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Estuary Sedimentation : a Review of Estuarine Sedimentation in the Waikato Region

Prepared by:
Shaw Mead BSc, MSc (Hons), PhD
Andrew Moores BSc, MSc (Hons)
ASR Ltd
Marine Consulting and Research

For:
Environment Waikato
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HAMILTON EAST

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Cover picture: Port Waikato, where the Waikato River flows into the sea (http://www.ew.govt.nz/enviroinfo/water/index.htm).

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Foreword

Estuary sedimentation is a continual natural process. However, in many instances the activities on the land within a catchment lead to accelerated estuarine sedimentation. This document provides straight-forward descriptions of how estuarine sedimentation occurs and the methodologies that can be employed to evaluate rates of sedimentation. In addition, the available information on sedimentation rates and calculations of the sediment yield of estuaries within the Waikato region are presented. In the future, as new information comes to hand, this document will be continually updated.

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1 Introduction

This report has been produced to explain the processes of sedimentation in the estuaries of the Waikato region. In the first sections, estuaries are defined and their processes described. Sedimentation monitoring techniques are then explained and finally, the existing data that is available for the Waikato region is presented and deficiencies in these data are identified.

1.1 Defining Estuaries

An estuary is "a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage" (Pritchard, 1967, cited in Kramer et al.,1994).

The formation of most of New Zealand's estuaries occurred approximately 15,000 years ago from existing river valleys flooded due to sea-level rise (Figure 1). Once sea-level stabilised to present levels about 6000 years ago estuaries have been infilling with sediments (at various rates) to form the features we see today.

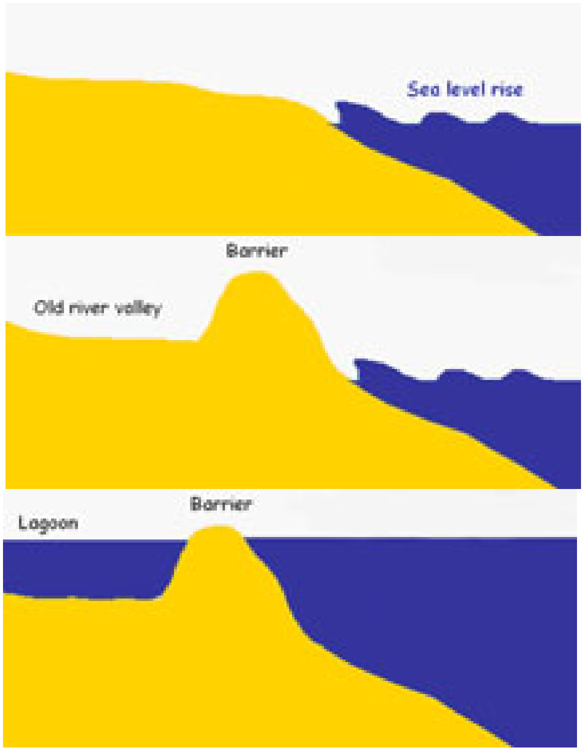
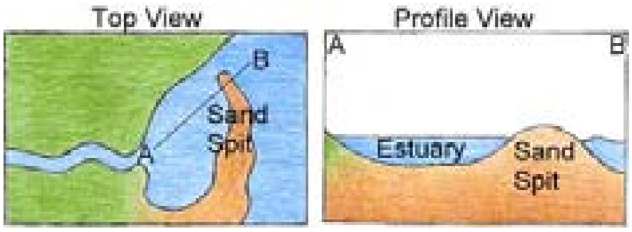


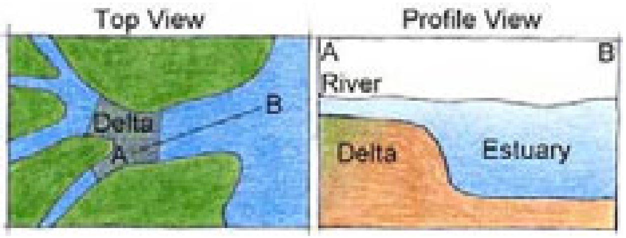
Figure 1: Diagrammatic Representation of Estuary Formation. The Uppermost Image Being the Oldest and the Lowest Image Being the Present Day (Stephens et al., 2003)

The Estuarine system includes the water body or basin and the marginal areas around the edge which are flooded by the tide and storm events. Water basins can take a number of different forms including embayments, bays, inlets, sounds, fiords, lagoons and tidal rivers (Figure 2). The marginal area includes the tideflats and mudflats; the tidal salt marshes and mangroves; and the upper wetlands – high-marsh flooded by spring tides (Knox, 1980).

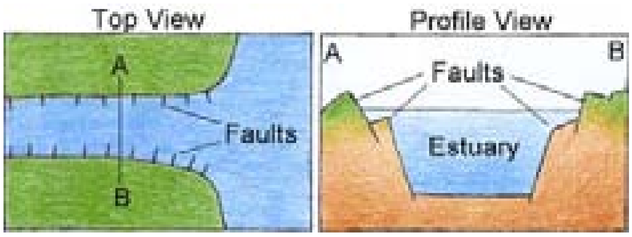
New Zealand has an example of every type of estuary (see Appendix 1). This variety is due to varied geology, rainfall, land use, coastal wave climate, different basin shapes and the degree of infilling (Potter, 2004). Figure 2 shows a variety of different estuary types which can be found in New Zealand.



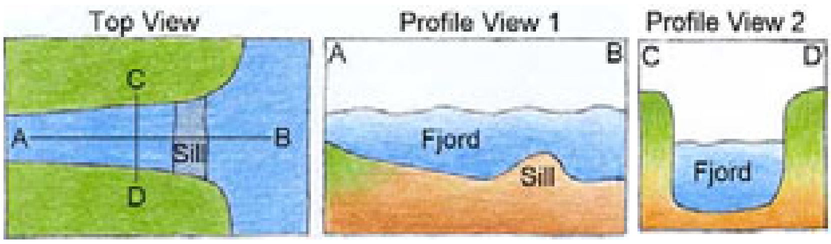
These bar built estuaries are most common along the west coast of the Waikato region. The shallow lagoon or bay is protected from the ocean by a sand bar, sand delta or barrier island.



Coastal plain estuaries are formed by the sea level rising and filling an existing river valley.



Tectonic estuaries are formed by the folding and faulting of land surfaces. Commonly found along major fault lines.



Fjords are formed by glacial action carving out a U shaped valley and subsequently filling with water.

Figure 2: Estuary Types Found in New Zealand (Potter, 2004)

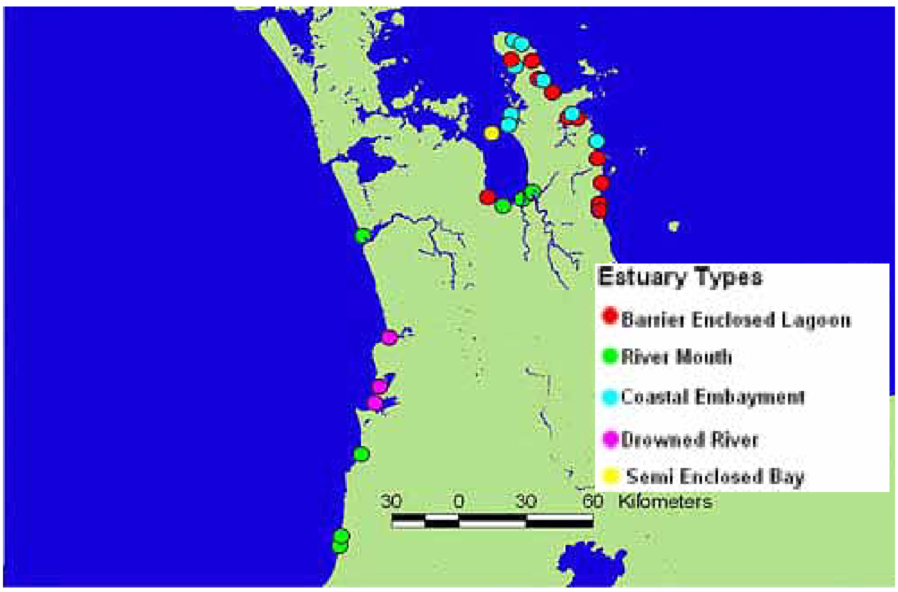


Figure 3: Estuary Types Found in the Waikato Region (Potter, 2004)

1.2 Estuary Value

1.2.1 Ecosystem

Estuaries are important coastal ecosystems. The productivity is comparable to that of a tropical forest and about four times as productive as good ryegrass pasture. Figure 4 shows the comparison with other kinds of ecosystems (Knox, 1980).

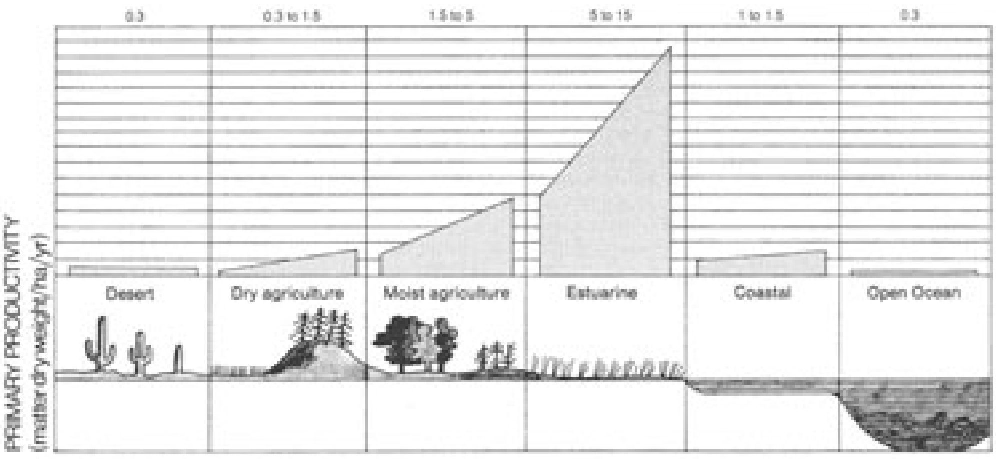


Figure 4: A Comparison of Primary Productivity of Estuaries with Other Types of Ecosystems (Knox, 1980)

Estuaries are very important in the overall economy of coastal water. The water is naturally filtered by microbe activity which break down organic material while sediments bind pollutants. The wetland vegetation (e.g. mangroves and saltmarshes) and intertidal areas act as enormous natural filters removing much of the nutrients, sediments and pollutants from the catchment (figure 5). This filtered water benefits human and marine life in the estuary.

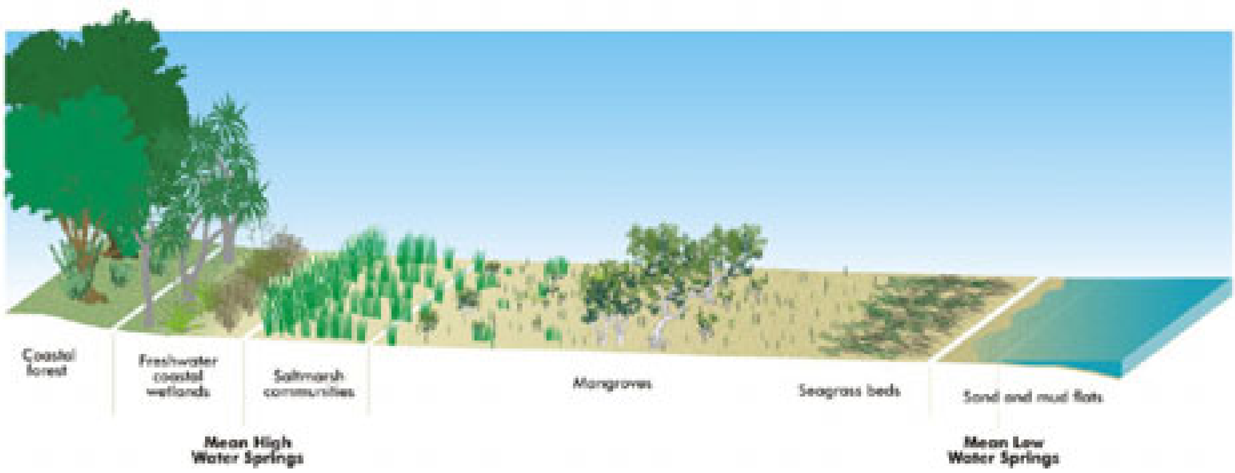


Figure 5: The Typical Margin of a Waikato Estuary (Turner & Riddle, 2001)

Estuaries provide a haven for many plants and animals increasing biodiversity. Thousands of birds, mammals, fish and other wildlife use estuaries as a place to live, feed and reproduce. Migratory birds use the areas as a place to feed and rest while fish and shellfish use estuaries to spawn and allow juveniles to grow (Potter, 2001). This is summarised in Figure 6, which shows the food web of a typical estuarine environment.

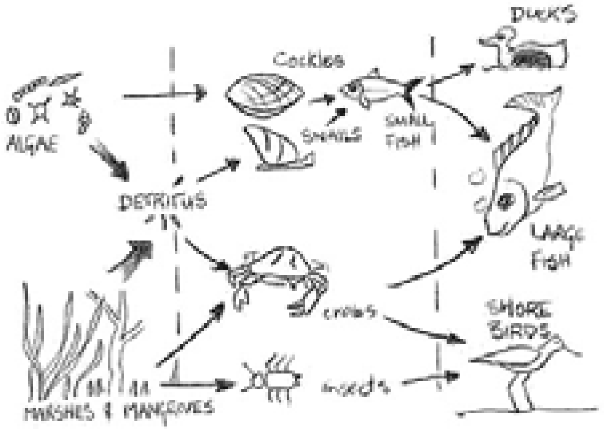


Figure 6: Figure 6. Estuarine Food Web (Potter, 2001)

Estuarine plants are grazed and filtered by invertebrates like snails, cockles and oysters. These in turn are eaten by juvenile and other small fish which may be hunted by larger fish like snapper, kingfish, rays and even sharks (Figure 6).

SEAGRASS (*Zostera capricorni or Z. novazealandica*):
A flowering plant occupying extensive intertidal and shallow water areas (to about mid tide). Seagrass is restricted to shallow coastal environments due to the relatively high (compared to phytoplankton) light requirements. This makes them highly vulnerable to the impacts of human activities (e.g. nutrient loading, high turbidity, smothering by sediments and physical disturbance) (Turner & Riddle, 2001).

Figure 7: Seagrass Beds in Whangapoua Harbour (source: Environment Waikato)

MANGROVES (*Avicennia marina or A. resinifera*):
A broadleaf evergreen tree that flourishes in the estuarine waters of the northern third of New Zealand. Mangroves grow between near mid-tide and high spring tide levels on sheltered accretive shores, with low energy wave action. Mangroves are one of the most productive types of indigenous forest in New Zealand in terms of litter production.

Figure 8: Mangroves in Whangapoua Harbour (source: Environment Waikato)

SALTMARSH:
Saltmarshes are areas of high intertidal soft sediments in estuaries and along sheltered parts of the coast. The ground is usually water-logged and regularly inundated with seawater by the tide. Three sub-communities have been identified (Graeme, cited in Turner & Riddle, 2001) within the broad saltmarsh community of the Waikato Region (1) The "rush/sedge community" (mid-high tide level) (2) The "salt meadow community" (above mid-high tide level) (3) The "saltmarsh ribbonwood community" (high tide level)

Figure 9: Rush/Sedge Community in Wharekawa Harbour (source: Environment Waikato)

OTHER VEGETATION

Both macroalgae and microalgae occur on open estuarine intertidal and shallow subtidal sand and mud flats, and among seagrass, mangroves and saltmarsh, where they may be attached to the stems, trunks, pneumatophores, or roots. On open intertidal and shallow subtidal sand and mud flats, microalgae are ubiquitous, abundant and often highly productive. Macroalgae also occur in soft-sediment habitats, but their distribution is often temporally and spatially patchy. Examples include the fast-growing green algae such as *Ulva* and *Enteromorpha*, the proliferation of which is often linked to organic enrichment. An estuarine form of the fucoid alga *Hormosira banksii* (Neptune's Necklace) is also an occasional feature of Waikato Region estuaries.

1.2.2 Cultural Value of Estuaries

Estuaries provide important cultural and recreational areas for humans. They offer safe moorings when the open coast is exposed to high wave energy and provide areas for many water based activities (swimming, sailing, skiing, kayaking, etc.). They are also sites of kaimoana gathering (e.g. cockles and pipis) and capture (e.g. flounder). They hold high aesthetic scenic values, and as a consequence the surrounding areas often have high cultural value (e.g. early settlement areas). As they are a breeding ground for juvenile fishes, estuaries are very important to a number of cultural, recreational and commercial fisheries including Snapper (Morrison et al, 2003).

A number of the Waikato Region's estuaries are regarded as internationally and nationally significant. The southern shore of the Firth of Thames, for example, is part of an internationally recognised wetland (RAMSAR) site, which is important for migratory birds, as well as having unique and globally rare landforms (e.g. chenier plains). Whaingaroa, Aotea and Kawhia Harbours on the West Coast are internationally and nationally important for many threatened coastal bird species and international migratory birds (Turner & Riddle, 2001).

2 Sedimentation Processes

An estuary is a dynamic environment in which many processes and sediment sources combine to influence estuary characteristics. An *estuary system* includes catchments that drain directly into the estuary through rivers and streams (fluvial processes) and open-coast marine systems in which the estuary is a link in the open-coast system.

The processes within an estuary can be summarised as follows. They are places where there is **IMPORT** from the river and the sea, where **TRANSFORMATION** of material takes place, where **RETENTION** of material occurs, and from which **EXPORT** to the sea and atmosphere occurs (Figure 10) (de Jonge, 2000, in Turner & Riddle, 2001). Note, river inputs include land sources of material within the catchment (discussed below).

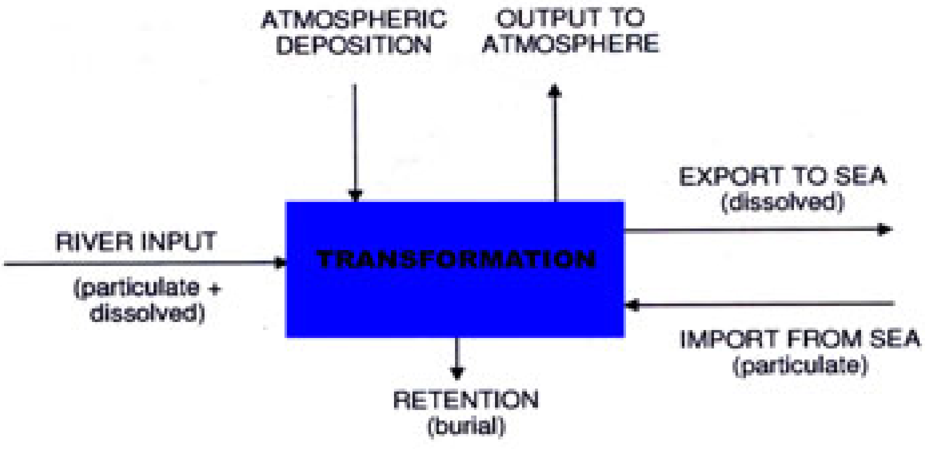


Figure 10: The Fluxes Occurring in Estuaries (Turner & Riddle, 2001)

Three important physical features play a role in moving sediment inside an estuary – tides, waves and rivers.

TIDES

The tidal currents provide a steady source of energy for sediments moving both into and out of and estuary. Tidal ranges in New Zealand typically range between 2 and 4 metres (Bell et al., 2000). Figure 11 shows the strong ebb tidal currents in the Omaha inlet.

Figure 11: Strong Ebb (outgoing) Tidal Currents in the Omaha Inlet (Image Copyright Terry Hume)

WAVES
Especially during storm events, waves and swell at estuary entrances can stir up huge amounts of sediment. This can then be moved into the estuary on the incoming (flood) tide. Waves generated inside the estuary basin can also scour sediment from the marginal areas. Figure 12 shows large waves acting on a sand bar at Port Waikato (Bell et al., 2000).

Figure 12: Large Waves Breaking at the Entrance of Port Waikato (Image Copyright Terry Healy)

RIVERS
Fresh river water is less dense than seawater and floats over seawater. Therefore when sediment that enters the estuary remains in suspension with the river water, it can be flushed out to sea quite quickly. However, heavier particles fall out of suspension and sink to the bottom as the flow meets saltwater. This is why sediment deposition is greatest near the upper reaches of the estuary (Bell et al., 2000). Figure 13 shows a river transporting sediment into an estuary.

Figure 13: Hellyers Tidal Creek in the Upper Waitemata Harbour (Hume & Swales, 2003)

Fine grained material will tend to move in suspension and follow the flow of water. Deposition may occur at times of slack water. Courser sediment will tend to travel along the sea bed and be affected most by high velocities in the direction of the maximum current (Dyer, 1979). This is covered in more detail in Section 2.3.

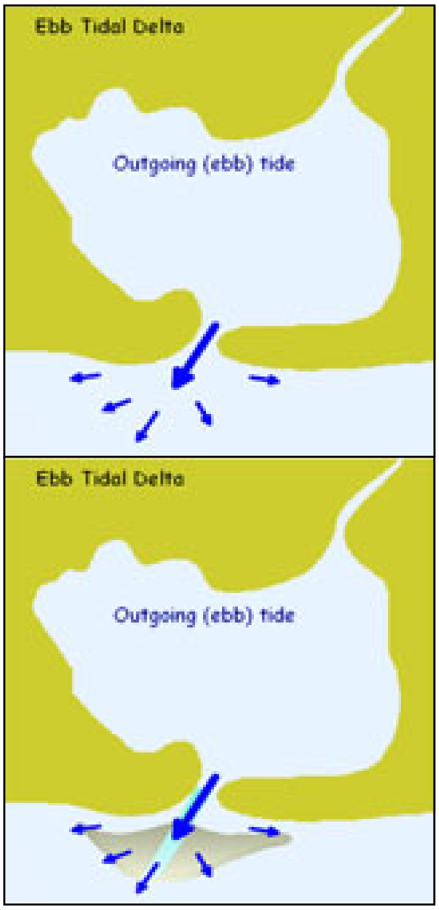
On the incoming (flood) tide, particulate material from the sea settles in the estuary through the process described in figure 14. The features formed outside the inlet throat are shown in figure 15.

Wave action lifts sediment from the sea bed and carries this particulate matter though the **inlet throat** during the incoming tide. Littoral drift sediment (caused when waves hit the shoreline at an oblique angle) also enters the estuary though the throat when the path of the sediment crosses the estuary mouth.

Once the current has passed through the inlet throat, the current speed drops as it spreads out, and some of the sediment settles out onto the estuary bed forming a large sandy deposit called the **flood tidal delta**.

During the outgoing tide the water tends to flow around the outer parts of the flood tidal delta to form the **ebb shield**. As the water nears the entrance small **ebb spits** are built up.

Figure 14: Characteristics of the Flood Tidal Delta (Stephens et al, 2003)



As the water passes through the inlet throat on the outgoing (ebb) tide, a similar process occurs (Figure 15). The current slows down as the water fans out, meets the littoral drift current and some of the sediment falls out of suspension to form the **ebb tidal delta**.

Unlike the flood tidal delta which forms in the shelter of the estuary, ebb tidal deltas are exposed to wave action. This gives them a similar shape to a bat's wing and causes a bar to form on the leading edge.

Figure 15: Characteristics of the Ebb Tidal Delta (Stephens et al, 2003)

The ability of the estuary to maintain the features described is dependant on the volume of water flowing through the inlet throat. This is known as the **Tidal Prism** and is measured in cubic metres. For example, Raglan Harbour has a mean spring tidal prism of 46 million m^3 (Hicks & Hume, 1996). When this large amount of water needs to pass through a small inlet throat, current speeds are high helping to flush sediment through the inlet and preventing it from closing (Figure 16).

Figure 16: Parengarenga Harbour with a Deep Channel Through the Ebb Tidal Delta (Image Copyright Terry Hume)

Tairua harbour has a small tidal prism of 5 million m^3 (Hicks & Hume, 1996). This means that waves occasionally push the ebb tidal delta into a bar that can close off the entrance at low tide (Figure 17).

Figure 17: Tairua Harbour with a Swash Bar Developed (Image Copyright Terry Healy).

The processes mentioned above all play a role in affecting the rates in which estuaries infill with sediment. It is important to realise that the process of sediment deposition and accumulation is natural. However, an accelerated rate of infilling is often caused by human influence.

The rate of estuarine infilling is controlled by a number of different processes including:

- The availability of the sediment;
- The efficiency of the processes that deliver the sediment;

- The ability of the estuary in retaining or flushing the sediment (Turner & Riddle, 2001).

Sedimentation of estuaries above natural rates is primarily due to catchment modification in the form of deforestation, farming, forestry and urbanisation. This increases the availability of the sediment.

2.1 Sediment Sources

The main sediment sources of an estuary are from existing base material, terrigenous material held in the catchment and sand transported from the open-coast marine environment (as described above). An estuary is also a *source* of sediment for the open-coast system and acts as a transitional environment for sediment to reach the open coast from terrigenous origins.

Figure 18 is a simplistic representation of how the rivers and oceans interact to form the estuarine system (Davis & Fitzgerald, 2004).

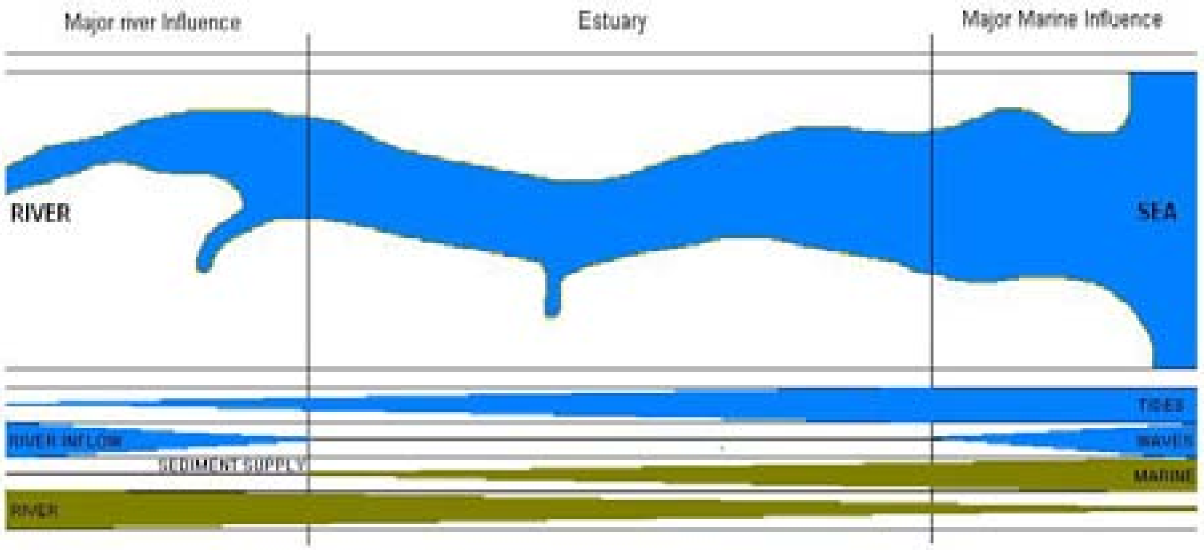


Figure 18: The Sources of Sediment and Water in a Hypothetical Estuary (adapted from Davis & FitzGerald, 2004)

2.1.1 Catchment

The susceptibility of sediments within the catchment to enter the estuary (erodability) is determined by a number of factors. Soil type, vegetation cover and terrain steepness within the catchment controls the amount of sediment finding its way into rivers, streams and estuaries.

Water (from precipitation or ground water) is the primary medium for sediment to become mobile within the catchment, either by direct contact with the sediment through impact and overland flow or by saturation of soils causing mass movement (soil slip) or by bank erosion of rivers and streams. High intensity rainfall events combined with already saturated soils are most likely to cause sediment mobilisation.

Vegetation plays an important part in limiting sediment movement in a number of ways:

- **By acting as a cover (either forest canopy or litter on the ground) reduces the amount of direct contact with exposed sediment.**

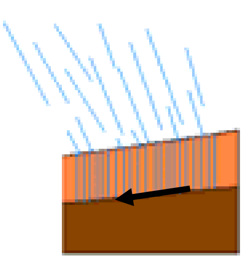
Canopy closure was shown to be very important in preventing the incidence of land slides during Cyclone Bola (March, 1988). Greatest damage in the Coromandel region occurred on hillslopes with forest stands less than 8 years old and incomplete canopy cover. Minimal damage occurred on those stands older than 8 years where canopy closure had occurred prior to Cyclone Bola (Phillips & Marden, 1999)[1].

- **Soil is strengthened by the presence of root structures binding soil together.**

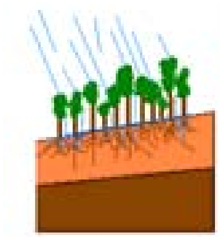
Studies have been made on the effect of tree roots on the strength of the soil. Soil with root structures has the ability to undergo larger shear displacements before reaching failure conditions than those without roots. The elasticity of the root structures also greatly help in strengthening the soil. When trees are harvested, their root structures begin to decay and therefore their addition to the slop stability is diminished. For example, the roots of *Pinus radiata* lose half their strength 15 months after logging.

The type of tree also makes a big difference to the soil strength. For example the shrubby hardwood Kanuka stands provide greater slope stability than *Pinus radiata* stands in the first nine years after establishment. Although an individual Kanuka has a lower cross sectional root structure than *Pinus radiata,* Kanuka **stands** are more stable. The two species achieve a similar safety factor after about 16 years due to the increased root biomass production of the *Pinus radiata* (Phillips & Marden, 1999).

- **Water within soil is taken up by vegetation through the root system.**



With no root system in place, water is not absorbed into the plant and is able to contribute in full to the erosion of the soil. Water that is not absorbed by root structures can permeate through a layer of soil and reach an impermeable layer to cause erosion.



With root structures in place, water can be prevented from reaching an impermeable layer in sufficient quantities to cause erosion. The mass movement of a permeable layer over an impermeable layer is just one of the ways root structures prevent erosion.

Figure 19: Diagrammatic Representation of Root Structures Absorbing Water

- **Dense vegetation acts as a physical buffer to overland flow.**

Overland flow is similar to sheet wash erosion where rain strikes the ground and runs down the hillslope. Vegetation prevents the rain from gathering momentum downslope and subsequently washing away the topsoil.

How water interacts with soil i.e. the hydraulic properties of the soil, determines how susceptible the soil is to erode. Figure 20 is very important in this respect, as it allows us to see how particles of different sizes will move under different velocities. Generally speaking, larger particles are harder to erode. However sand, silt and clay particles that are held together (cohesive), are shown to be more resistant to erosion (right red line).

[1] These data are for plantings of Pine on pasture land.

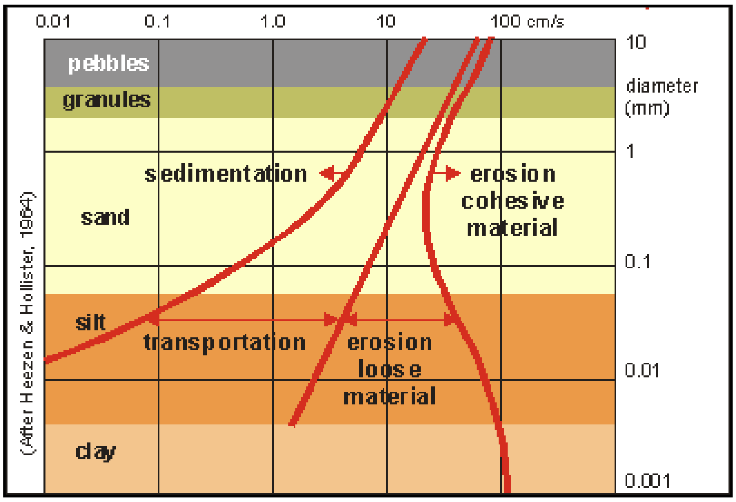


Figure 20: Current Velocities for Erosion, Sedimentation and Transport (http://www.seafriends.org.nz/enviro/soil/erosion.htm#rain)

Other physical properties of the soil determine the failure mechanisms with respect to slope steepness. For example, even a small increase in the ground slope can lead to instability with regard to certain soil types.

2.1.2 Open Coast

An estuary links with the open coast system in three ways. Firstly, sediment from the catchment may pass through the estuary directly to the coast. For instance, during a storm event when much of the fine sediment remains suspended in the water column from initial entrainment in the catchment until it is deposited on the open coast, either along the coastline or the ebb tide delta or further off shore.

Secondly, sediment deposited from the catchment may stay within the estuary for a period of time until wave action and currents re-suspend fine sediment and ebb tide currents deposit the sediment either along the coastline or the ebb tide delta or further off shore.

Thirdly, if an estuary is part of an extensive open coast system. Sediment that has been travelling along the coast (usually clean sand) can get trapped within the estuary (usually in the flood tide delta or sandbanks close to the entrance). The sediment can be transported out of the estuary and back along the coast or remain within the estuary if the ebb tidal current is not strong enough to flush the sediment back out (e.g. USACE, 1975).

2.1.3 The Estuary

The estuary itself can also be an important source of sediment. Wave action within the estuary margin can scour the estuary fringes with this sediment settling on the bed of the estuary. An analysis of all the sediment sources in Chesapeake Bay (USA) showed that 32% of the sediment was from shore erosion (Schubel and Carter, 1977, in Dyer, 1996).

2.2 Main Sources of Sediment to Estuaries in the Waikato Region

The exact sediment budget of estuaries in the Waikato Region is difficult to determine and relatively unknown. However, studies have been performed which provide an estimate of the sediment yields for estuaries in the region (presented in Section 5).

Numerous studies of the estuaries on the Coromandel Peninsula show that sedimentation rates have generally increased over time due to changes in the land use of the catchments. Similarly, a detailed mineralogical analysis of the sediments in Whaingaroa (Raglan) Harbour suggested that 50-80% of the sediment input was from catchment sources (Sherwood, 1973). Therefore we can say that ***catchments are generally providing most of the sediment to estuaries in the Waikato Region.***

2.3 Physical Processes Within the Estuary

2.3.1 Flocculation

Flocculation is the physical process by which sediment particles in the water column combine and settle (figure 21). It is the result of the total surface charge on the particles (Dyer, 1994) attracting each other much like a magnet. Flocculation normally occurs at the fresh water/salt water interface where a number of physical changes in density, temperature, turbulence, fluid shear, pH, organisms and organic matter induce the bonding and settling of fine sediment particles. The composition of sediments also influences flocculation. Sediments containing clay species such as Kaolinite, Illite and Montmorillonite are more susceptible to flocculation.

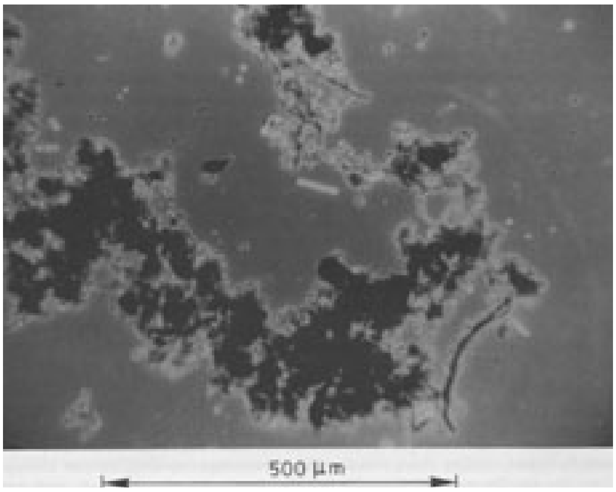
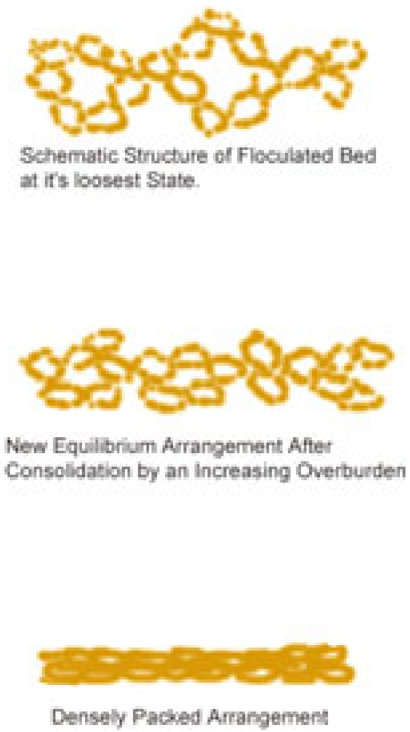


Figure 21: Photograph of Flocs in the River Rhine. (Leussen & Dronkers, 1988)



Flocs are influenced by turbulence in the water column and can be easily broken up in sufficient current flow. During times of low current speeds (i.e. slack water) these flocs can be large enough to settle out of the water column onto the seabed. This layering of flocculates can appear on echo sounders and are known as fluid mud. These can move slowly along the bed but once static begin to consolidate (Einstein and Krone 1962, in Dyer, 1979). Subsequent overlying layers of sediment force the pore water out of the floc and the structure collapses (Partheniades, 1965, in Dyer, 1979). The rearranged, compacted particles give the bed increased shear strength and increased resistance to erosion. Therefore individual fine sediment particles, which would have stayed in suspension and been flushed out to sea, have now been trapped in the estuary. This process is most likely to occur in the upper reaches of the estuary where the tidal flow is weakest.

Figure 22: Effect of the Aggregation Process on the Bed Structure (Adapted from Partheniades, 1965, in Dronkers & Leussen 1988)

As freshwater is less dense than salt water, sediment rich fresh water can form a layer over the salt water. This layering of the water column is called stratification. During heavy rain events stratification can occur over much of an estuary. Therefore, flocculation does not necessarily occur near fresh water inputs. Because there are two distinct layers it could be possible that the bottom salt water layer moves independently from the top layer. For instance, during a heavy rain event on an incoming tide the freshwater layer could be travelling seaward where as the salt water layer is travelling land-wards (figure 23).

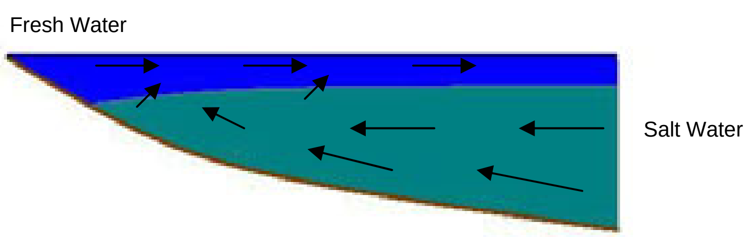


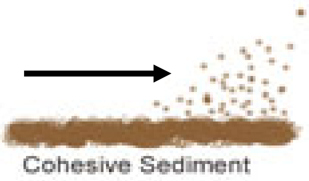
Figure 23: Stratification of an Estuary. Note how the salt water acts as a wedge beneath the fresh water layer (adapted from Silvester, 1974)

At the point of salt intrusion into an estuary the **Turbidity Maximum** can be found. This occurs where the salinity is around 1-5% and leads to suspended sediment concentrations higher than those of the river or further seaward. A number of processes operate in concentrating the sediment in this zone. This process is very important in controlling the circulation of fine sediment in the estuary (Dyer, 1994).

2.3.2 Sediment Transport and Accumulation

Bottom sediments within an estuary can be transported around an estuary by wave and current processes. The proportion of importance with regard to these processes depends on the exposure of the estuary to the open coast wave action. Estuaries tend to be influenced more by the uniform current flow of the flood and ebb tides (Allen, 1973). Turbulence, caused by wave action or currents can re-suspend sediments into the water column. Numerous studies have shown that as the velocity of the current flow is increased there comes a point where the force is strong enough to lift sediment from the bed into the flow of water (Allen, 1973). This point is known as the **threshold of movement** and when applied to the conditions of the bed is the **critical boundary shear stress**. This value changes dependant on the type of sediment involved where two main types exist (figure 24).

- Loose grains (most commonly clean sands and gravel) are known as *cohesionless* and are more readily moved off the bottom into the flow.



- Bonded sediment (mostly muds formed with silt or clay particles) known as *cohesive*. Held together by surface and electrochemical forces more resistant to moving off the bed.

Figure 24: Diagrammatic Representation of Current Flow Entraining Sediment. Note arrow depicts the force required.

Currents then transport the sediment until current velocities slow down enough (below the threshold of movement) to allow the sediment to settle back onto the bottom.

Physical barriers to water movement such as sand banks and vegetation (figure 24) cause currents to slow down, which enable sediments entrained in the water column to settle on the bottom.

The cordgrass *Spartina* is a vigorous invasive high shore plant renowned for its ability to trap sediments. *Spartina* has a wide tolerance of changes in physical factors, and has the potential to colonise intertidal areas and form dense meadows. Sedimentation rates of 3- 15 mm yr-1 have been measured in Spartina marshes in New Zealand estuaries, which is more rapid than for other saltmarsh species (Turner & Riddle, 2001).

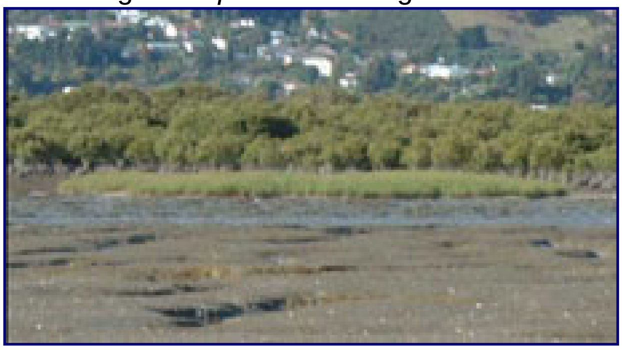
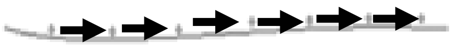


Figure 25: Spartina in the Firth of Thames

Therefore most sediment accumulation occurs on sandbanks or in areas of vegetation. In areas of higher current velocities such as channels, sediments do not tend to settle and are areas of sediment transport.



Sediments that are too heavy or big to be entrained into the water column may still be transported along the bottom of the estuary. This is called **Bedload Transport** and usually occurs in channels where current velocities are high enough to sustain transport.

Figure 26: Diagrammatic Representation of Sediment Transported Along the Bed (Bedload Transport)

2.3.3 Sediment Budget

Sediment input (from the catchment or the open coast), movement (suspended or bedload) and output (flushing) of either course or fine sediment is known as the **Sediment Budget** (French, 1997). Whether an estuary infills depends entirely on the balance of sediment settling out and re-suspended sediment flushing out of the estuary. Obviously if more sediment stays on the estuary bottom then is being flushed out the estuary will start to infill.

Sediment Input > Sediment Output = *Estuarine Infilling*

3 Monitoring Methods

A number of techniques are available to investigate if an estuary is infilling and at what rate. Because it is very hard too regularly monitor an entire estuary, different techniques (some times in combination) are used, depending on spatial and temporal considerations, to measure sedimentation rates.

3.1.1 Sediment Cores

A sediment core is an intact vertical profile through the bottom of an estuary. A core usually consists of a PVC or metal pipe that is forced into the estuary floor. Special mechanisms and procedures are used to pull the pipe out of the sediment with the profile of sediment intact within the pipe. The sediment within the core is then extracted and analysed. It is important that the structure of the core is intact and retained so that analysis techniques (below) can accurately determine sediment layers that have been deposited over the life of the estuary. An example of a sediment core, and analysis, from Whangamata Harbour can be found in Appendix 2.

3.1.1.1 Radiocarbon (^{14}C) Dating

Radiocarbon (^{14}C) dating is a method of dating the remains of plants and animals older than about 500 years. In estuarine and marine environments mainly bivalve and mollusc (shell) remnants are used for radiocarbon dating. By measuring the depth of a shell layer in a core an estimate of sedimentation since the radiocarbon date of the shell can be calculated.

Radiocarbon (C-14) dating is useful for dating material older than 250 years BP (Before Present). Dating was carried out on shell fragments in the Coromandel estuaries (Hume & Dahm, 1992) extracted from various sediment cores and sent to the University of Waikato for analysis.

There are three principal isotopes of carbon which occur naturally - C12, C13 (both stable) and C14 (unstable or radioactive). These isotopes are present in the following amounts C12 - 98.89%, C13 - 1.11% and C14 - 0.00000000010%. Thus, one carbon 14 atom exists in nature for every 1,000,000,000,000 C12 atoms in living material. The radiocarbon method is based on the rate of decay of the radioactive or unstable carbon isotope 14 (14C), which is formed in the upper atmosphere through the effect of cosmic ray neutrons upon nitrogen 14.

The C14 formed is rapidly oxidised to 14CO2 and enters the earth's plant and animal lifeways through photosynthesis and the food chain. Libby, Anderson and Arnold (1949) were the first to measure the rate of this decay. They found that after 5568 years, half the C14 in the original sample will have decayed and after another 5568 years, half of that remaining material will have decayed, and so on. By measuring the C14 concentration or residual radioactivity of a sample whose age is not known, it is possible to obtain the count rate or number of decay events per gram of Carbon. After 10 half-lives, there is a very small amount of radioactive carbon present in a sample. At about 50 - 60 000 years, then, the limit of the technique is reached (beyond this time, other radiometric techniques must be used for dating) (Higham, 2004).

Care needs to be taken when choosing shell to date. In some cases old shell could be reworked with younger shell (for instance if the core was taken near a meandering channel) or the animals may borough themselves deeper in the sediment, causing inaccuracies in sedimentation rates.

3.1.1.2 Pollen Dating (Palynology)

Pollen grains and spores emitted from terrestrial vegetation can be identified and measured within estuarine sediments. Sediment samples taken at regular depths through the core are analysed for pollen and spore types. The analysis produces a record of the abundance of plant species for each depth. A change in the abundance and type of pollen and spores indicates a change in vegetation in the estuary catchment. Cutting and clearing of forest changes the composition of the pollen that is transported to the estuary and therefore laid down in the sediments (Hume & Dahm, 1992). Documented historical changes in vegetation type within an estuary catchment can identify when changes occurred and therefore an estimate of sedimentation since the vegetation change can be calculated.

3.1.1.3 Radioisotope Dating

This method is similar to that of C14 however larger isotopes (e.g. 210Pb - Lead) are used with different half lives. This method is very useful for obtaining high resolution and accuracy of the sedimentation rates in the past 50 years and is presently being used by Environment Waikato. For example, 210Pb has a half life of 22 years and is therefore useful in dating sediments younger than 100 years (Sheffield *et al*, 1995). The measurement of decay in these isotopes is then possible and ages of sediment in the order of hundreds to millions of years can be estimated.

3.1.2 Bed Level Monitoring

Measuring the actual bed level over time can give accurate sediment accumulation rates over a short period of time. This method of sedimentation measurement is used at specific sites within an estuary, which are periodically measured using the methods below. Over a period of time a history of sedimentation rates can be calculated. If measurements are conducted very frequently, specific erosion events can be identified.

3.1.2.1 Transect Surveys

A transect is a path across a portion of an estuary along which distance and elevation measurements are taken (Figure 27). Very accurate survey equipment such as an EDM (Electronic Distance Meter) are usually used to take the distance and elevation measurements. Changes in elevation along a transect can be calculated over a period of time, however care is needed to identify changes along the transect which are not associated with sedimentation such as meandering channels.

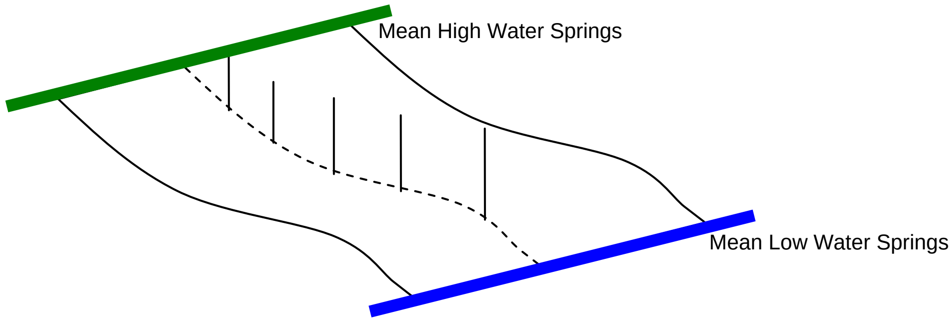


Figure 27: Diagrammatic Representation of an Estuarine Transect.

3.1.2.2 Buried Plates

A simple method of measuring bed elevation, which is currently used by Environment Waikato, is to measure the amount of sediment over a buried level plate. Once a plate has been buried and the elevation measured ('levelled in' using an EDM), probes are pushed into the sediment until they hit the plate and the penetration depth is measured. A number of measurements within the plate are averaged to take into account irregular sediment surfaces.

Once again, care is needed to identify changes in sediment elevation that are not associated with sedimentation such as meandering channels.

Figure 28: Plate Being Buried on a Tidal Flat (http://www.geog.sussex.ac.uk, 2004)

3.1.2.3 Pegs

The previous practice of measuring sedimentation is by placing pegs firmly in the substrate (Turner & Riddle, 2001) and measuring the sediment levels over time. The problem with this is the short term fluctuations in sediment level due to localised scouring from wave and current action around the base of the pegs.

3.1.2.4 Detailed Bathymetric Surveys

With the development of RTK (Real Time Kinematic) GPS, bathymetry surveys are now possible with sub-decimetre accuracy (http://www.trimble.com/ms750.html). The RTK system utilises vertical (as well as horizontal) satellite positioning in conjunction with a depth sounder. Since the horizontal height is measured to an 'imaginary' datum (usually the geoid, which is an established plane for the surface of the planet), any fluctuations associated with the sounder measurements that are not due to actual changes in the bathymetry (e.g. tidal changes, heave due to wind waves, etc.) are automatically corrected for and do not have to be separately processed (i.e. heave correction, tidal correction, etc.). Absolute error can still be as small as 3-5 cm when errors associated with depth sounding are taken into account. This level of accuracy allows for detailed estuary surveys and changes will be detectable over relatively short periods. Again, problems associated with short term fluctuations in sediment levels present themselves, and as is described below, annual sedimentation is often in the order of only several millimetres at most. The high costs associated with such a survey also present problems to this type of study.

It is preferable to use a method in which there are no physical impacts on the estuary leading to a more accurate measurement of sedimentation. A combination of different techniques leads to greater accuracy. A detailed bathymetric survey (carried out annually) with buried plates at a number of sites for example could provide accurate data on the sedimentation of an estuary.

3.1.2.5 LIDAR

Another method of bathymetry surveying is LIDAR, which is an acronym for LIght Detection And Ranging. LIDAR uses the same principle as RADAR. Light is transmitted from the LIDAR to the target. Some of this light is reflected/scattered back to the instrument where it is analysed. The change in the properties of the light due to interaction with the target enables some property of the target to be determined. The time for the light to travel out to the target and back to the LIDAR is used to determine the range to the target.

Airborne LIDAR Hydrography (ALH) was first conceived in the mid-1960's (Pope *et al*., 1999), i.e. the equipment is flown over the survey area to collect data. However, it was not the early 1990's that the technology came of age and operational systems were fielded. These systems were developed to meet specific requirements for nautical charting and port and harbour surveying for their respective governments. While sub-meter accuracies can be achieved, these techniques are better suited to assessing very large areas (for substrate characteristics as well as depths), rather than measuring the very small changes associated with sedimentation.

3.1.3 Grain Size Analysis

A change in surficial sediment composition (percentage of mud, sand and gravel) provides an indicator of changes in patterns of sedimentation within an estuary and provides information on relative inputs from marine and terrestrial sources. For instance, an increase in mud content in a sediment sample compared to a previous sample indicates that there has been increased deposition of fine sediment (mud/silt). A lack of fine sediments in the sample may indicate that the current velocities are strong enough to winnow away these grain sizes (Easton, 2002).

3.1.4 Ecological Monitoring

The abundance and extent of different habitats and biological communities within estuaries is strongly influenced by the sediment characteristics and the tidal regime (Turner & Riddle, 2001). Sedimentation is also strongly controlled by the biological communities themselves. The leaves and stems of emergent plants trap sediment by reducing water flow. The roots and rhizomes bind the sediment particles together to provide stability.

Mangroves - Observed increases in the spatial extent and distribution of mangroves throughout the Waikato Region (Turner & Riddle, 2001) reflect the continued infilling of estuaries with catchment derived sediments. Although, other factors such as increased nutrient runoff can also affect their distribution.

Seagrass – The reasons for the decline in seagrass in a number of Waikato's estuaries is largely undocumented. In some cases sediment deposition may have smothered the plants. For example, a storm in March, 1995, had a large impact on the siltation of Whangapoua Harbour (Morrisey *et al,* 1995). The increased rainfall caused severe erosion in the catchment and this sediment subsequently was deposited in the estuary. In other areas there is anecdotal evidence that extent of seagrass is increasing, which may be linked to better land management with respect to sediment run-off (e.g. Whaingaroa Harbour)

Species Composition – Monitoring of species composition has also been used to consider sedimentation in estuaries, although this is often in association with specific events or modifications to the estuary or catchment. Different species are associated with different types of sediment, especially infaunal species such as bivalves and polycheates (marine worms). Thus, by assessing the biological community composition and how it changes with time, sedimentation rates can be evaluated.

Figure 29: Eelgrass-bed Showing Silt 3.5cm Deep in the Depressions of the Tidal Flat (Morrisey et al, 1995)

4 Sedimentation Information

This section summarises the data available on sedimentation rates in the Waikato Region. Hydrodynamic information (where available) such as estuary area, tidal prism, tidal range is available in Table 1 below. The figures of each individual estuary were sourced from Land Information New Zealand (http://www.linz.govt.nz).

4.1 West Coast

The geology of the west coast of the central north island is relatively uniform. Whaingaroa (Raglan) Harbour's catchment (Sherwood & Nelson, 1979) is dominated by:

- indurated Mesozoic sandstones and mudstones in the **east**
- soft calcerous mudstones and muddy fine sandstones of the Oligocene Te Kuiti Group in the **north**
- andesites and basalts of the Upper Pliocene-Lower Pleistocene Alexandra Volcanics in the **south**

Quaternary volcanic ashes thinly mantle much of the area. Most of the 90km of shoreline to Whaingaroa Harbour are easily erodible mudstones of the Te Kuiti Group which commonly form extensive shore platforms in the region. Changes in land-use have altered the sedimentation rates of the estuaries on the West Coast of the Waikato region over time. There is a limited amount of sedimentation data on these estuaries due to the lack of coring studies (Turner & Riddle, 2001).

Whaingaroa Harbour is the most intensively studied of all West Coast estuaries. As mentioned previously, the harbour was formed by the drowning of a river valley during the post-glacial rise in sealevel.

Sands in the lower harbour are progressively replaced by more muddy sediments in the upper reaches. 50-80% of the sediment in the harbour is from catchment sources (Sherwood, 1973); while erosion of the mudstone shoreline through wetting and drying is likely to be a significant input (Sherwood & Nelson, 1979).

Whaingaroa, Aotea and Kawhia Harbours were formed by the post-glacial drowning of the lower part of a branching river system. These harbours are exposed to increasing pressure from a number of activities, especially land-use changes in the surrounding catchments. Careful management of these harbours is needed due to the inherently unstable catchment materials and the sensitivity of the sediment yield to land-use. The areas of concern are the greywackes under high producing pasture and forestry (Curtis, 1986 in Turner & Riddle, 2001).

4.1.1 Whaingaroa (Raglan) Harbour

Sedimentation Rates
Cores have been taken at various sites within the harbour. Results presented relate to the Waingaro River arm of the estuary as the study is yet to be completed (Swales, 2004).

Pre Polynesian (5000-2000 years BP) – Estuary largely infilled during this time as the existing river valley was drowned during sea level rise.

Polynesian Settlement - Present – No sign of infilling. All but the upper several centimetres of sediment deposited during the pre-Maori, Maori and most of the European era horizons are missing or never formed in the upper estuary. This absence is most likely due to the 'modern' eroded soils being exported or moved elsewhere in the estuary. Wave re-suspension and transport by tidal currents are likely to be transporting the sediment to long term sinks. These areas are sheltered bays, inlets, fringing habitats and tidal creeks. This re-suspended sediment may also be exported from the estuary entirely.

Existing information (Curtis, 1996 in Turner & Riddle, 2001) suggested that at the time (1986), net sedimentation was occurring (<1 mm/year).

It is worth noting that Aotea and Kawhia harbours are in a similar geological setting to Whaingaroa Harbour (Sherwood & Nelson, 1979) and were formed in the same way. Therefore results may be loosely transferable.

4.1.2 Kawhia Harbour

Sedimentation Rates
Increased sediment run-off has been noted from swamp drainage associated with land clearance on the Te Maika peninsula (Curtis, 1986 in Turner & Riddle, 2001).

Existing information (Curtis, 1986 in Turner & Riddle, 2001) suggested that at the time (1986), net sedimentation was occurring (<1 mm/year).

4.2 Coromandel Peninsula

The Coromandel Peninsula separates the relatively calm waters of the Firth of Thames and Hauraki Gulf in the west from the Pacific Ocean in the East. Steep, rugged topography dominate the region with maximum altitudes of 600-800m typical of the main axis of the peninsula (Hume & Dahm, 1992).

The precipitation is characterised by high intensity rainfall events particularly associated with cyclonic systems. 24 hour falls over large areas have been recorded up to 300mm, with peak falls near the main axis in excess of 550mm (Collen & Hessell in Hume & Dahm, 1992). The high rainfalls and steep land catchment result in significant runoff from the Coromandel catchments.

The rocks of the peninsula consist of a basement of Mesozoic greywackes that are overlaid by andesitic rocks of Miocene age, which are then in turn overlaid by younger Pliocene rhyolitic rocks. Igneous plutonic rocks intrude locally. There are also small discrete areas of hydrothermal alteration. Associated with this is widespread “porphyry” mineralization containing base metal sulphides and gold “epithermal” vein mineralization. Metals found include gold, silver, copper, lead, zinc, and to a lesser degree mercury, arsenic, antimony and trace amounts of selenium, tellurium, bismuth, molybdenum, tin and tungsten (Carter *et al*, 1987 in Hume & Dahm, 1992). Natural runoff leeches these elements into water courses and eventually estuaries. Mining activities may increase the likelihood of contamination by excavation and by erosion of, and leachate from, mullock tips, ore dumps and tailings (Carter *et al*, 1981 in Hume & Dahm, 1992).

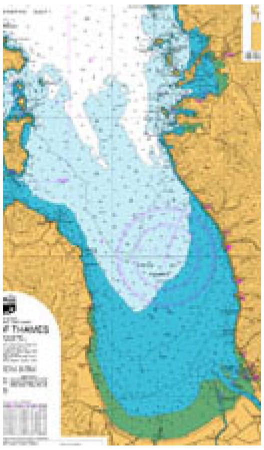
The estuaries of the Coromandel are described in terms of sedimentation rates through time. Catchment use during these periods is described as follows.

Pre Polynesian. The peninsula was densely forested. Archaeological and other historical data indicate that the region was settled by the Polynesian from c.700 yr BP (McGlone, 1988, 1989 in Hume & Dahm, 1992). During this period of occupation by the Polynesian (c.700-110 yr BP) there was small scale land clearance in coastal areas in preparation for crops although accidental large burn-offs did occur (Sale, 1978 in Hume & Dahm, 1992).

Early European. 1830/50-1910. Forest disruption and land use intensified and there was large scale uncontrolled burn off and bush clearance associated with Kauri logging, gum digging and mining activities (Sale, 1978 in Hume & Dahm, 1992). This, combined with the steep catchments and high rainfall, led to severe erosion. A number of mines also discharged their tailings straight into the estuaries.

Late European (1910-Present) and ***Recent*** (1950/1970-Present). This time period has shown pastoral development as the typical land use. Many catchments have also been allowed to revert to bush and become comparatively stabilised. Recent times have seen considerable short term disruption over large areas associated with the establishment of exotic forestry (particularly in the Coromandel, Whangapoua, Tairua, Opoutere and Whangamata Harbour catchments) (Hume & Dahm, 1992).

4.2.1 Firth of Thames



Sedimentation Rates

Core taken in 1.5 m water depth (relative to chart datum) 7.5 km off the mouth of the Waihou River and immediately to the west of the Tararu River mouth (Hume & Dahm, 1992)

Pre Polynesian – 0.09 mm/year

Polynesian Settlement – 0.13 mm/year

Post-European Settlement – 0.5 mm/year (low rate probably due to the limited localized nature of forest clearance practices).

Core taken in 6m water depth 12 km off the mouth of the Waihou River (Hume & Dahm, 1992).

Pre Polynesian – 0.18 mm/year

Polynesian/Post-European Settlement – 0.05 mm/year (lower than background than the sedimentation rate).

Core taken in 3.5 m water depth about 1.7km off the coast of Waiomu (Hume & Dahm, 1992).

Pre Polynesian – 0.10 mm/year

Polynesian Settlement – 0.38 mm/year

Post-European Settlement – 1.3-1.5 mm/year (proximity to the steep streams draining the western side of the Coromandel peninsula).

4.2.2 Te Kouma Harbour

The only data available of Te Kouma Harbour is of the estimated increase in Mangrove coverage from 1971 to 1995 being 66.5 % (Turner & Riddle, 2001).

(The spread of Mangroves cannot be attributed solely to increased sedimentation. Increased nutrient runoff for example can also affect the abundance and spatial extent of mangroves)

4.2.3 Manaia Harbour

Between 1971 and 1995 the spatial extent of mangrove in the harbour has grown 194.6% (Turner & Riddle, 2001).

(The spread of Mangroves cannot be attributed solely to increased sedimentation. Increased nutrient runoff for example can also affect the abundance and spatial extent of mangroves).

4.2.4 Coromandel Harbour

Sedimentation Rates
Core taken close to the shore at the southern end of the intertidal flats in McGregor Bay – about midway between the oyster farm and the jetty. 1.0 m above chart datum (Hume & Dahm, 1992).
Pre Polynesian – 0.02 mm/year
Polynesian Settlement – 0.07 mm/year
Post-European Settlement – 0.82 mm/year (unsure as to whether the increase is due to early or more recent post European land management practices)
Core taken 1-1.5 km offshore in the subtidal regions of McGregor Bay. Bed level ~2.0m relative to chart datum (Hume & Dahm, 1992).
Pre Polynesian – 0.07 mm/year
Polynesian Settlement – 0.05 mm/year
Post-European Settlement – 0.31 mm/year (unsure as to whether the increase is due to early or more recent post European land management practices)
Core taken close to the shore on the intertidal flats between Preece's Point and Te Kouma Bay. ~0.0 m relative to chart datum (Hume & Dahm, 1992).
Pre Polynesian – 0.94 mm/year
Polynesian Settlement – 0.39-0.57 mm/year
Post-European Settlement – 1.01 mm/year
Recent (~1970 – 1988) – 11.7 mm/year(?) (Large figure due to pine pollen found in the top 8 cm to 12-14 cm and possibly deeper. However this could have resulted from mixing processes translating the pine pollen to the lower sediments)

4.2.5 Whangapoua Harbour

Sedimentation Rates
Core taken from the intertidal flats in the upper estuary at the mouth of the Opitonui River (Hume & Dahm, 1992).
Pre Polynesian – 0.03 mm/year
Polynesian Settlement – 0.13 mm/year
Post-European Settlement – 1.3 mm/year
Recent (1960 – 1988) – 0.89 mm/year

Core taken about the mid tide level on the tidal flats at the mouth of the Opitonui River (Hume & Dahm, 1992).
Pre Polynesian – 0.08 mm/year
Polynesian Settlement – 0.12 mm/year
Post-European Settlement – 1.5 mm/year
Recent (1950 – 1988) – 1.33 mm/year
Four cores taken and the pollen records analysed (McGlone, 1988 in Turner & Riddle, 2001).
Pre European – ~0.16 mm/year
Post-European Settlement – as high as 1.0 mm/year

4.2.6 Whitianga Harbour

Sedimentation Rates
Four cores taken and the pollen records analysed (McGlone, 1988 in Turner & Riddle, 2001).
Rates since the 1950 are up to 10 times greater than pre-human sedimentation rates.

4.2.7 Tairua Harbour

Between 1983 and 1996 the spatial extent of mangrove in the harbour has grown 214.9% (Turner & Riddle, 2001).

(The spread of Mangroves cannot be attributed solely to increased sedimentation. Increased nutrient runoff for example can also affect the abundance and spatial extent of mangroves)

4.2.8 Wharekawa Estuary

Sedimentation Rates
5 cores taken at various sites within the estuary (Swales & Hume, 1995).
Pre Polynesian settlement - 0.09–0.12mm/year
Catchment Deforestation (1880-1945) – 3.6-7.2mm/year
Recent (1945-1995) – 5.0-8.0mm/year (Production forestry established during this period. 20mm/year sedimentation at the Wharekawa River mouth during this period)

4.2.9 Whangamata Estuary

Sedimentation Rates
3 cores taken from representative locations within the harbour. (Sheffield *et al*, 1995).
Pre Polynesian settlement - 0.1mm/year (~700 years BP)
Polynesian settlement – 0.3mm/year (probably due to land use practices)
After 1880 – 6 - 11mm/year due to clearance of the relatively steep catchment and development of commercial forestry.

4.2.10 Otahu River

Between 1983 and 1996 the spatial extent of mangrove in the harbour has grown 214.9% (Turner & Riddle, 2001).
(The spread of Mangroves cannot be attributed solely to increased sedimentation. Increased nutrient runoff for example can also affect the abundance and spatial extent of mangroves).

It can be seen that there is far more data on those estuaries of the East Coast compared to that of the West. Table 1 summarises the physical parameters of Waikato estuaries. Figure 30 summarises all of the information and the types of data that the sedimentation rates have been drawn from.

Table 1: Hydrological characteristics of Waikato Estuaries.

No.	Estuary	Area ($x10^6m^2$) (at High Tide)	Area (ha)	Tidal Prism (10^6m^3) (Mean Spring)	Tidal Range (m) (Mean Spring Tidal Range)
West Coast					
1	Mokau River Mouth				
2	Awakino River Mouth				
3	Marakopa River Mouth				
4	Kawhia Harbour	67	1532	121	2.9
5	Aotea Harbour	36	768	59	3.6
6	Raglan Harbour	24	806	46	2.8
7	Port Waikato		510		
Coromandel West					
8	Firth of Thames	741	1476	1951	2.8
9	Piako River		(Part of 8)		
10	Waihau River	19	(Part of 8)	28	2.8
11	Miranda		(Part of 8)		
12	Waitakaruru River		(Part of 8)		
13	Manaia Harbour	4.4	125	6.4	2.3
14	Te Kouma Harbour	2.7	50	5.3	2.3
15	Coromandel Harbour	23.6	450	47.8	2.3
16	Colville Bay	4.5	75	8.3	2.3
17	Port Jackson				
Coromandel East					
18	Stony Bay				
19	Port Charles		19		
20	Kennedy's Bay		38		
21	Whangapoua Harbour	13.1	280	8.5	1.72
22	Whitianga Harbour	15.6	1485	12.6	1.6
23	Puranga River (Cook's Beach)		45		
24	Tairua Harbour	6.12	106	6.1	1.6
25	Wharekawa Estuary	1.8			>2.0
26	Whangamata Harbour	4.3	106	3.9	1.6
27	Otahu River		(Part of 26)		

Sources (McClay, 1976) (Hicks & Hume, 1996) (Hume & Herdendorf, 1993) (Sheffield et al, 1995) (Swales & Hume, 1995)

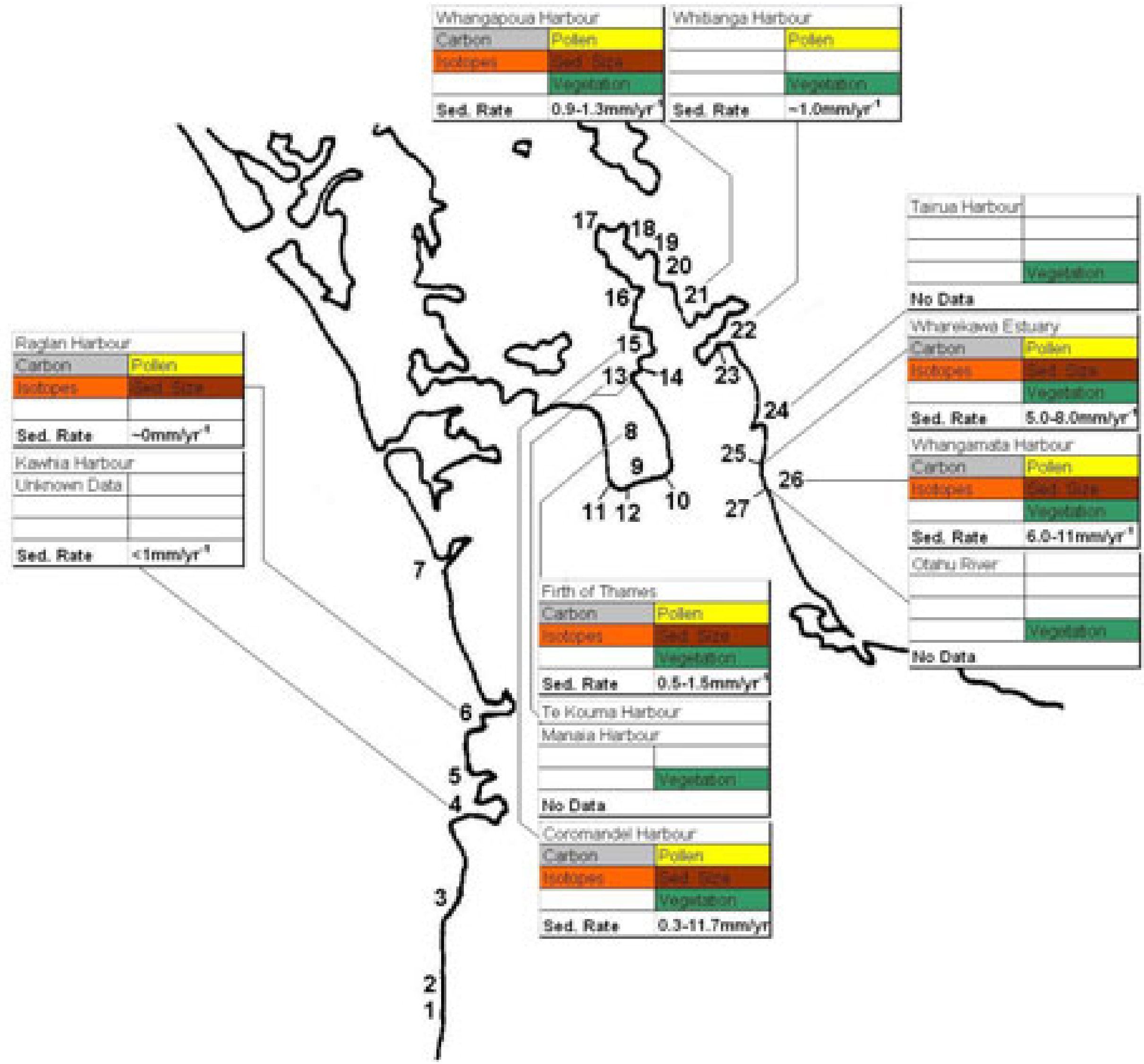


Figure 30: **Summary Map showing the Type of Studies Undertaken and the Inferred Sedimentation Rates for Estuaries in the Waikato Region (various sources as discussed in text)**

4.3 Data Limitations

It must be noted that a number of factors contribute to the lack of accurate sedimentation data. These are outlined as follows.

- In order to calculate sedimentation rates accurately from core samples, detailed historical accounts of catchment use are needed. This is to correlate land-use changes with dated sediments (Turner & Riddle, 2001).
- Sediment coring is very expensive and the data that is presented here is from a very small number of cores from each estuary. Therefore, they may not be fully representative from each estuaries range of sedimentation rates. A study carried out on Whangamata Harbour (Sheffield *et al* 1995) showed considerable variation in different environments within the estuary. A very high rate of sedimentation in one of the cores was most likely due to channel migration rather than net estuarine sedimentation.
- Even away from such influences as channel migration, cores can vary considerably. Greater replication is needed before solid conclusions can be made.

- Difficulty has also been described in the counting and identifying of pollen and spores in estuarine sediments (McGlone, 1988 in Turner and Riddle, 2001). This is partly due to the breaking down of pollen grains; and the significant amounts of undigested material present in the sediment which is inorganic and obscures the pollen grains.
- Blurred horizons due to sediment reworking near the surface have also affected the dating of sediment in cores (Swales & Hume, 1995 in Turner & Riddle, 2001).
- There can be a delay in the impact of a catchment event (e.g. deforestation) and the sedimentation of the estuary due to storage within the stream systems.
- High rates (11-12 mm/yr) of sedimentation have been tentatively attributed to mixing processes (Hume & Dahm, 1992 in Turner & Riddle, 2001). However, if this assumption is incorrect, the observed results represent rates of sedimentation associated with pine reforestation that could be of concern. Because of the importance of this on future forestry activities more detailed work is required to resolve the issue.

5 Waikato Regional Sediment Yields

Section 2.2 stated that catchments provide the most significant source of sediment in Waikato's estuaries. This section summarises sediment yield data from the estuaries in the Waikato Region and can provide some insight into sedimentation rates in particular areas.

5.1 Estuary Data

Table 2: Catchment yield data (Environment Waikato, 2004)

Estuary	tonnes/year	Catchment Area (km^2)
Aotea	33408.52	168.88
Awakino	105188.59	382.65
Colville	4656.85	44.16
Coromandel Harbour	9473.49	73.57
Kawhia	98353.09	480.07
Kennedy Bay	4535.59	57.10
Manaia	6717.86	61.54
Marakopa	168449.19	363.73
Mercury Bay	32232.23	492.01
Mokau	654419.16	1443.98
Otahu	6650.57	70.25
Piako	35327.15	1479.20
Port Waikato	370000.00	14426.28
Port Charles	1769.36	32.53
Raglan	122926.68	525.99
Stony Bay	2348.64	17.22
Tairua	22125.27	282.35
Te Kouma	181.04	6.29
Waiaro	2180.27	11.74
Waihou	151628.72	1972.95
Waikawau Estuary	1238.47	28.12
Waikawau_river	34106.03	81.99
Waitakaruru	9208.60	166.65
Whangamata	4656.85	51.69
Whangapoua	5798.28	106.56
Wharekawa Harbour	8583.55	92.06
Firth of Thames (total)	230498.20	4106.52
Miranda - Kaiaua coast	15941.72	162.75
Thames coast	18392.00	324.98

Relative sediment yields (tonnes/year/km^2 of catchment) are shown graphically in Figure 31. It must be noted that sediment yield from the catchment is only part of the process leading to sedimentation in estuaries. The tidal flushing plays a key part in determining how much of the sediment input is retained in the estuary.

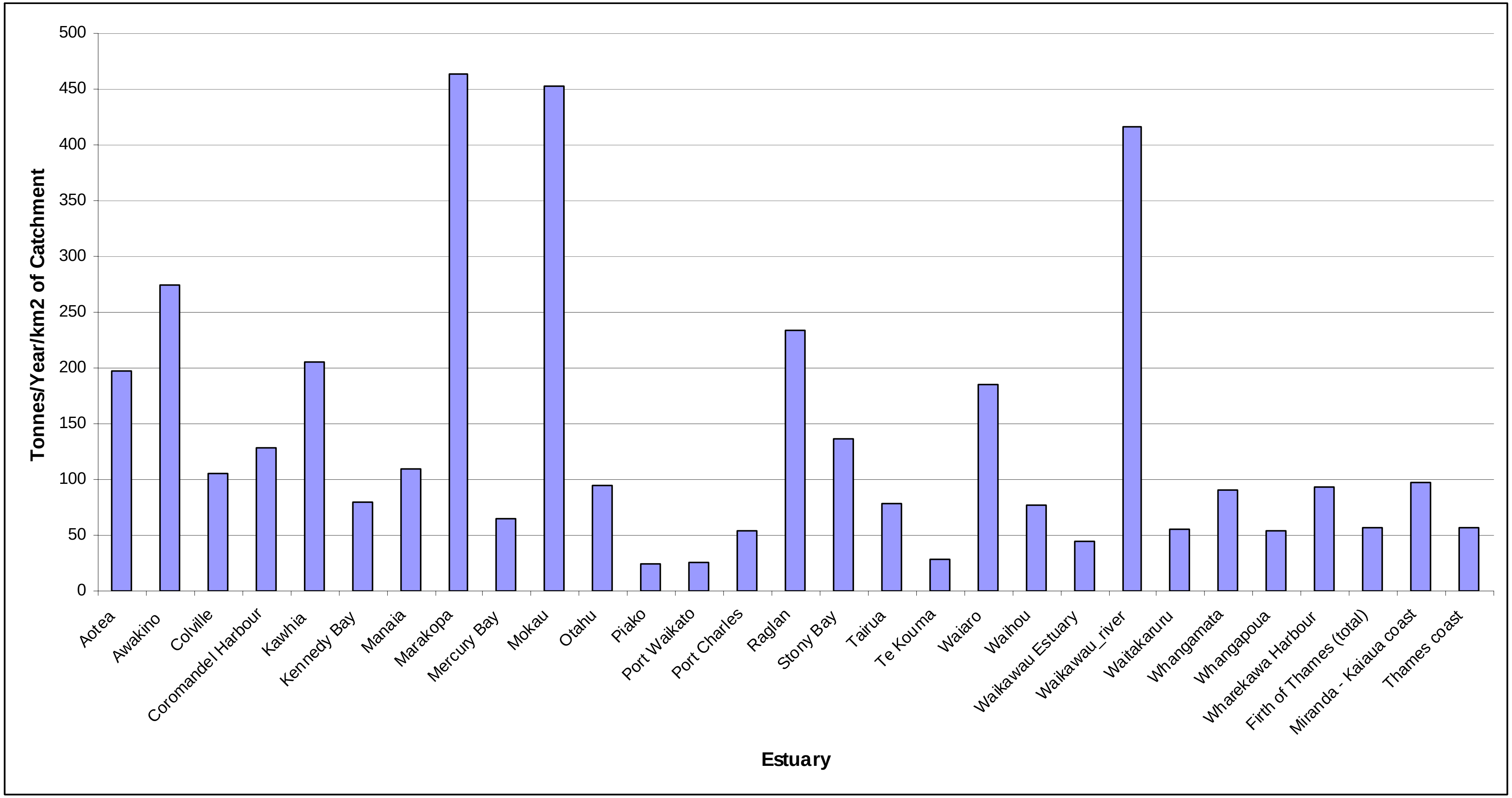


Figure 31: Relative sediment yield for Waikato estuaries.

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6 Areas Where More Information is Needed

This section lists the estuaries where no sedimentation data exists. An aerial photograph of each estuary is also provided.

6.1 West Coast

Mokau River

Awakino River

Marakopa River

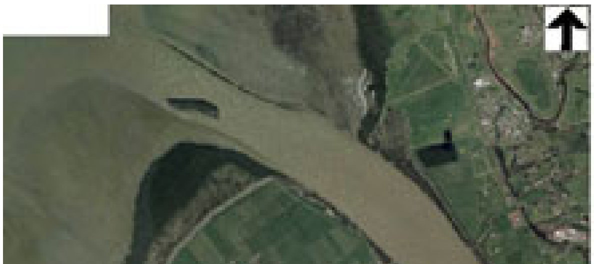
Aotea Harbour
(See results from Whaingaroa (Raglan) Harbour)

Port Waikato

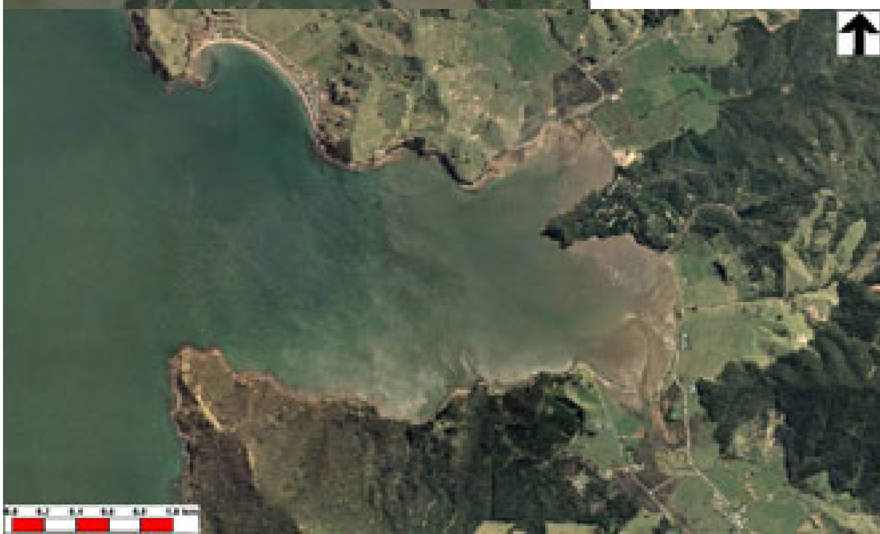
6.2 East Coast

Miranda

Waitakaruru River



Waihou River



Colville Bay

Port Jackson

Stony Bay

Port Charles

Kennedy's Bay

Purangi River

Figure 32 summarises all of the sites where data is unavailable.

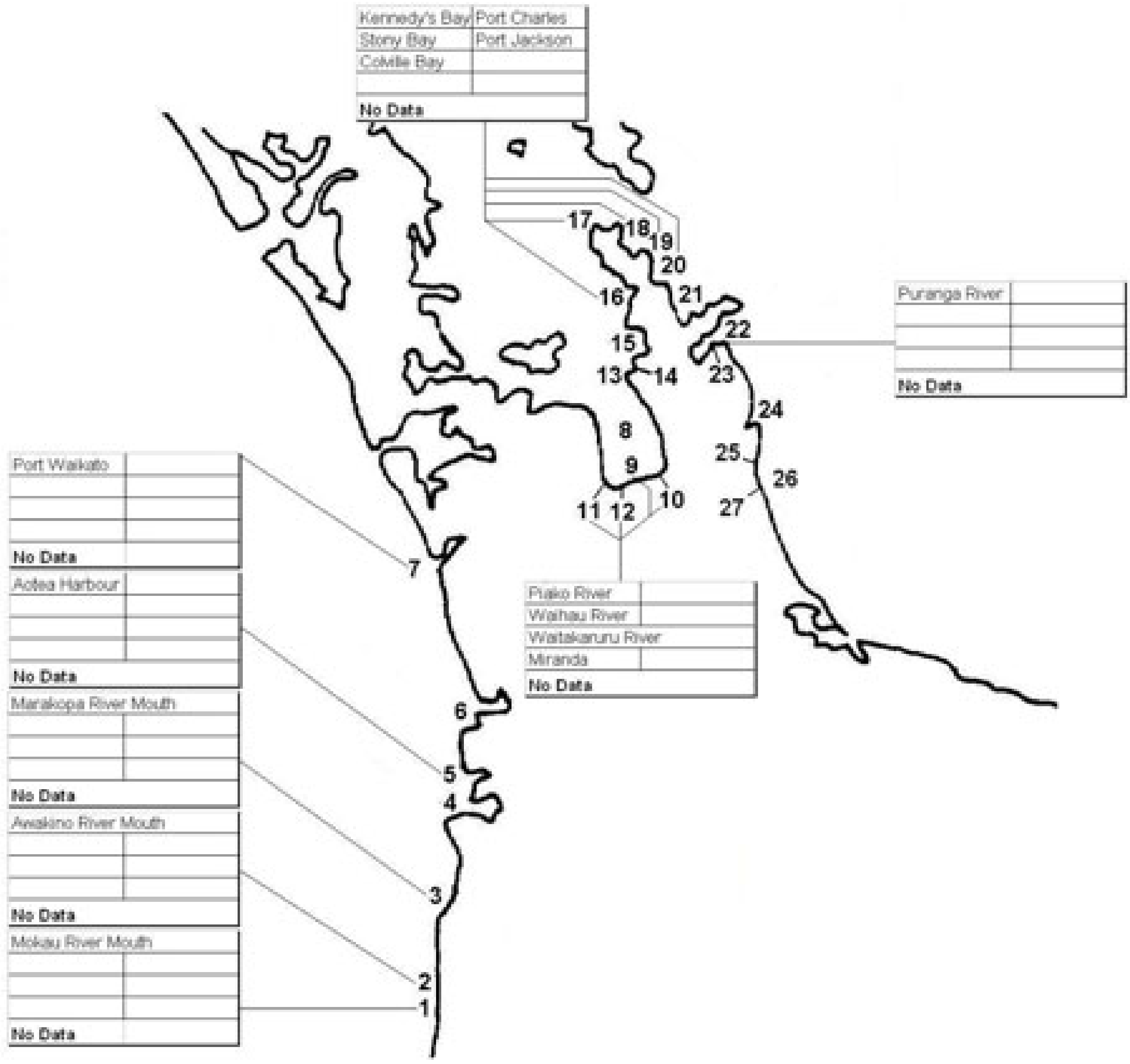


Figure 32: Summary Map Showing the Estuaries of the Waikato Region Where No Data is Available

The Regional Estuary Monitoring Programme was started by Environment Waikato in 2001 with a view to obtaining data on the Firth of Thames and Whaingaroa (Raglan) Harbour. The aim is expand the study to other estuaries in the region. Once established, high quality state of the environment information on estuaries in the Waikato Region will be available (Turner & Riddle, 2001).

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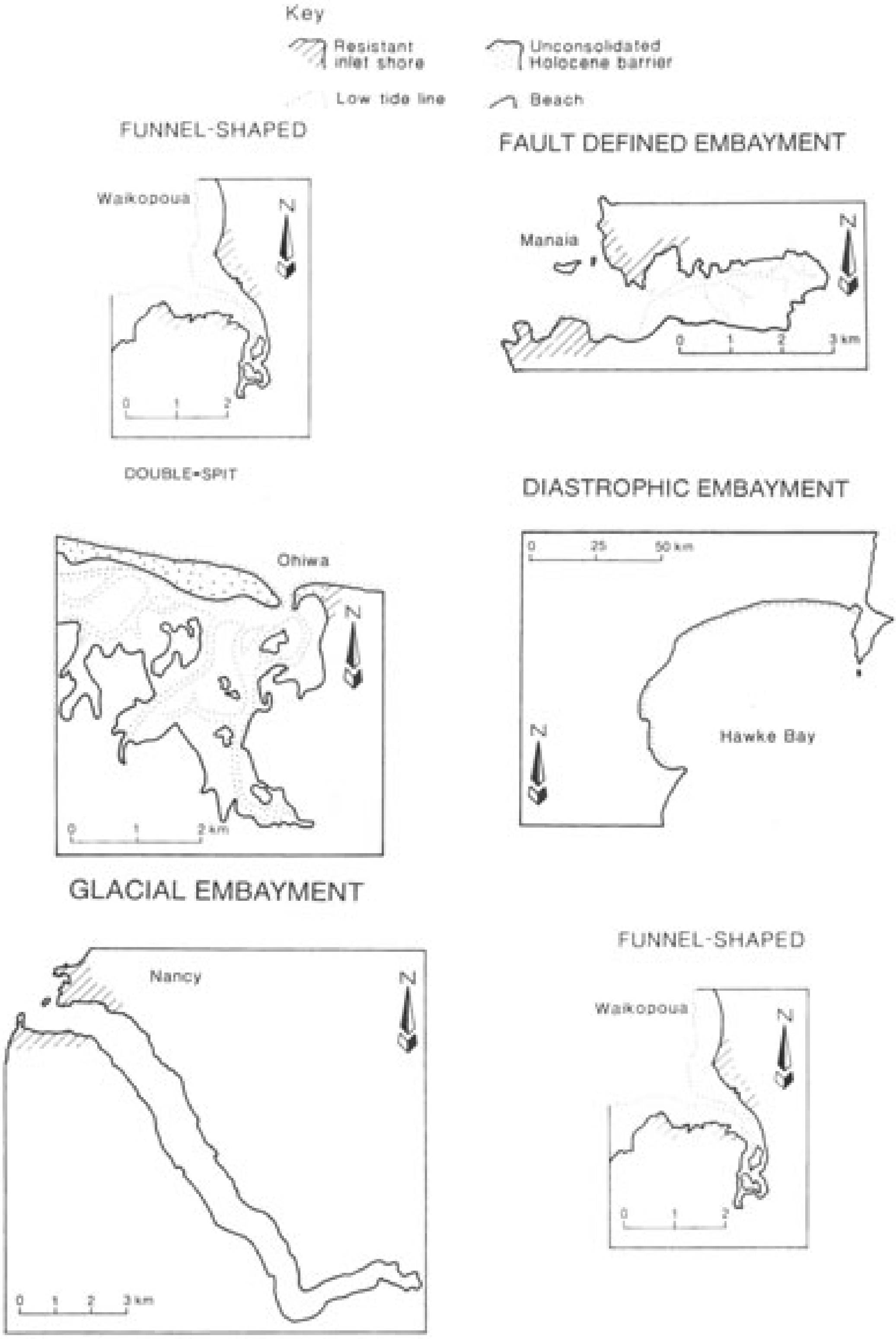
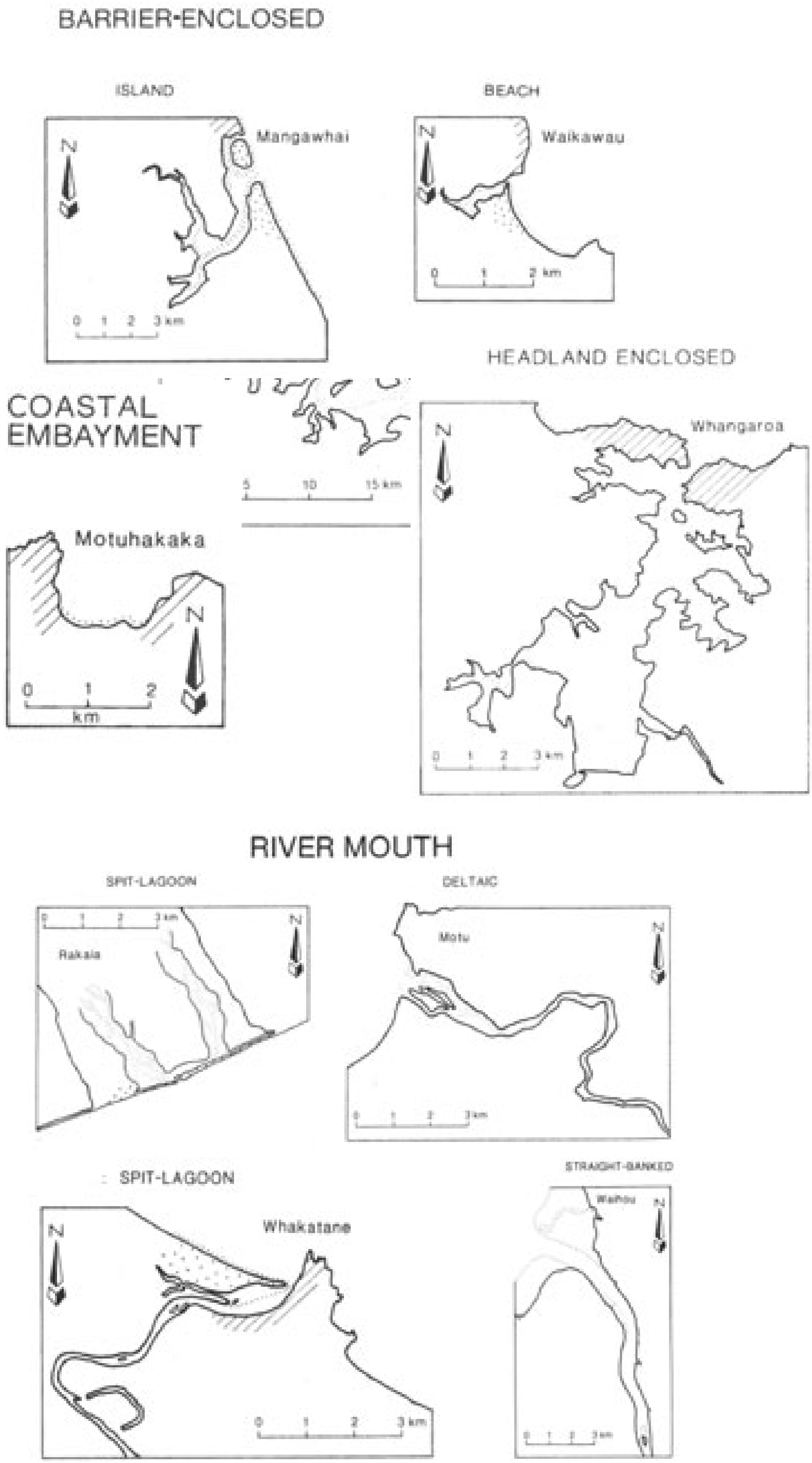
Appendix 1 – A Variety of New Zealand Estuary Types

(Hume & Herdendorf, 1988)




BARRIER-ENCLOSED
ISLAND
BEACH
Mangawhai
Waikawau
N
0 1 2 3 km
0 1 2 km
HEADLAND ENCLOSED
COASTAL
EMBAYMENT
5 10 15 km
Whangaroa
Motuhakaka
0 1 2
km
RIVER MOUTH
SPIT-LAGOON
DELTAIC
Rakaia
Motu
SPIT-LAGOON
STRAIGHT-BANKED
Whakatane

Appendix 2 - Whangamata Estuary Core

A 1.5m core taken from Whangamata Estuary on the Causeway. This core shows the evolution of the catchment from diverse coastal forest to modification by Polynesians and the introduction of European vegetation and exotic forestry (Sheffield et al., 1995)