method could have produced more accurate estimates of annual contaminant loads if these assumptions had not been used and additional long-term sampling of storm events had been undertaken.

The supply of nutrients to the Estuary is, if not well, at least better understood. Table 4.11 indicates that the greatest input of nutrients, represented in Table 4.11 by the figures for ammoniacal nitrogen and

reactive phosphorous, is from the CWTP. This number is well constrained due to the controlled release of discharge from the CWTP and the continuous routine monitoring. In addition to being the primary supplier of nutrients to the Estuary, the CWTP is also a major supplier of organic matter. Assuming, for the moment, that the Pratt (2000) estimates are in fact an accurate representation of the input of suspended solids to the Estuary from the rivers, and that 22% of the sediment load of the Avon (ca. 1,246 t/yr) and 13.7% of the sediment load in the Heathcote (ca. 2,495 t/yr) actually comprises organic matter (Hicks, 1993), then the CWTP contributes approximately 22% of the annual allocthonous input of fine organic matter to the Estuary as its suspended sediment load is ca. 90% algae cells (ca. 1,033 t/yr) (Gilson, 2001). On the other hand, if the Hicks (1993) estimates of suspended sediment load are assumed to be correct this figure increases to ca. 42% of the annual input of fine organic matter to the Estuary. Overall it is readily apparent that, regardless of the inputs from the rivers, the CWTP is the primary external source of nutrients and organic matter to the current estuarine ecosystem. This raises questions regarding the effect of the future removal of the CWTP outfall from the Estuary to the Pacific Ocean. The diversion of the effluent discharge could result in a decline in the productivity of the Estuary (Sagar, 2000; Fenwick, 2005) which may in turn affect the sedimentation regime by reducing the number of burrowing invertebrates (Sagar, 2000; Fenwick, 2005) which seem to play a role in the removal of sediment from the Estuary (Macpherson, 1978; Hicks, 1993). Furthermore a reduction in the organic matter and nutrients input to the Estuary is likely to affect the distribution of algae (Fenwick, 2005) which acts to promote the sedimentation of finer sediments (Knox & Kilner, 1973). This reduction in effluent is, however, likely to improve water clarity and may result in an increase in the growth of benthic macro- and micro algae over time (Fenwick, 2005). This may, in the medium to long term, offset any adverse effects on the ecosystem and, by extension, the sedimentation regime.

It is apparent from this review, however, that the supply of sediment and the associated nutrients and contaminants to the Estuary is, overall, poorly understood. Contrary to the general acceptance of the Pratt (2000) estimates in recent reports and in evidence given to Resource Consent Hearings (e.g. Gilson, 2001; Bolton-Ritchie & Main, 2005) the estimates summarised in this review should, at most, be treated as rough guidelines. Further work on establishing the actual contribution of sediment, and the associated contaminants and nutrients is desperately required.

Future work on the input of sediments and their associated contaminants should include:

1. Further sampling of storm events for both suspended sediment and contaminants on the Avon and Heathcote rivers over several years. This should be undertaken so as to obtain a representative spread of the different storm events. This monitoring must use a standardised method to enable a direct comparison of the results. Direct measurements of storm discharge should be compared both to the scale (total mm of rain over the entire catchment) and the intensity (mm of rain per hour) of the events.

2. The sediment/nutrient/heavy metal input of sub-catchments should be sampled over several years to determine the relative contribution of the individual sub-catchments. This will enable a more accurate calculation of mass loads in the rivers.

3. Monitoring of the CWTP discharge and of the outfall drains should continue. Efforts should be made to sample the outfall drains during storm events to obtain a more accurate measure of their relative contribution.

Section 5 – Final summary & prioritised recommendations for future work

This report has been written in three separate sections and a synthesis and general recommendations for future work have been made at the end of each section. This final section briefly summarises the major findings and prioritises the recommended courses of future study.

Section 2 reviewed the currently available information on the distribution of sediment within the Estuary and the pattern of deposition and erosion. While patterns of sediment distribution appear to have remained relatively constant since the 1970s there have been no major quantitative studies of sediment distribution since the mid 1980s (Rodrigo, 1985; Christchurch Drainage Board, 1988) and while the data from the 1980s is robust it is now two decades out of date. Furthermore, while the level of deposition and erosion over the entire Estuary appeared to be balanced at a net accumulation of ca. 1mm/yr in the mid 1980s (Hicks, 1993) some areas of the Estuary appear to be undergoing erosion (e.g. the mud flats (Knox, 1992; 2001)) and quantitative estimates of the rate of change for these areas is unknown.

Section 3 examined the available information on the levels of contaminants in the Estuary sediments. The level of information available is mixed. While levels of heavy metals in the different regions of the Estuary are reasonably well known, and appear to be decreasing, the information regarding other contaminants is poor although, from the limited information available, they do not appear to be in high enough concentrations to warrant immediate concern.

Section 4 reviewed the input of sediment and contaminants to the Estuary. Like the studies of contaminant levels in the Estuary sediments the level of information available is mixed. The routine monitoring and controlled release of effluent from the CWTP enables well constrained estimates of the supply of nutrients and contaminants to the Estuary from this source to be calculated. The supply of sediment and contaminants from other sources are, however, poorly known due to the poor sampling of storm events and the use of false assumptions used in some studies. This is particularly apparent for estimates of sediment mass loads from the Heathcote River which shows massive variability depending on the size of annual storm events.

Overall the information on sedimentation in the Estuary appears to be out of date or of limited value. The following two studies *need* to be undertaken to produce a robust estimate of sediment supply to, and accumulation within, the Estuary:

1. A detailed survey of the bed levels at sites within the Estuary so as to determine changes in the location and rate of sediment accumulation and erosion since the last surveys in the late 1980s (Hicks, 1993). To ensure compatibility with previous surveys of the Estuary this survey

should re-use the survey lines established by Royds Garden in 1962 and re-used by Christchurch Drainage Board in 1975-77 and in 1988.

2. A long term (i.e. multi-year) study of sediment loads in the Avon and Heathcote rivers during storm events in order to establish a robust estimate of annual sediment loads from the primary suppliers of sediment to the Estuary. Such a study should also examined the scale and intensity of the storm events.

The following studies are also desirable, although not immediately necessary, in order to up-date quantitative estimates of sediment distribution and contamination in the Estuary.

3. An extensive quantitative study of sediment size distribution across the Estuary in order to establish the current composition of sediments and to identify the best locations to undertake monitoring studies.

4. An extensive study of sediment contaminants and nutrients with sampling sites chosen so as to best represent all available habitats within the Estuary.

Once these studies have been completed a series of sites can be selected which best represent the overall distribution of sediments within the Estuary. To ensure compatibility between different studies both within, and between, different estuaries, it is suggested that the Estuarine Environmental and Monitoring protocols established by Robertson et al. (2002), and used recently for the Avon-Heathcote Estuary/ Ihutai by Thompson (2005), should be adopted as the standard methodology for the future studies.

Three additional studies should be undertaken on the input of contaminants to the Estuary. Again these studies are not be immediately necessary but will enable a better understanding of the contribution of sediment nutrients and contaminants to the Estuary.

5. A study of contaminants in the Avon and Heathcote Rivers over multiple storm events so as to establish the long term contribution of these contaminants to the Estuary.

6. The sediment/nutrient/heavy metal input of sub-catchments should be sampled (over multiple years) to determine the relative contribution of the individual sub-catchments.

7. Sampling the six major drains during storm events to obtain a more accurate measure of their relative contribution.

Finally, due to the time constraint on this review, it has concentrated solely on the Estuary, and the input of contaminants and sediment to the Estuary. No review of the work conducted on sedimentation

patterns in the rest of the Avon-Heathcote catchment system (e.g. studies of erosion and deposition in the Avon and Heathcote rivers), has been made and a review of sedimentation in the rest of the catchment system should also be undertaken.

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Appendix A – Sampling site grid references

This appendix contains the grid references for the sampling sites of Robertson et al. (2002), Thompson (2005), and Gust et al. (2004) (Table A.1).

Study	Sampling Site		
Robertson et al. (2002)		**New Zealand Map Grid coordinate of corners**	
		NZMG-Eastings (m)	**NZMG-Northings (m)**
	Site A	2487144.71411	5739772.25194
		2487159.37042	5739749.90537
		2487192.73595	5739807.46749
		2487207.48805	5739782.04015
	Site B	2488943.33227	5739792.08805
		2488971.10525	5739780.81258
		2488960.16882	5739849.69565
		2488987.82732	5739838.31048
	Site C	2488424.20385	5740887.91739
		2488455.58164	5740837.42806
		2488481.55603	5740851.94403
		2488449.69764	5740902.82627
Thompson (2005)		**GPS coordinates of site corners**	
	Site 1	43° 32.420	172° 43.287
		43° 32.427	172° 43.315
		43° 32.458	172° 43.299
		43° 32.452	172° 43.274
	Site 2	43° 32.914	172° 42.814
		43° 32.939	172° 42.809
		43° 32.932	172° 42.755
		43° 32.910	172° 72.772
	Site 3	43° 33.256	172° 42.228
		43° 33.287	172° 42.240
		43° 33.285	172° 42.265
		43° 33.252	172° 42.257
	Site 4	43° 31.852	172° 43.800
		43° 31.886	172° 43.804
		43° 31.891	172° 43.777
		43° 31.859	172° 43.770
	Site 5	43° 32.903	172° 44.559
		43° 32.878	172° 44.540
		43° 32.874	172° 44.571
		43° 32.873	172° 44.587
		New Zealand Map Grid coordinate for core location	
Gust et al. (2004)		**NZMG-Eastings**	**NZMG-Northings**
	AH1	2487642	5741797
	AH2	2487740	5741777
	AH3	2487839	5741761
	AH4	2487984	5741760
	AH5	2488131	5741753
	AH6	2488186	5741748
	AH7	2488186	5741748

Table A.1. Coordinates of the four corners of the sampling sites used in the studies of Roberston et al. (2002) and Thompson (2005). Also included are the locations of the cores obtained by Gust et al. (2004). .