Hutt River Sediment Transport
- source to beach

Prepared for Greater Wellington
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- source to beach

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1 Introduction

In the past, concern has been raised regarding the potential effect of sediment extraction and by-product deposition activities on the character of Petone Beach; particularly near the Winstone's sediment mining plant. Concern related to increasing stoniness and the build-up of silt; the impact of this on the landscape and beach profile; and the adequacy of data to monitor these potential effects.

The resource consents granted for both sediment extraction and the dumping of waste by-product include conditions requiring specific monitoring of the potentially affected environments. These include: cross-sectional surveys of the river bed at 5-yearly intervals; full hydrographic surveys of the greater river mouth area at 10-yearly intervals; aerial photography of the greater river mouth area at 2-yearly intervals; and six beach profile surveys, including photographs and sediment size analysis of samples from MSL on each profile at 6-monthly intervals.

This report discusses the physical environmental processes operating in the Hutt River, and at the coast. It reviews the results of past monitoring, and assesses the potential environmental effects of continued sediment extraction from the river mouth. Finally, it provides recommendations as to possible conditions and monitoring for any future consent.

2 Sediment transport

Understanding the sediment transport processes operating within the Hutt River, and the volume of material involved, is critical to making an assessment of the potential environmental effects of sediment extraction from the river mouth.

2.1 Sediment transport processes

Every river has the capacity to erode, transport, and deposit sediment. A wide range of properties, however, control the amount and type of sediment transport. The actual mode of transport depends on the interaction of available energy of water in the river and material resistance. The total amount of sediment (i.e., load) transported by a river can be divided into components depending on its mode of transport (Figure 1).

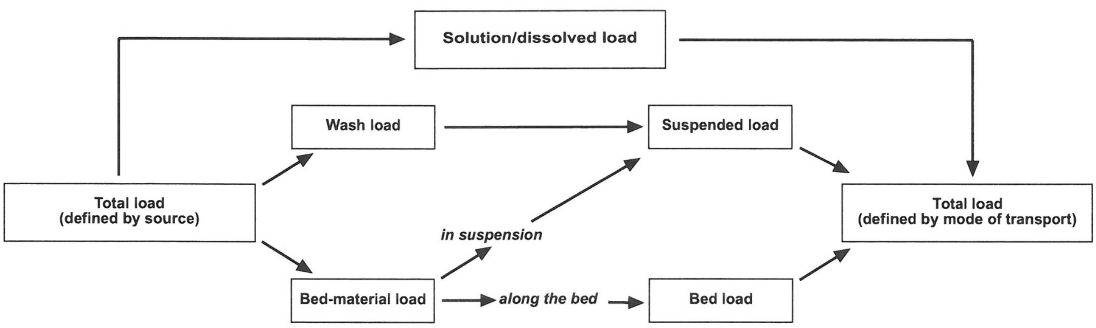

Figure 1: The total sediment load of a river can be divided into fractions depending on the primary mode of transport.

1. Solution/Dissolved load includes all material which is actually dissolved in the flow, i.e., the ions in the water. Dissolved load is derived from several sources: rock and soil weathering, from the atmosphere, and from human activity on the land (e.g., fertilizers, industrial plants). The majority of dissolved load comes from subsurface flows of water in the river as this water has had the longest contact time with the soil and rock.

2. Wash load is the material which stays in suspension all the time. That is, the material is floated rather than hydraulically pushed. Therefore wash load, like solution load, is not controlled by stream power and is often defined as that material which is smaller than fine sand (<0.062mm) i.e., silt and clay.

3. Suspended load is all the material which is held in the flowing water by turbulence and moves at basically the same rate as the water. However, because suspended load transport requires energy it varies with the flow in the river. Determining suspended load is problematic as there are times when particles move in suspension and others when they drop back onto the bed, or may even stop moving completely.

4. Bedload is that material which rolls, saltates (hops), and slides along the bed of the river. It is material which is hydraulically 'pushed' and therefore its movement requires stream energy.

The distinction between the modes of transport is rather arbitrary with material moving from one mode to the other as a function of available energy. Bedload transport is a function of energy; both the energy necessary to entrain particles, and the energy necessary to transport them. It is often therefore assumed that the rate of bedload movement is solely a function of the energy of the river. However, in many situations the actual transport rate is also a function of the availability of material (supply limited). The Hutt River is not generally supply limited as in the lower valley it flows within a bed and between banks composed of material it has previously deposited.

In summary, the sediment load of the Hutt River is all the inorganic material which is transported by the flowing water i.e., boulders, sand, silt, clay, etc. From the perspective of channel stability, and the potential environmental impacts of sediment extraction from the river mouth, it is the suspended and bedload components of the total load that are critical.

2.2 Controls on sediment transport

Although properties other than size influence sediment mobility (e.g., particle density and shape, degree of packing) size is often used as a convenient measure from which to estimate likely entrainment thresholds (Figure 2).

Entrainment thresholds are commonly defined for the median size (D_{50}) of bed and bank material. In some situations, including the Hutt River, coarser material forms a protective armouring layer on the surface of the river bed. It is therefore useful to estimate entrainment velocities for the D_{90} grain size (the coarsest 10% of material sampled). It is also important to note that although intermediate particle sizes (i.e., fine sand or coarse silt) are generally considered the easiest to entrain; smaller particles, once entrained, remain in suspension much longer.

Sediment transported down the Hutt River as suspended and bedload therefore includes silt, sand, and gravel. This material is eroded either from the flood plain or the slopes of the upper catchment. The method by which this material moves depends largely on its particle size and the energy of the water in the river, consequently sediment transport processes tend to operate only during flood conditions when there is sufficient energy to erode and transport the material. Fundamental to understanding the sediment transport regime is therefore knowledge of the flow regime, and how this varies over time.

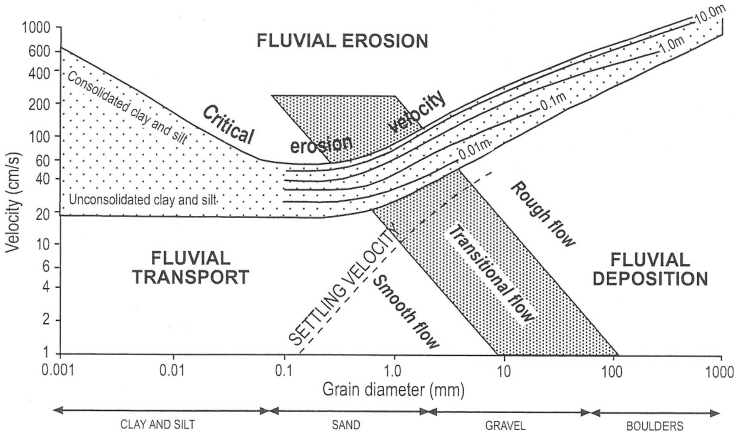

Figure 2: **Erosion, entrainment, and transport thresholds for different size particles (After Sundborg, 1956).**

2.3 Fluvial form and process

The interaction of stream flow with the landscape, and the erosion and transport of material tends to produce distinctive changes down a river profile. In general, the processes are characterised by the erosion and transport of the material from the upper catchment, conveyance through the mid reaches, and deposition within the lower channel or at the river mouth (Figure 3). This same sequence of processes is apparent within the Hutt catchment.

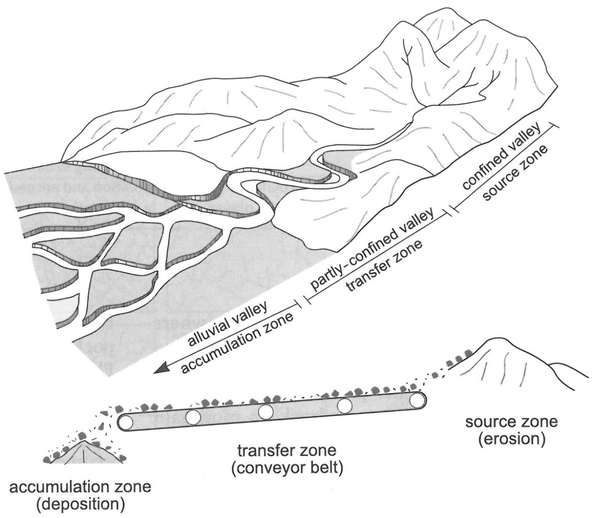

Figure 3: **Characteristic erosion and sediment transport processes down a river profile (Brierley & Fryirs, 2005).**

This sequence of processes and landscape features has also been affected by a number of climatic fluctuations which have affected the erosion and transport of material. During glacial periods erosion processes are greatly accelerated in the Tararua Ranges; enhanced by reduced vegetation cover. This provides large amounts of sediment and debris which is transported out of the mountains by the river. Reduced channel gradient and energy in the lower valley means that much of this material is deposited forming an extensive flood plain and terraces. During interglacial periods, such as at present, vegetation cover in the catchment increases reducing the amount of ground exposed, and consequently the rate of erosion. In response to the reduced sediment supply, the Hutt River has become incised into its earlier alluvial deposits. This means that the Hutt River now largely flows within bed and banks composed of material that it has transported and deposited previously. Therefore, the river has available a large amount of material which it can readily transport further downstream and out into the harbour.

The relationship between stream power and sediment transport, and the landscape features that are formed as a consequence, can also be seen in the change in the character of the river from its headwaters to mouth (Figure 4).

It can be seen that while total flow (volume) increases downstream, gross stream power (energy) does not. This is because, while the amount of water increases down the catchment, the slope decreases. This leads to a reduction in both the size and amount of sediment transported downstream. This variation in stream power down the river also helps to explain why the bed tends to degrade (i.e., erode) in its upper reaches and aggrade (i.e., build up) further down. This pattern of channel behaviour in the Hutt River although the steep nature of the river explains why those features related to a low gradient, fine sediment, system are not present.

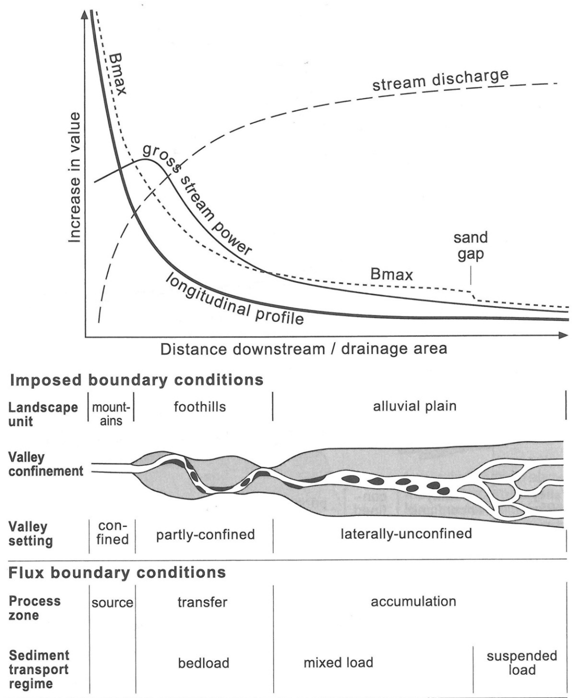

Figure 4: Changes in sediment and river character from the headwaters to the mouth (Brierley & Fryirs, 2005).

3 Streamflow

The critical control of streamflow on erosion and sediment transport makes it is important to have a good understanding of the flow (or hydrologic) regime of the Hutt River. The most downstream flow gauging station on the Hutt River is at Taita Gorge, approximately 40km upstream from the river mouth. Flows have been measured at Taita Gorge since 1979 (Figure 5). It therefore provides a reliable basis upon which to assess variability of the flow regime of the lower Hutt River.

This site is below the last tributary providing significant inputs of water and sediment to the river. It is also at the upstream limit of the effect of the water level in Wellington harbour during extreme flood events. All calculations for bedload and suspended load transport have therefore been undertaken using the flow record and sediment characteristics of this site as it provides a good estimate of energy and sediment inputs to the lower river.

The highly variable flow regime of the Hutt River is typical of a river draining a mountainous catchment. There are occasional large floods interspersed with long periods of relatively low flow. Consequently, the median flow is significantly less than the mean as it is less affected by the flood flows (Table 1). Over the past 31 years flows in the Hutt River have varied from as low as 1.6m³/s to approximately 1562m³/s (Figure 5 & Table 1).

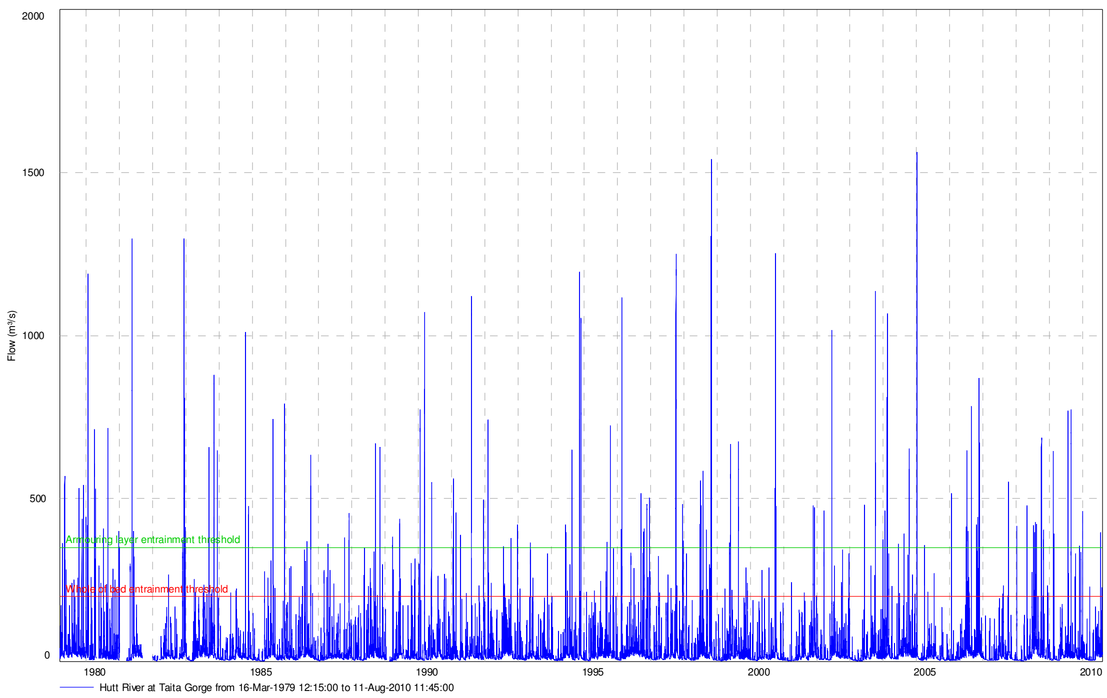

Figure 5: Flow record for the Hutt River at Taita Gorge, including two bedload entrainment thresholds (1979-2010).

Table 1: Statistical summary of flow record at Taita Gorge 1979-2010 (m³/s).

Minimum	Mean	Maximum	Standard deviation	Lower quartile	Median	Upper quartile
1.6	24.8	1562	44.5	8.1	14.2	25.7

According to Williams (1991) the average flow threshold for bedload transport for the lower valley, when considering just the D_{50} of the armouring layer, is approximately 350m³/s. When the characteristics of the sediment forming the entire bed are considered the entrainment threshold reduces to 200m³/s because of the increased resistance of the larger material forming the armouring layer (Figure 5). Therefore, there should be no bedload movement at flows below 200m³/s, although there will be material moved in suspension.

Over the entire flow record from Taita Gorge the upper entrainment threshold has been exceeded 0.3% of the time; the lower threshold 0.8% of the time. Notwithstanding these relatively low percentages, the large amount of available energy during these periods is sufficient to erode and transport a significant volume of material.

4 Sediment transport modelling

Mitigating the flood risk of the Hutt River, maintaining the flood defences, determining the sustainable volume of sediment which can be extracted, and assessing the potential environmental effects of sediment extraction at the river mouth all require knowledge of the sediment budget of the river. In particular, the volume of both suspended and bedload need to be quantified.

4.1 Assessment of bedload transport

Bedload transport past Taita Gorge, and by implication in the lower Hutt River, was assessed using BAGS (Bedload Assessment for Gravel-bed Streams) is sediment transport modelling software developed by Rocky Mountain Research Station, Forest Service, USDA. BAGS is now regarded as one of the ‘industry standards’ with regard to bedload transport modelling. Transport capacities are calculated on the basis of field measurements of energy of flow, channel geometry, average reach slope, and the bed material grain size. While BAGS provides the choice of six bedload transport equations, developed specifically for gravel-bed rivers, after calibration it was found that the equation proposed by Wilcock and Crowe (2003) for mixed sand and gravel transport was the most suitable for the Hutt River.

To allow comparability with changes in various measured channel cross-sections, analysis was undertaken on the flow record from each inter-survey period (1987-1993, 1993-1998, 1998-2004 & 2004-2009). The results were converted from a bedload transport rate (kg/s or tonnes/day), to a total bedload volume over the inter-survey period (Table 2).

Table 2: Bedload transport volume (m³) based on the flow record from Taita Gorge and the Wilcock and Crowe (2003) equation.

Period	W&C (980&720)
1987-1993	34,200
1993-1998	37,500
1998-2004	62,700
2004-2009	44,300

4.2 Suspended sediment

Bedload is, however, only one component of the load transported past Taita Gorge. Consideration of the suspended sediment load is also required to develop a complete sediment budget as it relates to sediment extraction from the river. Therefore, the relationship between suspended sediment transport and flow developed by Williams (1991) was used in combination with the flow regime from Taita Gorge to derive the volume of suspended sediment transported over each inter-survey period (Table 3).

Table 3: Calculated inter-survey period suspended sediment volume (m^3).

Period	Total suspended sediment volume (m^3)
1987-1993	409,000
1993-1998	478,000
1998-2004	772,000
2004-2009	419,000

4.3 Net sediment balance

The total volume of sediment transported by the Hutt River past Taita Gorge is the sum of both the bedload and suspended sediment. This calculation does not include the dissolved and wash load which is transported out of the system and into Wellington Harbour.

The total volume of sediment transported past Taita Gorge over each inter-survey period is shown in Figure 6. These values agree very favourably with those derived from the summation of sediment aggradation and extraction volumes and are therefore realistic.

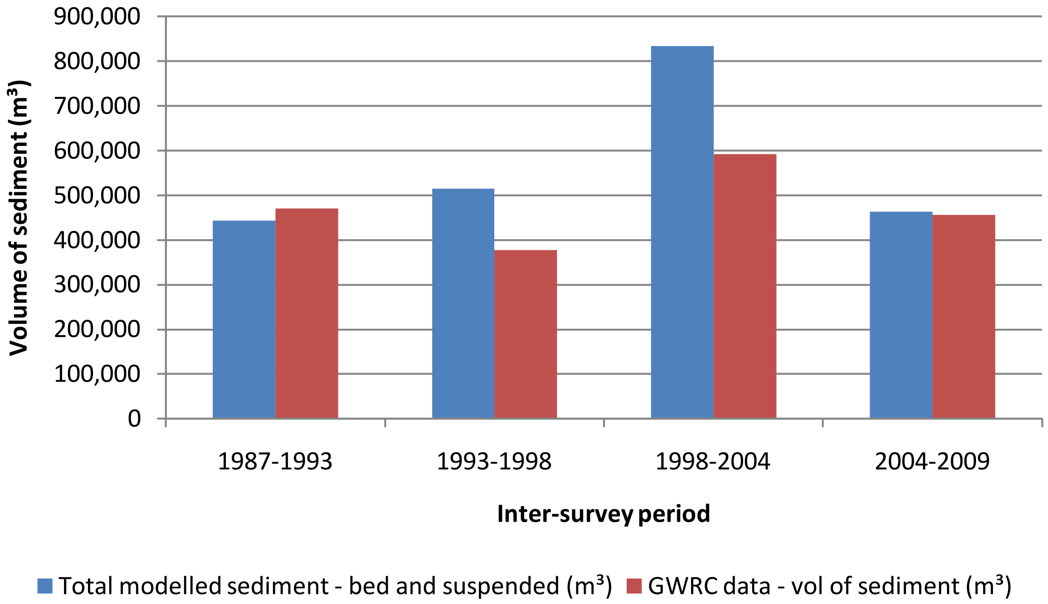

Figure 6: Comparison of total sediment volumes estimated from modelling and analysis of sediment aggradation and extraction.

Figure 7 and Table 4 show that bedload makes up about 8% of the total load, with the remainder being composed of suspended load. This is consistent with other estimates from New Zealand which indicate that bedload transport is typically 3-10% of the total load.

Table 4: Total modelled sediment load for each inter-survey period.

Period	Suspended sediment volume (m^3)	Bedload sediment volume (m^3)	Total modelled sediment - bed and suspended (m^3)	Bedload as a percentage of total volume (%)
1987-1993	409,000	34,200	443,000	7.7
1993-1998	477,000	37,500	514,000	7.3
1998-2004	770,000	62,700	833,000	7.5
2004-2009	419,000	44,300	463,000	9.6

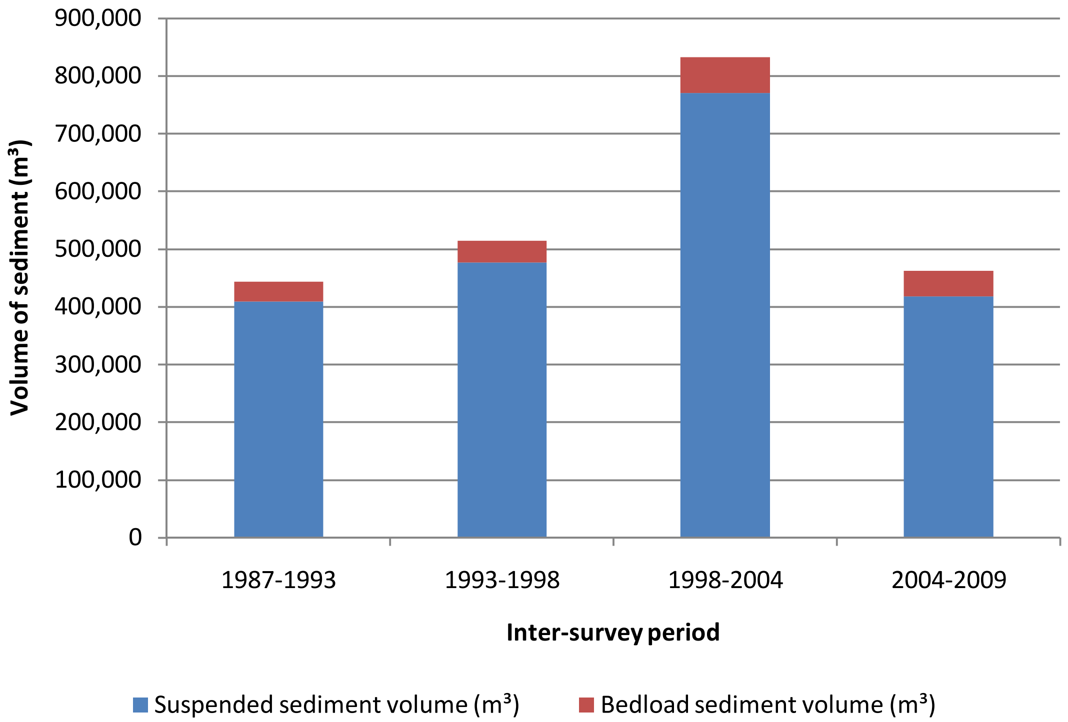

Figure 7: Suspended load and bedload as a proportions of total sediment transport.

The volumes of sediment transported during each inter-survey period have been transformed into an annual average value. These are then compared with those derived from the analysis of cross-section changes and sediment extraction over the same period (Table 5).

There is a high degree of variation in the amount of suspended sediment, bedload, and consequently total load, over each inter-survey period. This is to be expected because of the variation in the flow regimes over these different periods; particularly the number, magnitude, and duration of flood events. A greater degree of variation is apparent in the modelled results when compared to those derived from the cross-section analysis. This is because of the greater sensitivity of the sediment transport modelling which is based on the actual flow regime. The results from the analysis of cross-sections are the average net change in material over the reach, and not a measure of actual sediment transport.

Table 5: Annual average sediment volumes.

Period	Annual average suspended sediment volume (m^3)	Annual average bedload sediment volume (m^3)	Annual average total sediment load (m^3)	Annual average GWRC total volume (m^3)
1987-1993	69,200	5,780	75,000	79,600
1993-1998	102,000	8,050	110,000	80,800
1998-2004	129,000	10,500	139,000	98,700
2004-2009	83,900	8,860	92,700	91,200
Long term 1987-2009	***96,300***	***8,280***	***105,000***	***87,800***

4.4 Summary

The potential transport of both bedload and suspended load indicate that:

- The average annual sediment transport past Taita Gorge is 104,600m^3/year. The total load is composed of all material transported as either suspended load or bedload.
- The sediment transport rate calculated compares favourably to that calculated in Opus (2010a) of 87,800m^3/year. The difference relates largely to material deposited downstream of cross-section 30 and beyond the river mouth. This material is not considered in Opus (2010a), although it is discussed in Opus (2010b).
- Of the total sediment transport approximately 8% is bedload. The remaining 82% is suspended sediment. These estimates are consistent with other New Zealand data.
- There is a high degree of variability in sediment transport. This relates to flow variability within the Hutt River.
- The annual rate of sediment transport since 1987 has ranged from 75,000 to 139,000m^3.
- Annual sediment transport is controlled largely by the number, magnitude, and duration of flood events.
- Sediment which accumulates at the river mouth reflects the average rates of sediment transport over time, rather than the sediment pulse from a specific year.
- While the average rate of sediment accumulation provides an indication of long term trends, there is a high degree of inter-annual variability.
- Lower than average rates of sediment accumulation since 2004 likely reflects the lack of significant flood events over this period.
- It is likely that an average annual sediment transport rate of approximately 88,000m^3 is indicative of the long term sediment transport regime.

5 Changes to the river channel

5.1 Introduction

The Greater Wellington Regional Council (GWRC) regularly surveys cross-sections at 313 locations along the lower 33.5km of the Hutt River. The data from these surveys are used to analyse trends in gravel bed material movement, and bed aggradation and degradation along the river. The results of this analysis are used to guide policy on gravel extraction and general river management.

5.2 Aggradation of the river bed

Using the changes in the various cross-sections from successive surveys cumulative sediment volume change curves were produced for each inter-survey period (Figure 8). These curves start at approximately Taita Gorge and terminate adjacent to Winstone's sand mining plant. A positive slope with increasing downstream distance on these curves is indicative of aggradation of the bed while a negative slope is indicative of degradation.

Figure 8 shows that in general the bed over this section of the Hutt River has been aggrading over time. In the 2004-2009 inter-survey period there has been a degradational trend over the 4km immediately downstream Taita Gorge. Further downstream the bed has aggraded. The largest net increase in sediment aggradation occurred over the 1998-2004 inter-survey period. This is likely related to the number of significant flood events over that period.

Table 6 summarises the net aggradation volumes over the inter-survey periods. It should be noted that these net aggradation volumes exclude any sediment deposited between Winstone's sand mining plant and the end of the Seaview reclamation.

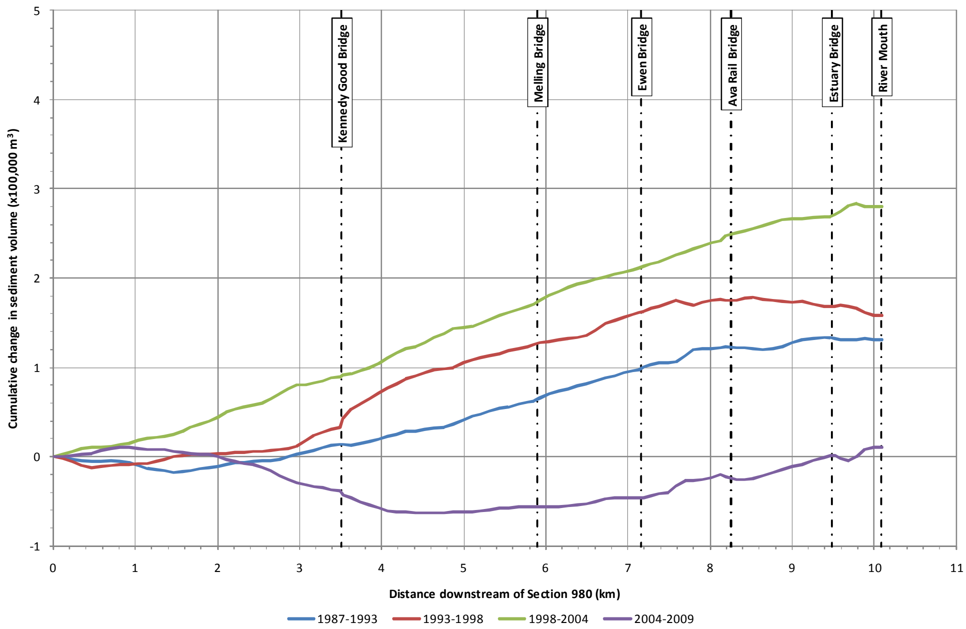

Figure 8: Cumulative change in sediment volume in Hutt River downstream of Taita Gorge for each inter-survey period from 1987-2009.

Table 6: Net sediment aggradational volumes downstream of Taita Gorge.

Inter-survey period	Build-up (m^3)
1 Sep 1987- 31 Jul1993	131,300
1 Aug 1993 – 31 Mar 1998	156,600
1 Apr 1998 – 31 Mar 2004	282,000
1 Apr 2004 – 31 Mar 2009	9,800
Total (1 Sep 1987-31 Mar 2009)	579,700

The total amount of sediment deposited within the Hutt River downstream of Taita Gorge, however, includes not only that still remaining in the river bed but also that extracted for various reasons e.g., flood control and sand mining at the river mouth. The average annual volume of sediment therefore deposited over each inter-survey period are summarised in Table 7 and Figure 9.

Table 7: Average annual sediment balance for control volume.

Component	Sediment volume (m^3/year)				
	1987-1993	1993-1998	1998-2004	2004-2009	1987-2009
Net aggradation	22,200	33,600	47,000	1,960	26,900
Extraction - River - Mouth	 10,200 47,200	 0 47,200	 7,780 43,900	 45,200 44,100	 15,400 45,500
Input	79,600	80,800	98,700	91,300	87,800

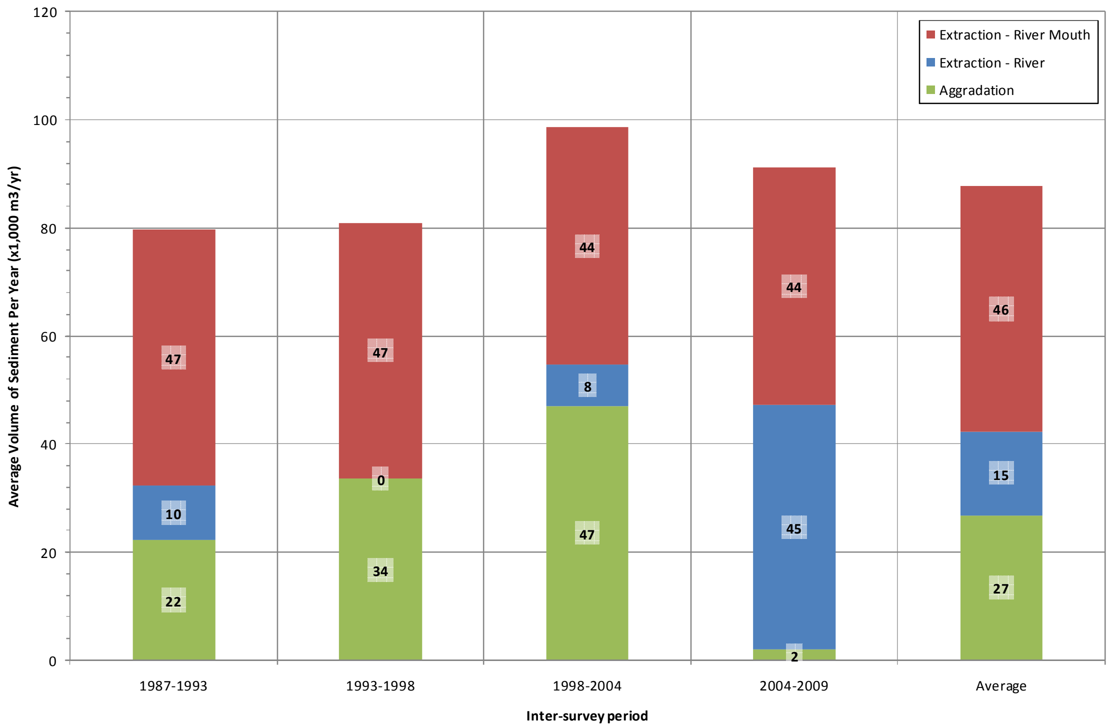

Figure 9: Average annual sediment deposited downstream of Taita Gorge.

These results, which are consistent with those discussed earlier with regard to the modelled suspended and bedload rates, show that the annual input of sediment from upstream was relatively constant over the first two inter-survey periods i.e., between 1987 and 1998. The input of sediment was highest over the 1998-2004 inter-survey period. The amount of sediment deposited during the inter-survey periods is directly related to flood activity as discussed earlier.

5.3 Summary

The average annual sediment input over the period 1987-2009 is estimated to be approximately 87,800m^3/year. This is likely to be a slight under-estimate as it excludes any allowance for sediment aggradation in the 660m long reach between Winstone's sand mining plant and the end of the Seaview reclamation. This result is less than, but consistent with, that determined from the sediment transport modelling because it ignores wash load and material deposited beyond the river mouth.

6 Sediment extraction at the river mouth

6.1 Introduction

As discussed the majority of sediment transported down the Hutt River arrives in pulses associated with discrete flood events. For the past 35 years some of this material has been extracted from the river mouth to mitigate the potential effects of floods, and to meet the needs of the building industry for sand.

6.2 Sediment extraction

Data over the past 35 years shows that there has been a gradual decline in the volume of sediment extracted, despite some years (e.g., 1975 and 1991) having higher than average extraction (Figure 10). Over this period, extraction has remained below both the permitted maximum annual extraction rate and the 5-yearly average.

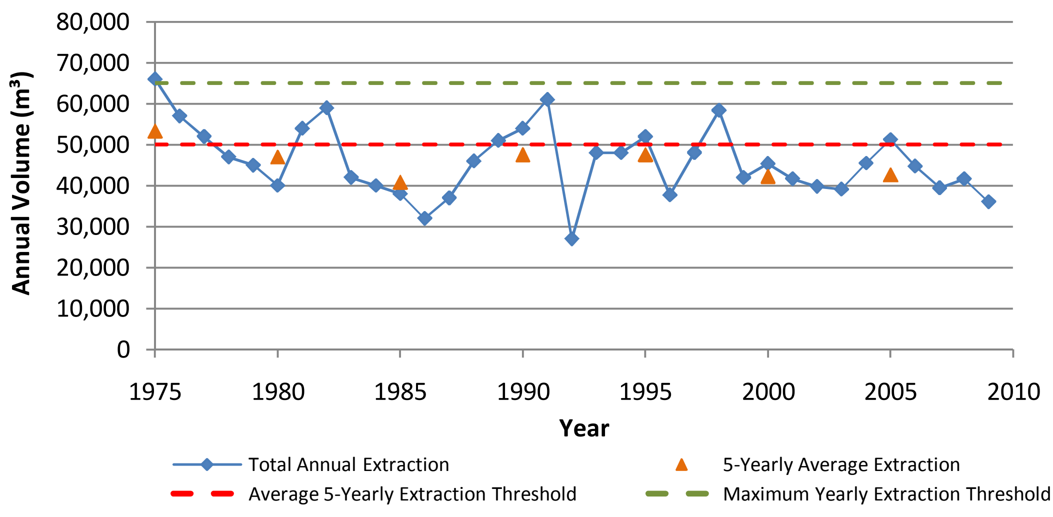

Figure 10: Annual river dredging extraction rates at the Hutt River mouth 1975 to 1999.

A closer look at extraction over the past 15 years shows that the monthly extraction rates vary significantly (Figure 11). There also appears to be some cyclic variability apparent in the longer term average extraction rates (i.e., 12-month moving average). This is likely related to both the frequency of flood activity, which tends to be episodic, and the nature of extraction operations. Larger volumes of material are extracted when more material is available.

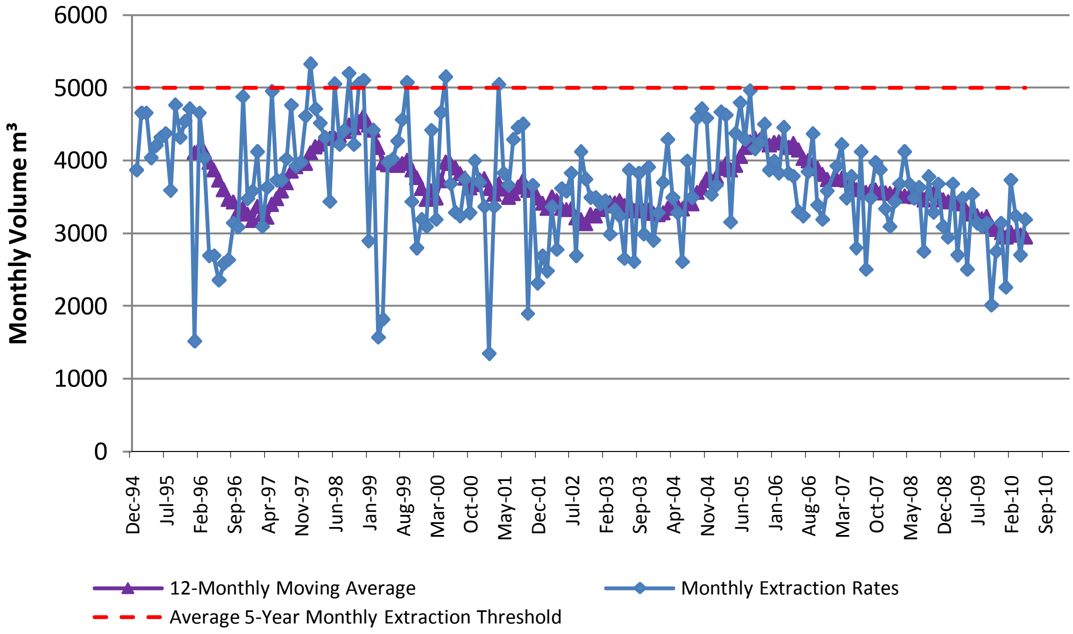

Figure 11: Monthly river dredging extraction rates at the Hutt River mouth 1995 to 1999.

Figure 12 shows that total annual extraction has varied between about 35,000 and 51,000m³ over the past 10 years. It would appear that there has been a slight reduction in total abstraction, particularly since 2005. The total volume of 'product' appears to have decreased markedly over the past 10 years, and particularly since 2005. The volume of waste by-product has consequently increased significantly; particularly the finer fraction. This likely reflects reduced flood activity over recent years, and consequently the deposition of less sand and gravel and more silt.

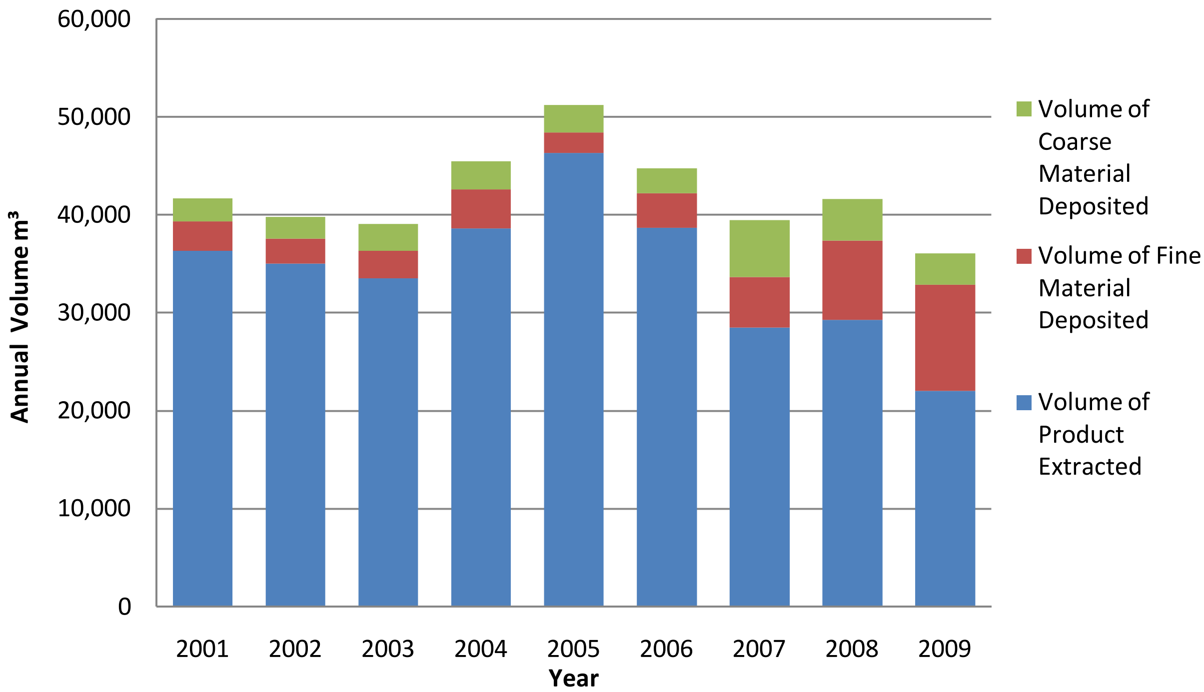

Figure 12: **Annual extraction and deposition volumes 2001–2009; including the volume of both coarse and fine fractions deposited.** Note: Total extraction is the sum of all three volumes each year.

7 Effects at the coast

7.1 Introduction

Beaches reflect the balance between the processes operating on the land and in the coastal zone. Consequently, beaches are dynamic systems subject to a high degree of spatial and temporal variability and change. The principal controls on beach form and process are the energy of the wave regime, and the character of the sediment on the beach; including the input, loss, and storage of sediment on the active beach face (Figure 13). The wave regime affects the amount of energy which is available to do work i.e., to cause change to the beach. Whether any change actually occurs depends on the nature of the material forming the beach; including its type, character, size, amount, and resistance.

Beach form is therefore the result of a complex set of interactions and not a single factor. Change is natural and ongoing. Sand and gravel beaches such as at Petone are among the most mobile, and changeable, of all landforms. Beaches change over different temporal scales: daily, with the tidal cycle; seasonally, in response to shifts in dominant weather patterns; and over longer timescales in response to sediment supply, erosion or deposition, and changes in sea-level. Any assessment of beach form and changes over time must be viewed in the context of overall beach dynamics.

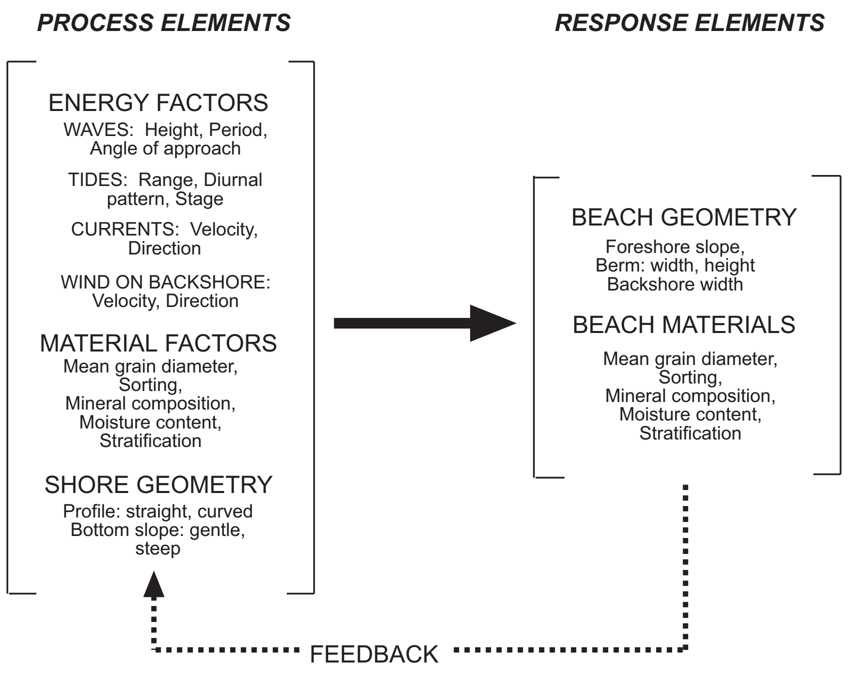

Figure 13: Conceptual beach model (after Kirk and Single, 2000).

Figure 14 presents a simple model for shoreline stability (i.e., whether shorelines are advancing, stable, or eroding. Advance can be caused by an excess supply of sediment, a fall in sea level relative to the land, or a combination of both factors. Similarly, coasts that retreat will reflect a shortage of sediment, a rise of sea level, or a combination of both factors. The removal of sediment from the river and river mouth therefore has the potential to affect the beach form and processes at Petone.

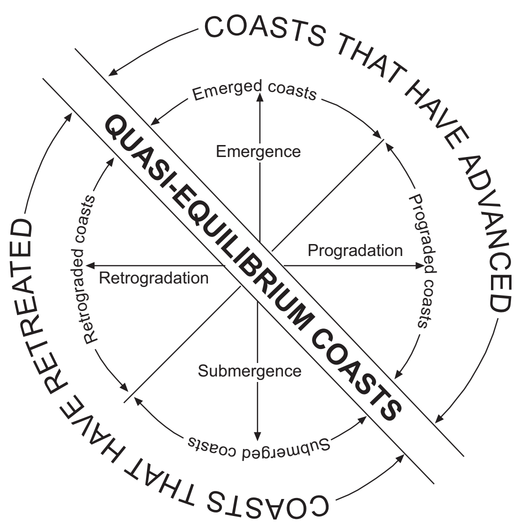

Figure 14: Model of shoreline stability (after Kirk and Single, 2000).

Beach sediment budgets distinguish between inputs (gains) to the beach system, outputs (losses), and internal transfers. In a 'book-keeping' sense, if inputs exceed outputs over a defined period then the budget is in surplus. The beach will consequently advance sea-ward. Similarly, if outputs exceed inputs the budget is in deficit and the shoreline will erode. It should be noted from this that shoreline erosion is always an indication of a sediment budget in deficit. The deficit may arise through: a decrease in sediment supply; an increase in losses, including the extraction of sediment; a change in the energy regime; or some combination of factors (Kirk and Single, 2000). Where a beach sediment budget is in deficit erosion is inevitable. Persistent beach erosion is not apparent at Petone.

Important relationships also exist between wave characteristics and beach form. Coarser-grained sediments give rise to more steeply sloping beaches. Consequently, there is a greater concentration of wave energy per unit area of beach surface than where the beach is formed from finer-grained sediments. Generally, erosion leads to the flattening of the beach slope while accretion steepens the foreshore.

7.2 Coastal form and dynamics

The Hutt River mouth has been transformed considerably since 1900; from a coastal estuary to a well-defined river channel. The channel has been straightened and the bed excavated for flood management purposes. A large area has been reclaimed on the true left bank to form the Seaview industrial area. The most hydraulically-efficient channel shape for the Hutt River mouth was defined in 1973 to help mitigate the flood risk. This is now known as the "Hydraulic Line" and forms the effective true right bank of the river. The area now being dredged for sand is between these two banks, downstream of the Estuary Bridge. The area excludes the section of river in front of Hikoikoi Pa, and the western mudflat embayment. It also excludes the area directly in front of the Waiwhetu Stream confluence.

A mobile hydraulic excavator on a barge extracts some of this material from the river bed to a maximum depth of 4.65m below mean sea level. The extraction depth is limited to protect the integrity of the underlying Hutt Aquifer.

Petone Beach

Petone foreshore is a sand and gravel beach which extends in a northwest arc approximately 3.8km from the Hutt River mouth to State Highway 2 in the west. Petone Beach is not expected to be especially sandy. This is because high energy waves generated under southerly conditions erode any fine material from the beach, transporting it offshore. This leaves behind a 'lag deposit' of coarser gravel. The beach is mostly gravel at the eastern end; averaging 75% gravel within 500m of the Hutt River mouth. Immediately off the beach is a significant sand source, some of which is transported back onto the beach by waves under less energetic northerly conditions. The main sediment source for Petone Beach is the Hutt River, with a minor amount of sediment entering the system from Korokoro Stream in the west. Sand and gravel is also transported through the heads and into Wellington Harbour during large southerly storms. Some of this may be deposited on Petone Beach.

The by-product of sediment extracted from the river mouth; consisting mainly of organic material, coarse sands to gravels, some finer sand, and shell, was initially (until 1999) placed in a 120m bund on the high tide line of Petone foreshore. This material was then redistributed along the foreshore by coastal processes, generally driven by southerly storm waves. This practice contributed to significant accretion at the eastern end of Petone Beach. From the early 1980s to mid-1990s the eastern end of the beach advanced at a greater rate than in the west; approximately 15m (~1m/yr) compared to 8m (~0.5m/yr). The extraction and redistribution of coarse material caused a lower proportion of sand at the eastern end of the beach.

This practice changed in 1999 when a resource consent was granted to dump the coarse waste material offshore. From that time only fine sand and silt material has been deposited within the bund.

Disposal Site

The characteristics of sediment offshore from Petone indicate a belt of sands, 0.016-0.075mm in diameter, out to approximately 300m. The sediment is finer the further offshore. Beyond 300m from the shore, harbour bed surface sediments are mainly silt and silty-mud. The disposal site for coarse waste material since 1999 was initially composed of mainly very fine homogenous silt and clay. This is typical of other areas within the harbour at depths of over 10m.

The currently consented coarse by-product disposal site, a 400x150m north-south orientated rectangle, is situated approximately 700m southwest of the Hutt River mouth in water about 10–14m deep. However, there is a proposal for the disposal site to be moved approximately 190m to the south which should prevent any excessive build-up of sediment. The new site is at the same depth as the previous location so the processes and effects should be the same. The sea floor at this depth is a low kinetic environment with maximum current flows of only 1.5-2cm/s. The flow of these bottom currents runs parallel to the sea floor contours, and consequently the beach. They travel northwards during incoming tides and southwards on outgoing tides. The depth of the waste dumping zone, and the low velocity and lateral currents, are sufficient to avoid the migration of sediment back onto Petone Beach, or into the river mouth. This has been confirmed by bathymetric surveys.

7.3 Sediment transport processes

Southerly generated ground-swell and wind-wave action is the predominant sediment transport process on Petone Beach. Waves of up to 2.2m are capable of moving sand out into the harbour to a depth of 4.5m. Coarser sediment can therefore only move at shallower depths, and in lesser volumes, because of the energy required to move the larger particles. Silt and very fine sand within the by-product disposal bund is easily eroded from the beach by wave action and is lost offshore. This material, and naturally occurring sediment, can also be re-deposited further along the beach by longshore drift. Stronger longshore drift occurs around the reclaimed land near Winstone's extraction processing plant than on the remainder of Petone Beach. This is because of the north-northwest alignment of this section of the coast relative to the southerly wave approach. Southerly waves can also push sediment back into the river mouth as the shoreline is aligned due north at the eastern end of the Winstone's plant.

These sediment transport processes are strong enough to move gravels west along the beach for approximately 500m. This, combined with the material previously available from the disposal bund, has caused Petone Beach to be composed of mainly gravel in this vicinity. Sand is more predominant further west as the sediment transport processes lessen, and more offshore sand is available to the system. Very little of the larger-sized sediment is transported all the way to the western end of Petone Beach. This is because the short fetch within the harbour limits significant wave build-up, and therefore longshore drift from any direction other than the south.

A range of measurements have been made relating to the lower channel of the Hutt River, and along Petone beach. These measurements include: river bed cross-sections; dredging extraction and deposition volumes; harbour floor hydrographic surveys; aerial photography; and beach profile surveys and sediment analysis. It is important to recognise, however, that these data are of varying quality, and have different temporal resolution. Furthermore, these data usually reflect those conditions on the beach immediately prior to the measurement, or following the last major beach changing event.

7.4 Coastal landscape change

Between the Estuary Bridge and Hutt River mouth the main channel has remained largely unchanged, although overall the bed is higher and therefore the channel slightly shallower (Figure 15). In places the channel has widened and the thalweg (i.e., the deepest part of the channel) deepened. The overall rise in bed level indicates a net surplus of material even after sediment extraction. However, the flood capacity of the channel has been maintained by the wider channel and deeper thalweg. Beyond the river mouth the main channel has deepened slightly. These deeper bed levels tend to mitigate the flood risk by reducing the backwater effect during floods.

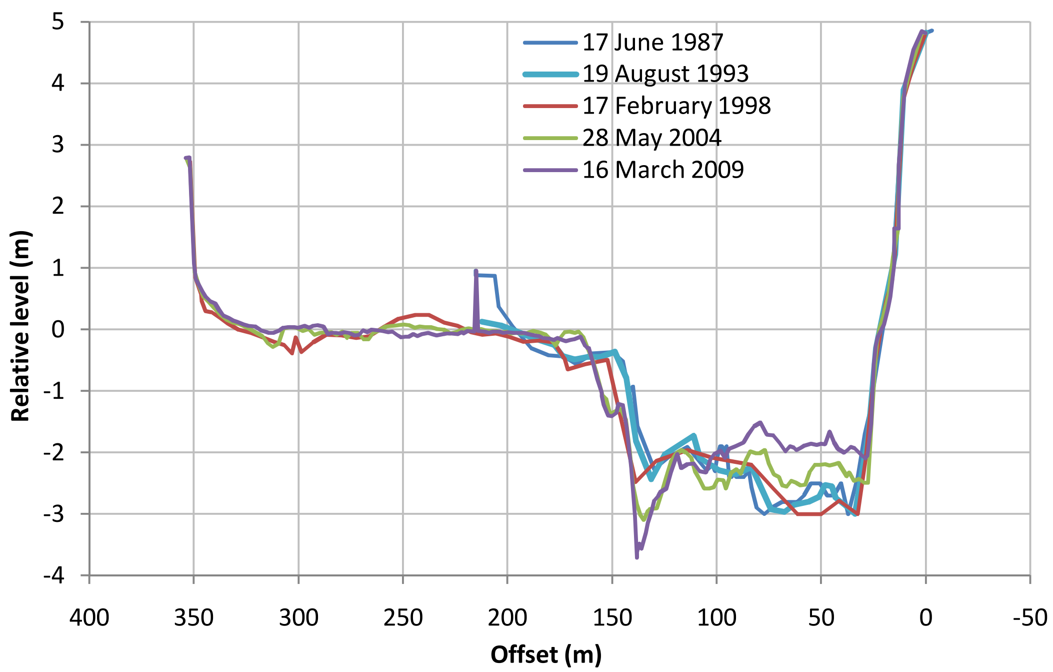

Figure 15: Changes in the river mouth cross-section showing general aggradation but deepening of the main channel.

Profiles measured on Petone Beach reflect the sediment composition, and also the dominant sediment transport processes. The eastern end of the beach is relatively steep (Figure 16); compared to the flatter profiles further west where sand is more dominant (Figure 17). The eastern beach consists of more gravel, and therefore steepens to reflect energy during wave attack. Once the gravel is 'pushed' high up the profile it is only mobilised under the most severe storm waves. Any sand or silt within the profile is, however, likely to be removed more regularly.

The profile of Petone beach varies significantly between each survey, although no consistent trend of either progradation or erosion is apparent. Since the dumping of coarse material ceased, the beach has retreated back towards its likely original position. The beach in this area now appears to be in equilibrium (Figure 16). The material eroded from the eastern end of the beach was re-deposited towards the west, resulting in slight progradation along much of Petone Beach (Figure 17).

Other change between successive surveys is likely to reflect the wave environment immediately prior to sampling. It is not possible to identify any effect of extraction or dumping apart from that discussed close to the river mouth.

While there are constraints relating to the available particle size data, the results indicate no net change in beach character. Like the profiles, the sediment character reflects the wave environment prior to sampling, and the relative position of the sample along the beach profile.

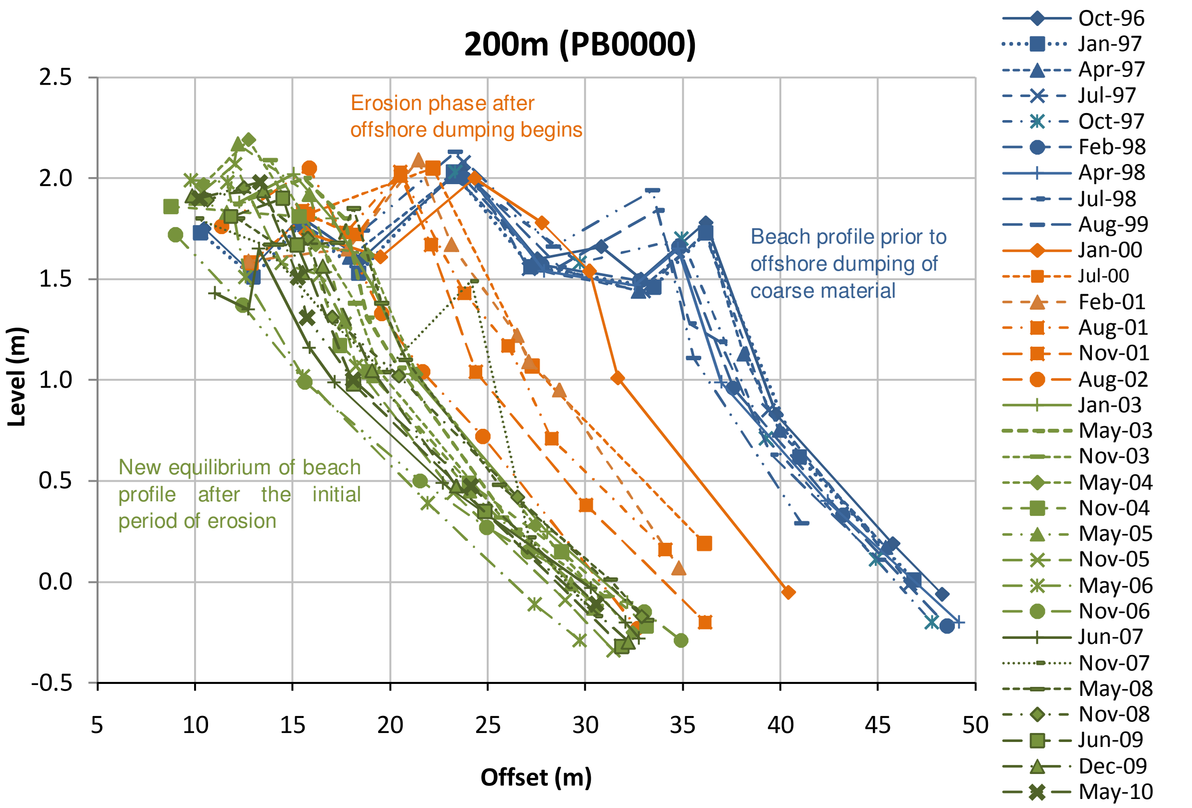

Figure 16: **Changes in the beach profile at the eastern end of Petone Beach (200m from the river mouth).**

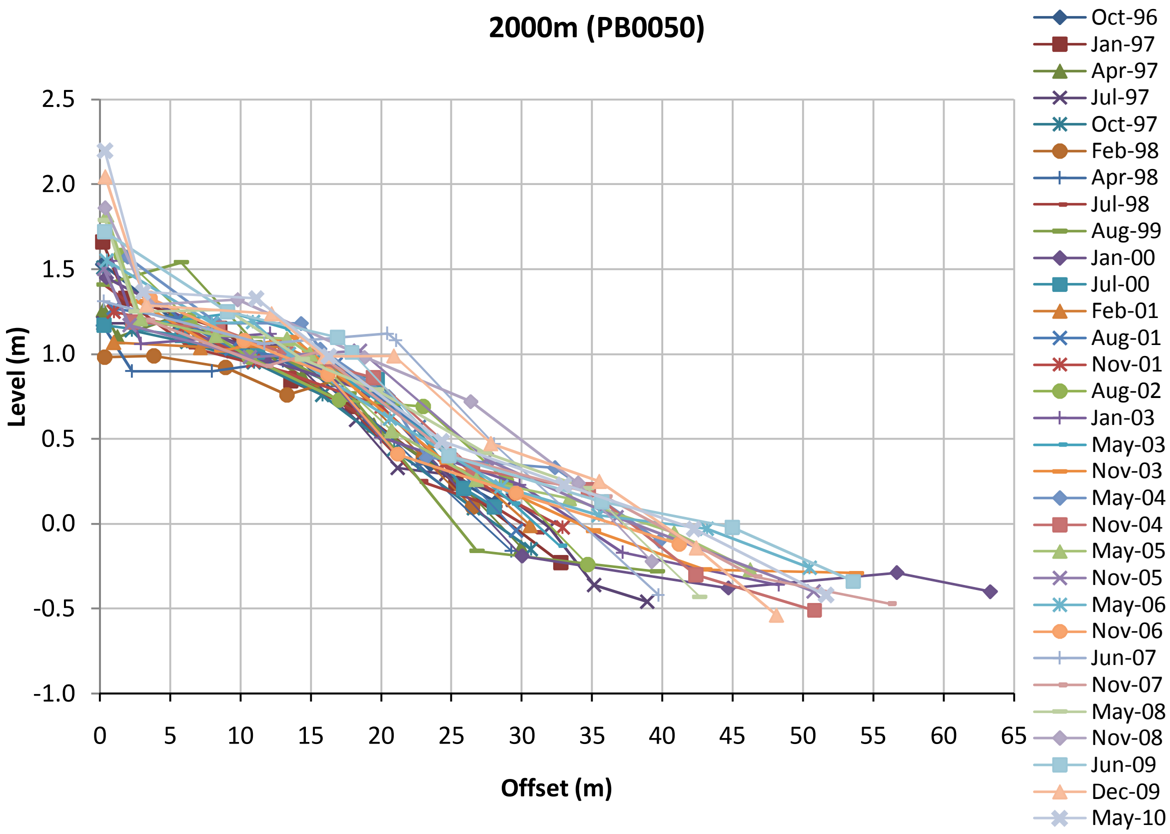

Figure 17: Changes in the beach profile at the western end of Petone Beach (2km from the river mouth).

Figure 18 shows the differences between the 1998 and 2009 bathymetric surveys. This period covers much of the current dredging and offshore deposition activities. There is a pattern of degradation to the north and aggradation in the south (i.e., further into the harbour). There is also an area of slight, 0–1m, aggradation at the river mouth. This may represent a sediment pulse coming out from the river during one of the major floods over this period. Patches of high aggradation (1-2 and >2m) are evident around the offshore deposition zone. This confirms a net surplus of material and the relative stability of material within the deposition zone. High degradation is present in the area around the Winstone's plant and the beach. This is unexpected given the by-product disposal bund is situated here. It is believed that this is actually an artefact of the 'edge effect' of the surface modelling as only the 2009 survey came within 20m of this point. The average overall change in bed level over this period was aggradation of 0.13m.

There is very little change on the harbour floor beyond its interface with the river. The slight apparent rise in the sea bed is likely to be within the measurement error of the sampling and modelling techniques used. Measurable change is observed in the area of the 'dumping site' which is to be expected. Aggradation of the sea bed in this area confirms that the dumping site is beyond the limit of natural sediment mobilisation.

7.5 Summary

Detailed analysis of these measurements shows that the beach and river mouth respond largely to natural processes of sedimentation and sediment transport. The processes and changes identified from these measurements are generally consistent over time. That is, no significant change in behaviour is apparent in the most recent information collected.

It is considered that much of the apparent change discussed above might actually be simply a function of the accuracy and resolution of the bathymetric surveys and the surface modelling techniques.

Notwithstanding the above, it would appear that the extraction of sediment from the river mouth, and the dumping of waste offshore, have had very minor effect on the environment. Despite the extraction of 35,000-50,000m³ of material each year there still appears to be a net surplus of material arriving at the river mouth. This is shown by the continued net aggradation over recent years.

Overall, the Hutt River mouth and Petone beach reflect a range of natural processes. There has been slight net aggradation of the lower river channel and sea bed. This reflects a surplus of sediment, above the rate of extraction, moving down the river.

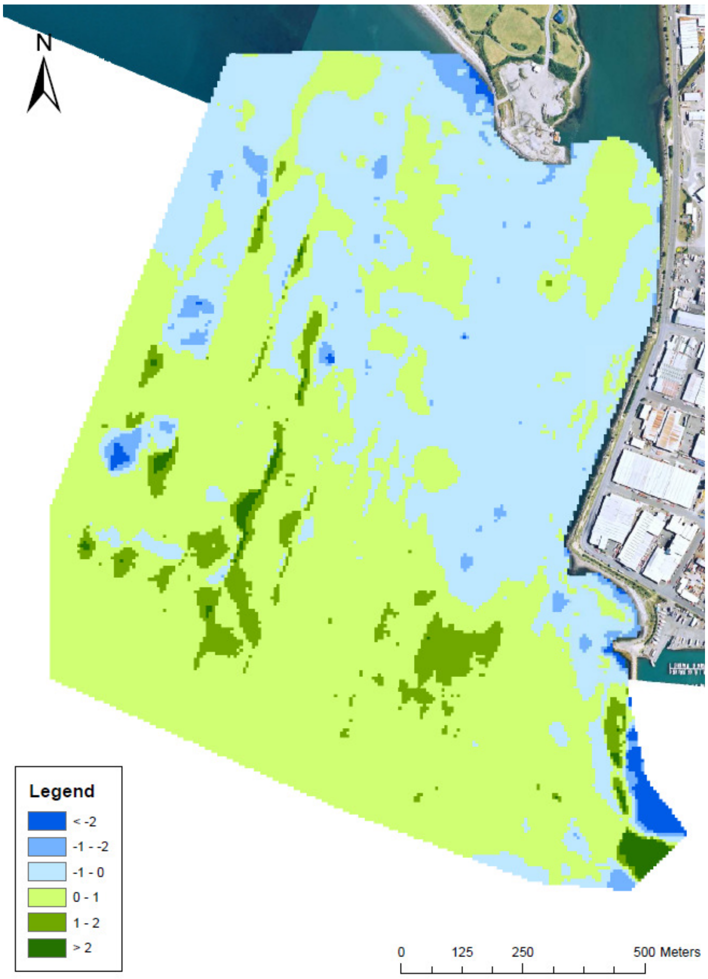

Figure 18: Differences in Hutt River mouth surfaces 1998–2009 (From Gardner, 2010).

8 Term of consent

There have been no adverse environmental effects caused by sediment extraction over the current period of consent. The sediment resource is currently being managed in a sustainable manner. Therefore, a term of consent of 35 years is considered reasonable. Such a term will also accommodate the annual variability in both sediment supply (by the river) and extraction rate.

Appropriate conditions and monitoring will ensure that the 5-year average, and maximum annual, extraction rates are managed in a manner consistent with sustainable resource utilisation, flood risk mitigation, and environmental stewardship.

There should be 5-yearly reviews, linked to specific monitoring data, to ensure that the sediment system and any environmental effects remain within the bounds expected.

Should the 5-yearly review indicate unanticipated changes in either the supply of material or environmental effects then the consent conditions should be reviewed as appropriate.

9 Possible conditions and monitoring

No adverse environmental effects of continued sediment extraction from the river mouth are expected. However, a number of conditions and continued monitoring are recommended.

Conditions are linked clearly and specifically to a number of potential issues, the nature of the environment, and physical processes operating.

Monitoring must be undertaken at a resolution and frequency that allows any significant changes to the environment to be identified and quantified.

The extraction of sediment has the potential to impact on the:

- Sediment budget of the Hutt River;
- Channel stability;
- Flood protection works;
- Hydraulic efficiency;
- Foundations of Estuary Bridge;
- Stability and biodiversity of the off-shore disposal area; and
- Form and character of Petone Beach

9.1 Specific conditions and monitoring

All data shall be recorded in digital form to facilitate transfer, storage, analysis, and review.

All results from the monitoring should be peer reviewed by an independent expert approved by the consenting authority.

Sediment budget

1. To maintain the sediment balance of the Hutt River, the 5-year average annual sediment extraction should not exceed 50,000m³.
2. The maximum volume of sediment extracted in any one year should not exceed 65,000m³.
3. At 5-yearly intervals, the sediment budget for the river below the Taita Gorge gauging station should be calculated.
4. Average sediment extraction rates for the next 5-year period should be set to maintain a net surplus of material at the river mouth to supply Petone Beach.
5. Average extraction rates can be increased above those specified above if necessary to maintain the hydraulic efficiency of the channel; but the sediment budget at the river mouth must remain in surplus.
6. Each month the total volume of sediment extracted from each of the quadrants in the lower river below the Estuary Bridge, and the volumes placed in each of the two disposal areas should be recorded.
7. Once a year for the first 5 years, bulk sediment samples should be taken from the river bed at quadrants A1, D1, and G3. At the same time, samples should also be taken from the two disposal areas.
8. These samples shall be analysed in such a manner that the entire particle size distribution can be characterised using best practice sedimentological techniques. This will include determination of the mean, median, sorting, skewness, and kurtosis.
9. Sediment sampling should be carried out in October-November following the generally higher flow period over winter.
10. At the end of the first 5 years the results relating to sediment characterisation should be reviewed. If the results adequately describe the nature of the sediment this phase of sampling can cease.

Ensuring channel stability, maintaining hydraulic efficiency, and safeguarding flood protection works

1. River cross-sections should continue to be measured at 5-yearly intervals.
2. Surveys should be carried out following the generally higher flow period over winter.
3. The same cross-sections should be used as during the current consent period.
4. Surveys should be carried out in a manner to ensure resolution equal to or better than that during the current consent period.

Safeguarding foundations of Estuary Bridge

1. No sediment extraction shall occur within 25m of the downstream end of the piers of the Estuary Bridge.

2. Extraction of sediment from 25 to 50m downstream of the Estuary Bridge piers shall not reduce the river bed level by more than would result from a linear trend between the following levels:

Distance downstream from the Estuary Bridge piers (m)	RL (m)
25	-3.00
50	-4.65

3. The sediment extraction at distances in excess of 50m of the downstream end of the piers of the Estuary Bridge shall not occur at any level deeper than RL -4.65m.

Stability of off-shore disposal area

1. Bathymetric surveys of the river mouth and near-shore zone, out to beyond the coarse sediment disposal area, should continue to be undertaken at not more than 10-year intervals.
2. Surveys should be carried out in a manner to ensure resolution equal to or better than that during the current consent period.
3. The results of these surveys should be reviewed to ensure the waste material is distributed throughout the disposal zone.

Maintenance of form and character of Petone Beach

1. Beach profiles across Petone Beach should continue to be surveyed twice each year for the next 5 years.
2. One survey should be undertaken during September-October and reflect the beach character under higher energy ‘winter’ conditions.
3. One survey should be undertaken during March-April and reflect the beach character under lower energy ‘summer’ conditions. To ensure this, the survey should occur only once any effects of strong ‘southerly’ conditions have dissipated.
4. The profiles should continue to be tied to the existing benchmarks.
5. Surveys should be carried out in a manner to ensure resolution equal to or better than that during the current consent period.
6. After 5 years, the profiles should be analysed by an independent geomorphologist for any consistent trends. If analysis of the ‘summer’ profiles indicates consistent replicable data, and no significant changes, the ‘winter’ surveying of profiles should be allowed to cease.
7. Photographs of the beach at each profile should be taken at the time of the survey and labelled clearly and appropriately.
8. Sediment samples to quantify the character of the beach along the profile should be taken in the following manner:
    - A sediment sample of approximately 200gm should be collected at 2m intervals from the benchmark marking the start of each transect (or the edge of any vegetation) down to mean tide level;

- All samples from the transect should be aggregated to provide a single bulk sample for each profile;
- Each bulk sample should be sub-sampled to provide three replicates for analysis;
- Each replicate should be analysed in such a manner that the entire particle size distribution can be characterised using best-practice sedimentological techniques. This will include determination of the mean, median, sorting, skewness, and kurtosis; and
- Following the first 5-years of sediment analyses, the results shall be reviewed to confirm whether three replicates from each profile are required. If all three replicates are producing similar results, analyses should reduce to a single sample from each profile.

10 Detailed information

This report provides only a synopsis of detailed quantitative analysis of the physical processes relating to sediment transport and landscape change. This more detailed information is provided in:

Opus, 2010a: *Hutt River Mouth: Coastal sediment transport processes and beach dynamics.* Report prepared for Greater Wellington Regional Council by Opus International Consultants Ltd. Reference 350861.00, September 2010.

Opus, 2010b: *Hutt River Mouth: Sediment input and aggradation in the lower Hutt River*. Report prepared for Greater Wellington Regional Council by Opus International Consultants Ltd. Reference 350861.00, October 2010.

Opus, 2010c: *Hutt River Mouth: Fluvial sediment transport.* Report prepared for Greater Wellington Regional Council by Opus International Consultants Ltd. Reference 350861.00, October 2010.

Opus, 2010d: *Hutt River Estuary Bridge: Sediment extraction from the Hutt River mouth and foundation stability of Estuary Bridge.* Report prepared for Greater Wellington Regional Council by Opus International Consultants Ltd. Reference 350861.00, October 2010.

11 References

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