REPORT

Tonkin+Taylor

River Management Activities: Western Rivers Coastal Processes Input

Desktop Coastal Processes Review

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1 Introduction

Greater Wellington Regional Council (GWRC) engaged Tonkin & Taylor Ltd (T+T) to provide the regulatory department information in relation to the effects of activities of flood protection on the rate of coastal erosion on the Kāpiti Coast (refer to letter to T. Berghan dated 22 September 2017). This task includes a desktop review of the existing information relating to the Waikanae River and Ōtaki River consent applications, analysis of the existing information from a coastal process effects perspective and provide our findings in a report for further comment and consultation. This report presents the review findings.

2 Background

River management activities (including flood protection) have been carried out in the Ōtaki River for over 80 years, and in the Waikanae River and Waimeha Stream for almost 60 years. Gravel has been utilised historically by New Zealand Railways for ballast production and by construction aggregate producers. Extracted gravel continues to be used for this and for construction aggregate.

The operations and maintenance works undertaken by GWRC are required to protect settlements and assets from flooding and river erosion in a dynamic river system. These works include repairing erosion damage caused by periodic flood events, managing the continuous transport of gravel both through the river system as well as the deposition of gravel in the lower reaches, and managing the flood conveyance capacity of river channels.

GWRC is applying for renewal of the resource consents to carry out this work as part of a wider resource consent project which covers eight consents for flood protection operations and maintenance activities and three separate gravel extraction consents.

Coastal erosion is a significant natural hazard in the Kāpiti Coast District. The district borders a 2-4km wide coastal plain. The plain is well settled and contains a range of engineering structures established over the past half century to attempt to manage coastal erosion.

The Ōtaki and Waikanae Rivers are part of a system that moves sediment from the upper reaches of their catchments across the coastal plains, and provides sediment to the coast that contributes to the supply of material that nourishes the beaches of the Kāpiti Coast.

Key questions that may be associated with river management operations and their impact on coastal processes include:

1 *To what degree could river management activities impact the supply of beach forming sediment to the coast?*

   This question is concerned with activities that might alter the transport and supply of sediment to the coast.

2 *To what degree will river management activities altering the morphology of the river mouths impact coastal processes?*

   This question concerns how river management at the river mouth may influence how sediment is deposited and eroded and how this may impact coastal erosion in the vicinity of the river mouths.

3 Summary of river management activities that may impact coastal processes

Table 1 summarises the activities described in the consent applications (T+T 2016a and 2016b) and their relevance to coastal processes. These are the activities considered most likely to have a perceived impact on sediment supply and coastal processes.

Commentary on the potential degree of impact these activities may have is discussed in the following section.

Table 1: Summary of river management activities that may have potential effects on coastal processes

Activity	Description	Potential effects
Gravel Extraction	Gravel extracted from the river to maintain the river mean bed levels and maintain flood capacity at the 1991 surveyed reference level. Gravel is proposed to be extracted at a rate to balance supply, calculated from analysis of monitoring surveys. Waikanae River – Extraction of 6,000m^3 of gravel per year, and 43,700m^3 of gravel accumulated to return bed levels to 1991 survey levels. Ōtaki River – extraction of 53,500m^3 per year over a five year period and an additional extraction of 35,000m^3 from near the mouth on the vegetated 'Mangahanene Island' See Figure 1 and 2 for schematic showing gravel extraction locations. Historical rates of extraction are shown in Table 2 and 3 for comparison.	Extraction of gravel from the river might result in a reduced quantity of sediment transported to the river mouth reducing the quantity available to supply beaches. Extraction of gravel may change the distribution of particle sizes of material moving down the river to the mouth. Typically larger gravel and cobble sized particles are targeted for extraction. This may remove armour layers and lower the threshold for mobilisation of finer sand sized particles. This has the potential to increase the rate of supply of finer material to the mouth. Gravel removal may also have the potential to modify meander patterns in some reaches. This may increase the supply of material eroded from the banks of the river into the system.
River bank stabilisation including willow planting, riprap bank lining and groynes	For flood and erosion protection, willow planting is primarily undertaken to stabilise the banks of the river. Groynes, and riprap bank lining also perform this function. Currently over half of both the left and right banks (51 % and 55% respectively) of the Waikanae River and 85% of the Ōtaki River banks within the application area are willow-lined. It is not envisaged that there will be a need for significant new plantings.	Confinement/modification of banks may affect hydraulics and sources of sediment transported by the river include the erosion of river banks. Activities that reduce the potential of the banks to supply sediment that is transported downstream could impact the quantity of sediment supplied to the river mouth.
Channel shaping and realignment including ripping, recontouring and diversions	Removal of beach vegetation, unwanted willows, diverting and reshaping of the river are activities undertaken to maintain the channel in a design alignment and avoid lateral erosion in undesirable areas	Reshaping of the channel may reduce the potential of the river to move sediment through the system. Activities such as ripping and vegetation removal may lower the threshold for sediment mobilisation,

Activity	Description	Potential effects
		potentially increasing the supply of sediment to the river mouth.
Management of river outlets	Outlets at the river mouths are to be cut when upstream water levels reach a certain point, or when the mouth has migrated beyond certain pre-set trigger points, to maintain hydraulic efficiency of discharging flood flows to the sea. Excavated material cut to form new outlets will be redeposited on the beach adjacent to the outlet. Maintenance of existing groynes and rock banks near the river mouth are also proposed.	Works around the river mouth may change depositional patterns and cause erosion of banks and beaches near the river mouth. Increasing the hydraulic gradient through the river mouth may allow increased supply of sediment to the coast in smaller flood events.

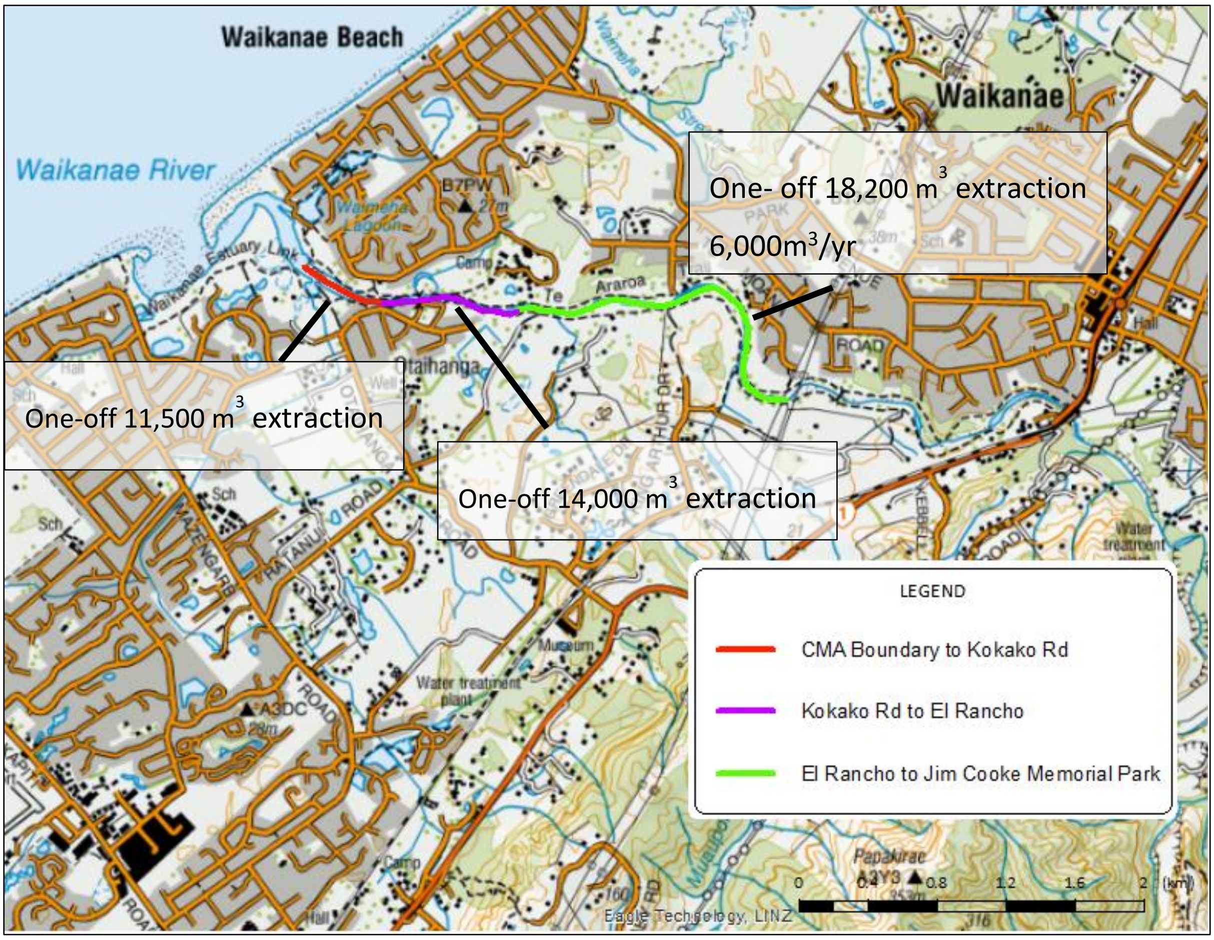

Figure 1: Locations of proposed gravel extraction in the Waikanae River

Table 2: Historical annual gravel extraction rates for the Waikanae River

Period	Average Annual Rate (m^3/y)	Source
1957-1975	10,000	Kutta (2016)
1975-1983	10,000	
1983-1987	10,000	
1987-1991	8,000	
1991-1995	2,000	
1995-1999	0	
1999-2004	3,600	
2004-2010	7,040	
2010-2014	390	
Average	7,000	

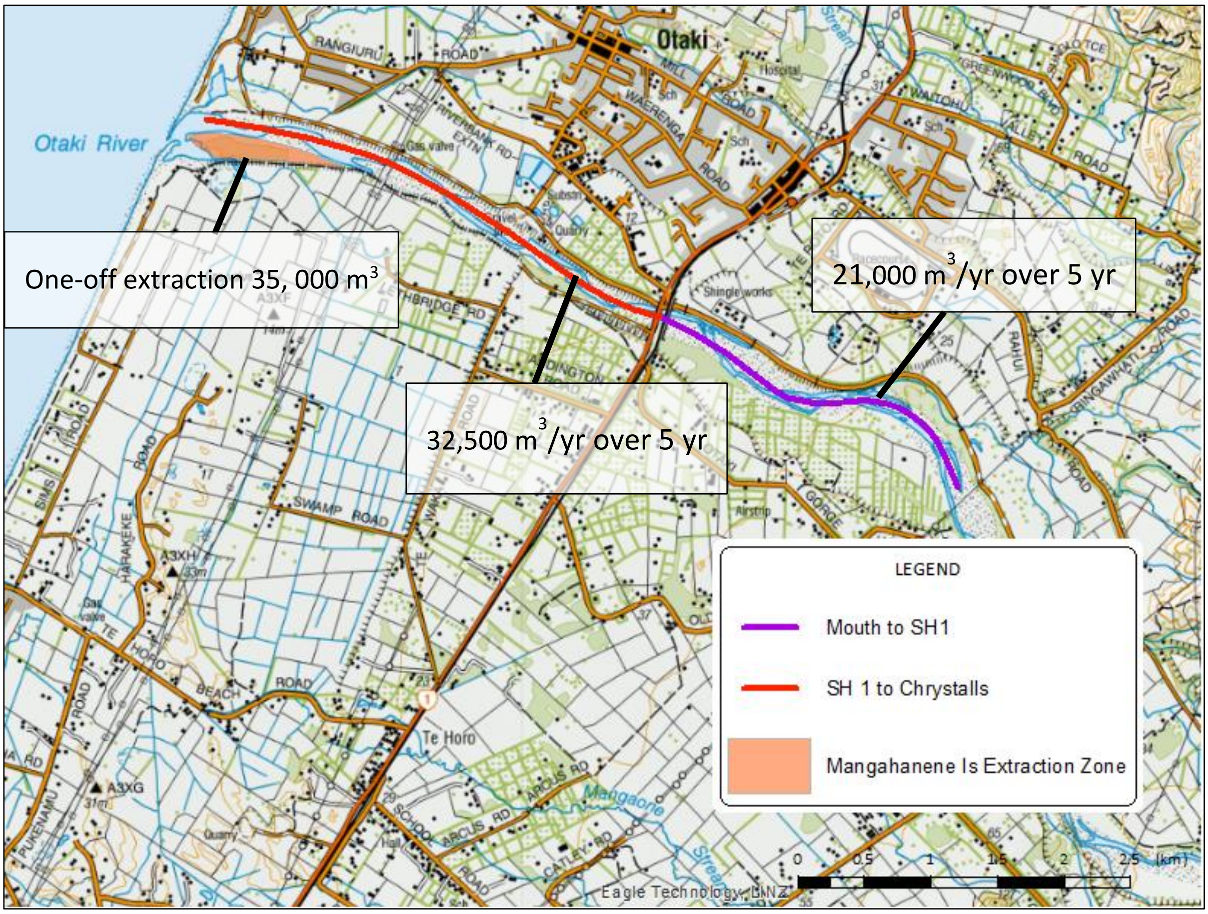

Figure 2: Locations of proposed gravel extraction in the Ōtaki River

Table 3: Historical annual gravel extraction rates for the Ōtaki River

Period	Average Annual Rate (m^3/y)	Source
1950-1967	63,000	Brougham & McLennan (1983)
1967-1977	153,000	
1977-1982	125,000	
1982-1991	No data	
1991-1996	48,000	Gardner (2011)
1996-2001	41,000	
2001-2006	39,000	
2006-2010	39,000	
Average	79,000	

4 Fluvial and coastal processes background

4.1 Fluvial processes

River systems move sediment eroded from the slopes and gullies in the headwaters through mid reaches to be deposited within an accumulation zone and eventually to the coast where coastal sediment transport processes take over (Figure 3). The river system moves material in two main ways. The first is suspended load transport where finer particles are suspended in the water column, and the second is bed load transport, where larger particles are mobilised by flow shear forces and slide, bounce and roll through the system. Both processes are intermittent (especially bed load transport) and most movement occurs during flood events.

The coastal plains of the Kāpiti Coast are transfer and accumulation zones, where sediment is stored temporarily to be eroded from the banks and bed of the river and transported during floods. Left to a completely natural state, most rivers will tend to traverse laterally back and forth across the coastal plains picking up and depositing sediment as the sediment gradually moves down towards the coast. Fine sediment can be stored underneath an 'armour layer' of gravel, on point bars, and under berm, bank and bed vegetation, to be remobilised during sufficiently large flood events. Fine sediment can be created during bed load mobilisation by the abrasion of larger particles as they are transported though this will be a very small component of the suspended load discharged to the coast by the river system.

The Waikanae River has a 149km^2 catchment and flows into a tidal river mouth estuary which drains onto a broad flat beach just north of Paraparaumu, and forms a spit with the mouth generally tending to migrate towards the south. The mouth is periodically mechanically opened to the sea at the north end of the spit to maintain the hydraulic efficiency of the channel to reduce flood levels upstream and manage the erosion of the buffer areas protecting nearby housing development.

The Waimeha stream used to constitute a northern branch of the Waikanae River. Following development at the end of the 19th century the catchment became separated from the Waikanae, and the steam opening was diverted directly to the sea along the line of Huiawa Street. The Waimeha Stream is approximately 3km long and drains a small local catchment (not currently well defined) on the Waikanae floodplain. Repeated mouth realignments have been made to retain the outlet at the centre of the estuary that has formed around the outlet. Vegetation is cleared from the stream bed to maintain hydraulic capacity.

The larger Ōtaki River has a 345km^2 catchment discharging through the coastal plains to the sea through an estuary which has a direct opening to the sea through a sand and gravel spit. The River Mouth is open to the coast the majority of the time.

Severe storms can temporarily destabilise river systems through causing increased sediment deposition in the headland reaches, which contributes a large input of sediment to the rivers which is transported through series of smaller events over time. Bed levels and channel instability will vary over time due to waves of sediment being transported downstream (Williams, 2013). The waves of sediment likely take decadal time scales to be transported and distributed down the river to the Coast (Grant, 1981).

Along the length of the river system the bed slope of the river generally decreases, and bed materials are observed to be finer. The Waikanae River deposits all of its gravel load on its coastal plain (no gravel is observed at the river mouth). The Ōtaki River generates large enough floods to move gravel all of the way to its River Mouth (it is the only River on the Manawatu / Kāpiti Coast to do so). The point at which the depositional reach terminates at the coast (the closeness of the depositional reach to the transport zone indicated in Figure 4) reflects the major geomorphological difference between the Waikanae and Ōtaki Rivers with respects to the nature of the sediment discharges to the coast. The Ōtaki River discharges gravel sized sediment to the coast while the Waikanae does not.

For flood risk management purposes, the Waikanae and Ōtaki Rivers have been in a managed state, where their lateral migration has been constrained to a relatively narrow corridor for many decades using plantings, groynes, stopbanks and channel maintenance. Bed levels and sediment transport processes have adjusted to this managed regime. In an unaltered state, rivers will migrate laterally depositing and eroding sediment and creating a form which maximises natural sediment transport capacity. In response to their confinement rivers have a long term tendency to aggrade as their lateral movement is restricted. In order to maintain flood capacity extraction of gravel bed material is required for confined rivers (Davies & McSaveney, 2006).

GWRC regularly conducts bed surveys of the Ōtaki and Waikanae Rivers in order to monitor the net change in average bed levels and determine volumes of gravel extraction that are required to maintain bed levels to preserve channel flood capacity to a reference 1991 level. These surveys do not measure the system sediment transport rates, only net gains or decreases through each reach.

The GRWC gravel extraction policy is to extract only measured net accumulations and estimated annual accumulations based on estimates from bed level surveys to maintain river bed and flood capacity at 1991 levels. The river gravel extraction rates are reviewed every 5 years to determine the required extraction rate for the next 5 years. This policy is proposed to continue in the present applications.

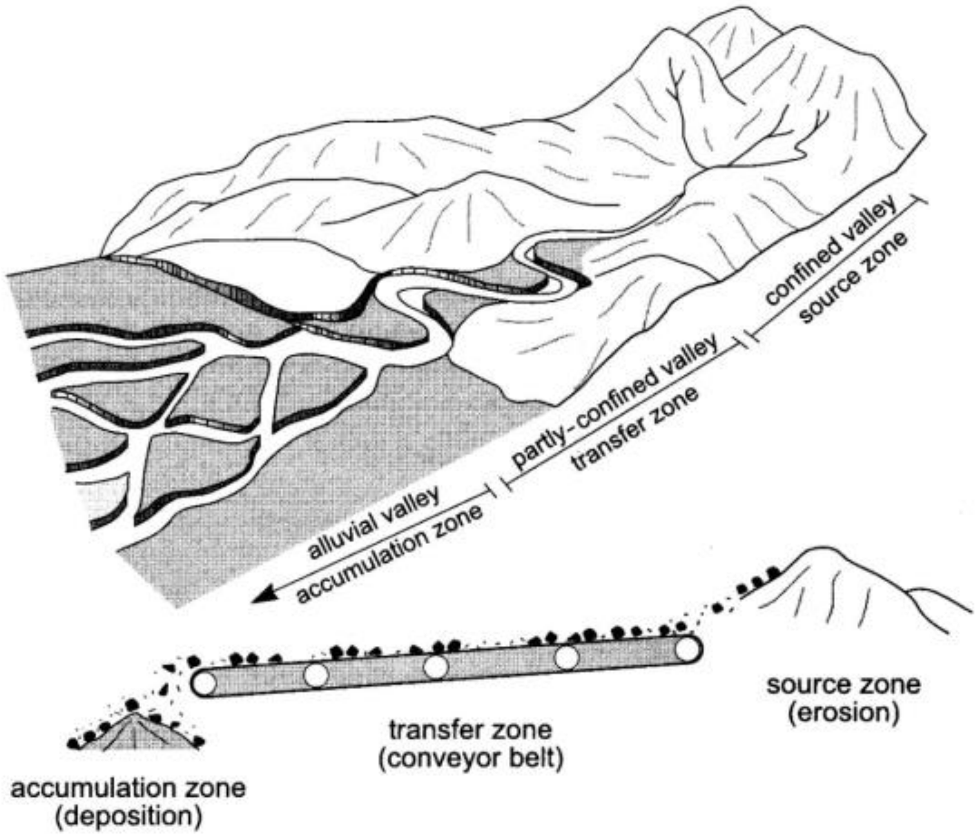

Figure 3: Conceptual illustration of the movement of sediment through a river system (Brieley and Fryirs, 2005)

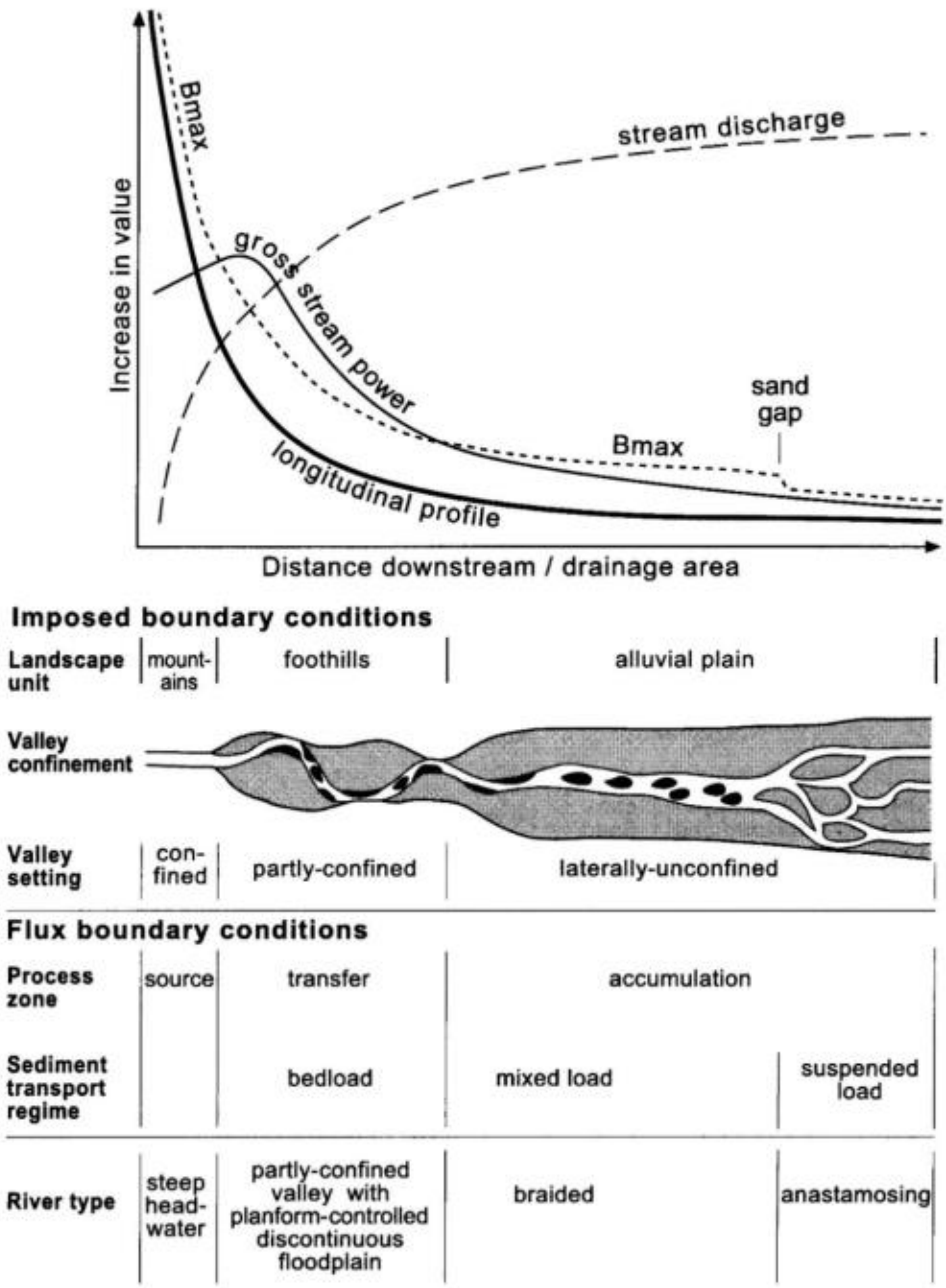

Figure 4: Changes in river pattern with increasing distance downstream (Brieley and Fryirs, 2005)

4.2 Coastal processes

Gibb (1978) establishes that the beaches of the Kāpiti Coast are predominantly comprised of very well sorted fine sand with a mean grain size of 0.15-.125mm. The mineralogy indicates that it is supplied from two volcanic sources (Taranaki and Ruapehu), a mixed source (Whanganui Basin) and a greywacke source (Tararua and Ruahine ranges). 5-10% is derived from volcanic sources and 90-95% from greywacke sources. The light grey colour of the beach sand results from the prevalence of greywacke sources. Gibb (1978) established strong evidence that the majority of sediment drift along the Kāpiti Coast is in a net southerly direction (although in certain conditions this can be reversed).

De Lange (2013) notes from Kasper-Zubillaga et al., (2007) that the compositional characteristics of sands between Ōtaki and Raumati indicate that the sediment is closely linked to sands found between Foxton and Wanganui predominantly derived from the Whanganui, Whangaehu, Rangitikei and Manawatu Rivers. De Lange (2013) also notes from Wright (1988), the present day gross mass longshore transport is of the order 40,000-120,000 m^3/y and that this is comparable to the estimated net total mass bedload discharge from the rivers mentioned above of 94,000m^3/y.

The numbers quoted in 'kt/y' in De Lange (2013) have been converted to m^3/y assuming a density of 1.8t/m^3 to allow comparison to other figures quoted in m^3/year – this assumed density appears in Holland and Holland (1985), though if an assumed submerged bulk density of 1.6t/m^3 is used as in Opus (2012) figures will differ. De Lange (2013) proposes the sediment budget for the Kāpiti Coast based on figures from Griffith and Glasby (1985) shown Figure 5 and Table 4. Note De Lange (2013) has taken only the bed load estimates produced from Griffith and Glasby (1985) to represent the portions of sediment output that contribute to longshore drift.

The majority of fine sand input to the Kāpiti Coast is predominantly from sources to the north of the Ōtaki River and is an order of magnitude larger than the contribution from the Ōtaki and Waikanae Rivers. The much larger size of the catchments to the north (shown in Figure 6) is indicative of their larger sediment contribution. De Lange (2013) concludes "it is likely that the observed shoreline changes involve mass transport at least an order of magnitude smaller than the potential sediment input to the system".

Lumsden (2013) produced an analysis of shoreline cross sections taken between 2000 and 2011 and calculated the volume change in m^3/m shoreline for each cross section. To produce a basic estimate the balance of volume eroded and accreted on the shoreline over this period, the volume change for each cross section was multiplied by the distance between each cross section and an average rate of accretion of approximately 70,000m^3/y was calculated. Note this period has been relatively calm compared to periods of significant coastal line erosion in the 1980s and this may not represent the long term rate of accretion which could be significantly lower, and almost certainly occurs in episodes and not uniformly along the coast.

Sediment transport in the Waikanae and Ōtaki Rivers comprises both bedload and suspended load transport. Gravel is transported as bedload, and fine sand is transported as suspended load. CMC (2002) notes that Holland and Holland (1985) estimated zero bedload output of gravel at the coast and 4,000m^3/yr of sand for the Waikanae River, and an output of 5,800-13,700 m^3/yr of gravel and 19,800 m^3/y of sand for the Ōtaki River. These figures also appear in Brougham and McLennan (1983) which appears to be the source. Opus (2012) estimated the annual average suspended sediment volume transported below Greenaway Road approximately 4km upstream of the mouth as between 770 and 14,000m^3/y. The majority of fine sand input to the Kāpiti Coast is predominantly from sources to the North of the Ōtaki River and is an order of magnitude larger than the contribution from the Ōtaki and Waikanae Rivers. The much larger size of the catchments to the north shown in Figure 6 is indicative of their larger sediment contribution.

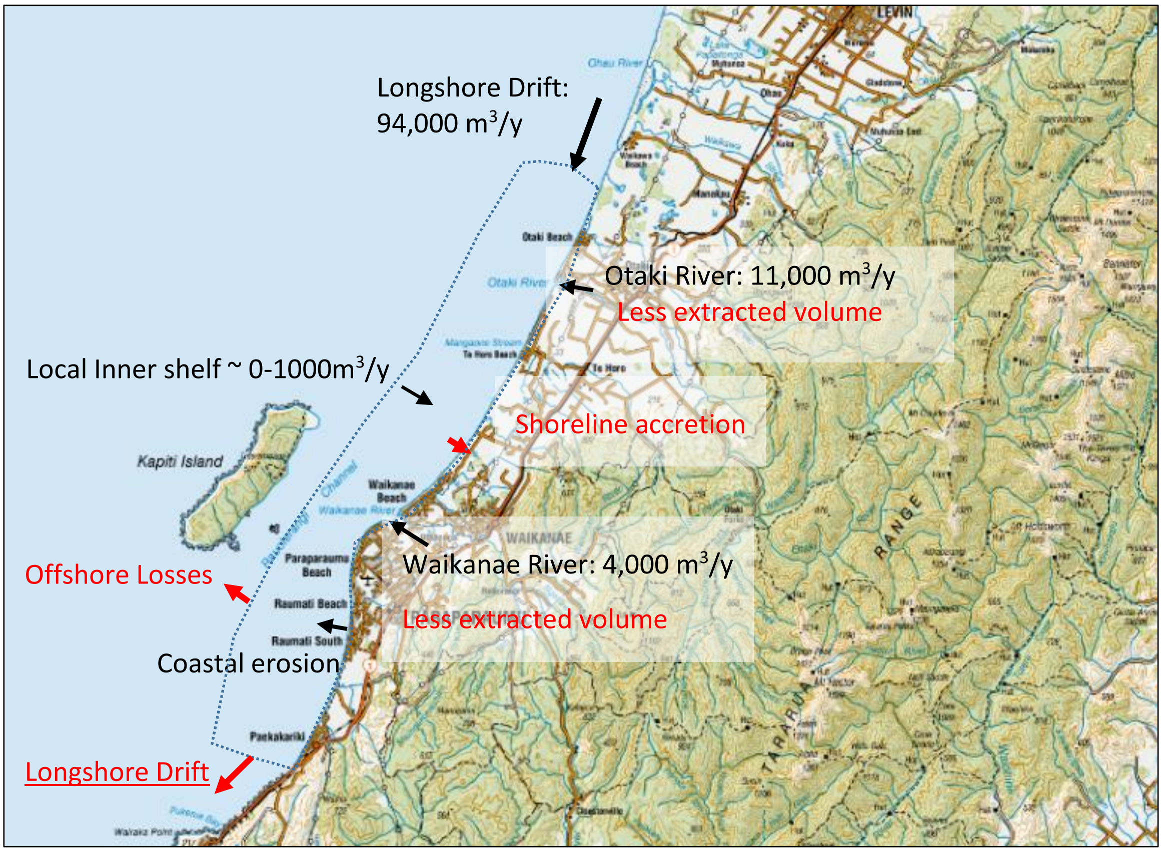

Figure 5: Sediment budget proposed by De Lange (2013) showing a proposed sediment budget into the Kāpiti Coast Littoral Cell (dashed line). Losses are shown in in red and credits in black.

Table 4: Sediment budget for the Kapiti Coast Littoral Cell proposed by De Lange (2013)

Credits		**Debits**	
Item	**m3/yr**	**Item**	**m3/yr**
Longshore Drift from North	94,000 [1]	Longshore Drift to South	Unknown
Ōtaki River	11,000 [2]	Ōtaki extracted volume that might reach the coast	Unknown
Waikanae River	4000 [2]	Waikanae extracted volume that might reach the coast	60-240 [4]
Other Streams	Unknown - minimal	Extraction from streams	~0
Coastal Erosion	Unknown	Accretion	Unknown [5]
Local Inner Shelf	0-1000 [3]	Offshore Losses	Unknown

1 Griffith and Glasby (1985)
2 Brougham and McLennan (1983)
3 De Lange (2013)
4 Derived from CSL (2002)
5 Net accretion derived from Lumsden (2013) for period 2000-2011 was approximately 70,000m^3

Williams (2013) notes that the gravel bed material of the Ōtaki River is relatively coarse: the medium size for the whole of bed material varies from 50 to 80 mm, and for the surface armouring layer it varies from 50 to 200 mm. According to Williams (2011) the Ōtaki River transports around 50,000 to 100,000 m^3 of gravel per year, with a substantial proportion reaching the coast, though no attempt to estimate the quantity exiting the system is made by Williams (2011), nor in the reporting on the gravel volume balancing exercises by Kutta (2016) and Gardiner (2011). The Brougham and McLennan (1983) estimate of gravel output to the coast on the order of 5,775-13,860 m^3/y implies gravel output to the coast may drop to approximately 5-20% of the sediment transport capacity further up the river.

De Lange (2013) notes from Hawke and McConchie (2006) that the mixed-sand gravel coast between the Ōtaki River and Te Horo has a positive sediment budget primarily derived from the Ōtaki River, with finer sand from further north largely bypassing it. Profiles and analysis by Lumsden (2013) indicates that this area is still accreting, continuing a trend of accretion from the Holocene (CSL, 2008a).

The cuspate foreland adjacent to Kāpiti Island which developed in the wave shadow in the lee of the island which acts as a large scale offshore breakwater and is one of the primary causes of long-term trend of shoreline advance from accretion north of Paraparaumu Beach compared to retreat to the South as far as Paekakarirki, as the foreland partially interrupts some of the sediment transport towards the south in a similar manner to a groyne. Gibb (1978) notes that notwithstanding long-term accretion, the coast is not stable and is subject to fluctuations in erosion and accretion on the order of 40-50m in response to severe episodic storms. The coast is also notable for its variety of seawalls. While holding the line of retreat the seawalls can also result in truncation of the beach profile and increased retreat adjacent to them.

CMC (2002) notes that bulk sampling and analysis of Waikanae riverbed gravels by Williams (1992) reveals that the content of sand decreases from about 16% at 1794m upstream from the mouth to 10%. The content of fine sand 0.125-0.25mm compatible with the beach is only 1 to 4%. The river bed above the tidal reach is predominantly pebble sized gravel.

CMC (2002) conducted an assessment of potential effects of gravel extraction from the Waikanae River on the Coast that remains highly relevant. In this he concluded that suspended load discharged by the river during floods is a source of fine sand for the Kāpiti Coast beaches. Such fines would be suspended during floods and not transported as bedload. Only 1-4% of fine sand is locked up in river bed gravels (from Williams 1992) in the reaches where the majority of extraction is proposed. Gibb concludes that, given that the most significant transport of sand is by suspended load alone and gravel does not contribute to the formation of beaches to the south of the Waikanae River, gravel extraction is unlikely to have an impact on rates of coastal erosion.

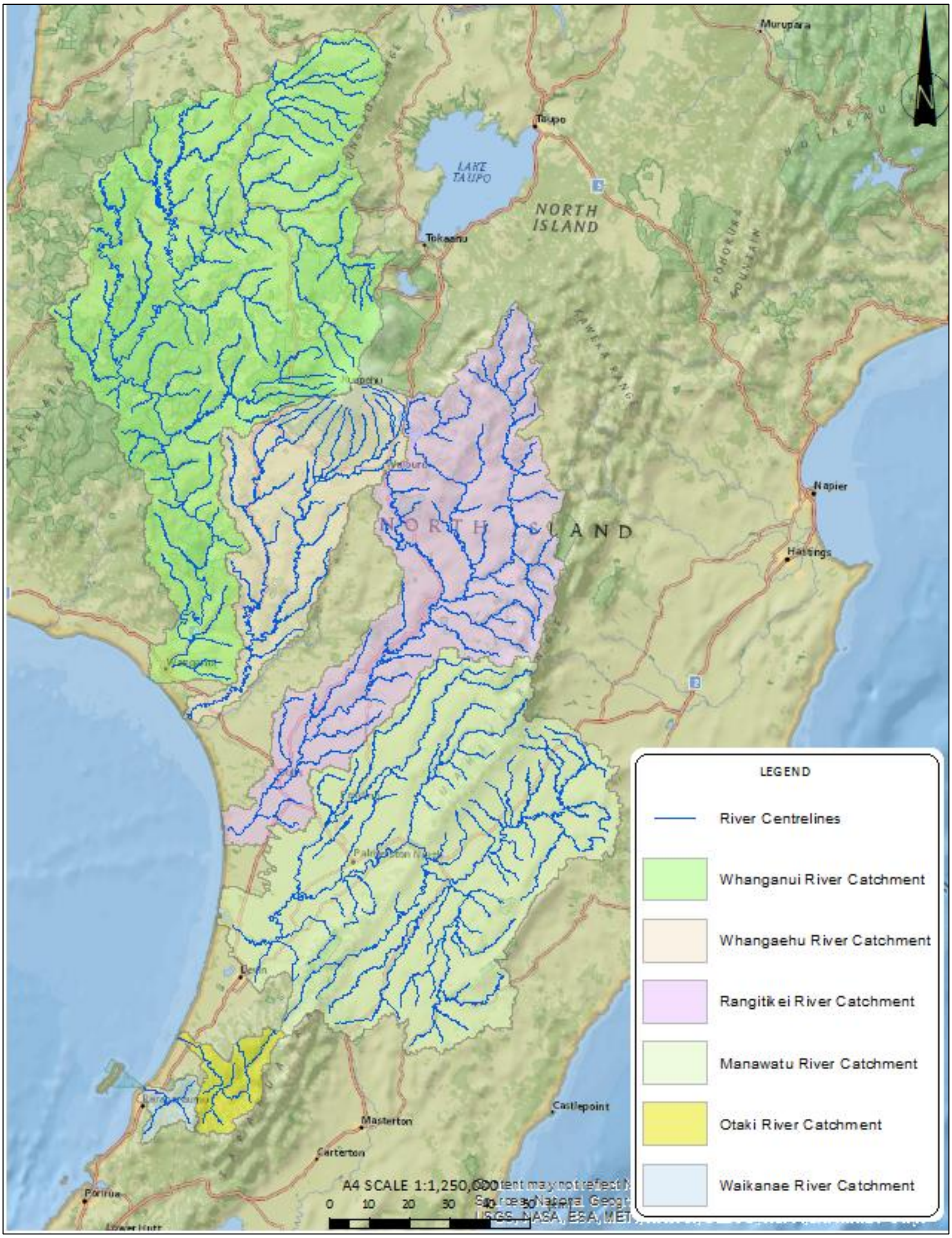

Figure 6: Map showing the location of the Waikanae and Ōtaki River Catchments, and other major river catchments further north which contribute a coastal supply of sediment to the Kāpiti Coast. Note the much larger size of the catchments north of the Ōtaki which is indicative of their larger sediment contribution.

4.3 Climate change

The potential for increased frequency and intensity of storms may cause an increase in supply of sediment to the rivers from their headwaters. While there may be some increase in the rivers ability to transport sediment, the current trend of river bed aggradation is likely to continue as long as the river remain confined to their managed corridors, and extraction will need to continue to maintain flood conveyance at current thresholds. De Lange (2013) notes that based on evidence reviewed in his work climate change is not a direct driver of sediment supply for the Kāpiti Coast.

The most recent sediment analyses for the Ōtaki River - Gardner (2011) and Waikanae River - Kutta (2016), do not consider potential changes in sediment budget as a result of climate change, but are rather focused on managing the impacts of cumulative aggradation measured since 1991 using bed surveys.

The sediment transport study Opus (2012) commented that the existing pattern of variability in flow in the Waikanae River contains greater variation from year to year than the overall shift predicted from climate change. Variability in stream flow and energy are therefore very much part of the normal, existing environment.

Opus (2012) also comments that the major impact of climate change on the sediment regime over the medium-term is likely to be a rise in sea level, and the consequential effect on the energy gradient within the river. The backwater effect caused by the interaction of sea level with the Waikanae River already has a significant effect on sediment transport below Otaihanga. The low bed shear stresses over this reach result in the majority of sediment being deposited, except during major flood events, and will likely exacerbate aggradation further. Opus (2012) does not make a conclusion on whether this will result in a drop in the supply of beach forming sediments to the coast, but it is a possibility.

De Lange (2013) notes that the development of the Kāpiti coastal plain occurred during a period of fluctuating sea levels, including intervals with higher sea levels than at present. He concludes that there is no clear relationship between regional sea level variations and the shoreline response along the Kāpiti Coast, and a trend of accretion has occurred regardless of whether sea level rose or fell.

Cardno (2014) makes the following comment about the effects of sea level rise relative to other climate change effects with respect to river mouths on sedimentary coasts: "given the speed at which inlets on sedimentary coasts demonstrably adjust, it can be reasonably assumed that future changes, due to climate change effects, will be due to alterations in sediment supply and/or wave climates (more intense storms, for example) or from changes to river flows due to alterations in rainfall/runoff conditions, not from increases in ocean water depths".

Cardno (2014) notes that as sea level rise occurs, the relative position of the entrance groyne on the southern side of the Waikanae River mouth is more likely to move relatively closer to the coast, becoming a more dominant feature and acting like an extended breakwater. As its dominance increases it is likely to modify the flow patterns and velocities that sustain the dynamics of the estuary. Eventually as the groyne penetrates the spit, the estuary is likely to totally infill due to the breaking off of the spit.

A change in the magnitude and direction of wave energy reaching the coast could have a significant impact on the direction of littoral drift and the sediment budget of the Kāpiti Coast. In their review of the coastal science undertaken for the proposed Kāpiti Coast District Plan, Carley et al. (2014) recommend additional investigation and analyses of beach-sediment budgets accompanied by examinations of the cumulative effects of climate change including increases in sea level rise, wave heights and surge level as well as the sediment volumes contributed by rivers.

5 Potential effects of activities

This section provides a commentary on what we consider to be the potential degree of impact of the activities based on our knowledge and a review of relevant literature.

The similarity of the activities in the rivers makes the commentary relevant to both the Ōtaki and Waikanae River systems. Where there are relevant key differences between the Ōtaki and Waikanae Rivers these are commented on separately.

5.1 Gravel extraction

5.1.1 Waikanae River

The Waikanae River lacks sufficient hydraulic gradient to move gravel all of the way to its river mouth. Gravel does not form a significant part of the beaches adjacent to and south of the Waikanae River, and gravel extraction from the proposed reaches will have a very low fine sand portion. In addition a major portion of the beaches in this area are formed and nourished from other major sources from north of the Kāpiti Coast.

CMC's (2002) concludes from Williams (1992) sampling of bed material in the Waikanae River that the bed contains only 1-4% fine sand. Most fine sand would be transported to the coast as suspended load. CMC (2002) does mention that river sediment sampling data from Williams (1992) is sparse and more samples would improve the confidence in this conclusion.

On this basis the proposed gravel extraction of a one off 30,000m^3 would represent a potential 300m^3-1200m^3 of fine sand loss of sediment that might contribute to the beaches south of the outlet and the 6000m^3/y over 5 years would represent 60-240m^3/y. Comparing this volume to the potential 94,000m^3/y of sediment supply from longshore drift that likely comprises most of the material of the Waikanae/Paraparaumu beaches, this represents a 0.0064%-1.277% loss for one year.

This suggests gravel extraction removes a very small proportion from the total beach sediment budget, and its loss is likely not significant. This is also evident due to the fact that the minerology of the sands of these beaches reflects their origin primarily being in the Manawatu Catchments (Kasper-Zubillaga et al, 2007).

Sea level rise may eventually result in a reduction in the energy gradient of the river at the lower reaches, reducing the sediment output to the coast. It is unclear on what the magnitude of this effect may be. However De Lange (2013) notes that there has been no clear correlation between sea level rise and shoreline response in the past.

Based on the literature reviewed, the proposed gravel extraction (regime which is adapted every 5 years based on bed surveys) is unlikely to have a significant effect on the rate of coastal erosion, provided the fine sand portion removed with the gravel remains low. A grading analysis representative of the extracted bed material from each reach would be able to confirm this.

5.1.2 Ōtaki River

Gravel from the Ōtaki River has been shown to contribute to the formation of the mixed sand gravel beaches south of the Ōtaki River Mouth to Te Horo.

It is likely that the Ōtaki River in its current managed state lacks sufficient hydraulic gradient to transport all of the gravel delivered from the upper reaches to the coast. This is the likely cause of the measured bed aggradation occurring in the river, as it attempts to adjust its grade and form to reach an equilibrium state where it can balance sediment input and output. This behaviour has been well documented in New Zealand gravel-bed rivers by Davies and McSaveny (2006). In its current state it is likely much of the gravel that is extracted would not be able to be transported by the river to the coast.

More gravel extraction occurred between the 1950s and 1980s in the Ōtaki River than occurred subsequently. Brougham and McLennan (1983) reported that extraction commenced around 1950, with an average of 63,000m^3/year until 1967. Between 95,000m^3 and 262,000m^3 per year was extracted between 1968 and 1977. After 1977 the extraction rate was reduced to 125,000m^3/y. These volumes are larger than the extraction from 1991 to the present, which has been approximately 40,000m^3/y. During the period of greatest extraction to the present, the mixed gravel sand beaches between Te Horo and Ōtaki have remained stable and accreted slowly as reported in Lumsden (2013), and Holland and Holland (1985).

Similarly to the Waikanae River, it may be probable that the Otaki River only contributes a minor portion of sediment to the beaches of the Kapiti Coast on the basis that the contribution from the river is likely proportionally very small to the contribution from longshore drift. However, this was not confirmed by sampling data or the literature reviewed.

Given that the mixed sand-gravel beaches south of the Ōtaki River have generally been stable or accreting based on historical surveys, this also suggests that the risk of proposed extraction resulting in shoreline retreat is low and the extraction strategy could be adapted if shoreline retreat is measured in the future.

Sampling of the river sediments proposed to be extracted as well as the sediments of the Ōtaki River beach may enable an assessment to be made on the relative contribution of the extracted river gravels to the beach might be. Further work to more accurately assess the contribution of the Ōtaki River to the sediment budget of the Kāpiti Coast would also be able to add confidence this.

5.2 River bank stabilisation

No significant new plantings, or bank stabilisation works are proposed (unless the river threatens critical assets such as stopbanks).

In general GWRC have enacted a policy of allowing the river some degree of meander freedom within its stopbank confined reaches by adopting recommendations in (Williams, 2013). This means that there is the possibility of some sediment stored in river banks being mobilised into the river and transported to the coast. Therefore this activity can be seen as positive or neutral in terms of its effects on rates of coastal erosion.

5.3 Channel shaping

Channel shaping is likely to break up armour layers and beach and berm colonising vegetation allowing mobilisation of sediment in less severe flood events, potentially increasing the rate of sediment movement, or allowing more frequent initiation of sediment movement. These activities may aid in the rate of sediment transport to the river mouth and therefore reduce the quantity of gravel extraction required.

This activity can therefore be seen as a neutral or positive activity in terms of rates of coastal erosion.

5.4 Management of river outlets

The outlet of the Ōtaki River, Waikanae River and Waimea Stream can naturally migrate both to the north and south of their upstream channels. For the purposes of minimising flood levels, the optimum alignment is the shortest route to the sea. As the outlet migrates from this alignment, hydraulic efficiency of the channel may reduce which may cause a consequent increase in flood levels upstream and erosion of the buffer areas protecting nearby dwellings.

For this reason, a new outlet at the river mouths may be cut when upstream water levels reach a certain point or when the mouth has migrated beyond certain pre-set trigger points shown in Table 5.

Greater Wellington Regional Council currently may cut a new opening as a permitted activity (with conditions), but often chooses not to depending on Flood Protection staff's professional judgement on the need to do so (*pers. comm. Sharyn Westlake*). GWRC seek to minimise the frequency of opening both due to the potential environmental effects of river mouth cutting, and the costs of carrying out the work.

Table 5: Trigger points for mechanical opening of stream mouths for the Ōtaki River, Waikanae River and Waimea Stream

River	Reason	Trigger
Ōtaki River	Erosion	When the channel outlet in the coastal marine area migrates either 300 metres south or 300 metres north of the centre line of the river measured 700 m upstream.
	Flooding	When the river mouth closes or the Rangiuru flood gates are unable to effectively operate due to high water levels.
Waikanae River	Erosion	When the channel outlet within the coastal marine area migrates either 500 metres south or 200 metres north of a projected line parallel to the centre line of the groyne on the south bank of the river.
	Flooding	When the water level increases 300 millimetres or more above normal river levels at the Otaihanga footbridge.
Waimeha Stream	Erosion	When the channel outlet within the coastal marine area migrates either 250 metres south or 150 metres north of a centre line determined by the training wall adjacent to Field way or the channel outlet creates a vertical scarp in the sand dunes which exceeds 2 metres in height.
	Flooding	When the water level increases 300 millimetres or more above normal river levels as measured at the Field Way road bridge.

The river mouths are constrained to migrate across a narrower extent to that which would occur naturally. Opening of the river mouths results in higher velocities through the river mouth flushing sandy sediment in the immediate vicinity of the river mouth out to the coast.

The material excavated during the cutting of a new channel is spread on the foreshore to assist in the realignment of the river outlet and /or erosion control at the outlet. This material will then be reworked by wave action and spread along the beach.

Cardno (2014) noted that the more frequently openings (natural and mechanical) of the Waikanae River mouth occur (whether natural or mechanical), the less time the estuary mouth has to migrate between breakouts, and hence greater infilling of the southern area of estuary is likely to take place.

Cardno (2014) notes that more frequent openings may occur in the future in response to more frequent storm events induced by climate change, or a period of more intense storm activity that may be associated with large scale climatic conditions such as a shift in the Inter-decadal Pacific Oscillation (IPO) and El Niño conditions. Since 2001, the Waikanae river mouth has been opened mechanically once, in 2001, and by flood in 2005.

The Waimeha Stream mouth is actively managed in order to ensure that it operates effectively in passing flood flows, and to ensure it does not create an unacceptable level of risk to the adjacent residential developments. The Waimeha Stream mouth has been cut 24 times since March 2000. The sediment contribution from the Waimeha Stream to the coast is negligible compared to the overall littoral drift, so no effects on coastal erosion are considered likely.

The Ōtaki River Mouth, which is able to flush gravel sized material out to the coast, results in a steep, narrow, high-energy beach near the river mouth. The Otaki River mouth has been cut five times since 1998: twice in 2002, and once each in 2005, 2009 and 2011. Mechanical opening of the river mouth may enable higher velocities and increased sediment transport to occur in the vicinity of the opening.

CSL (2008b) noted that a wetland has established in the original (pre-scheme) northern river mouth area. This has occurred because the area was sheltered from higher energy river and marine processes following the diversion of the Rangiuru Stream laterally into the Ōtaki River. The community group, Friends of the Ōtaki River, are focusing on restoring the estuary over the next few years, in conjunction with Greater Wellington Regional Council and Kāpiti Coast District Council.

The Ōtaki river mouth also appears to have taken on a more southward exit following stopbank construction. CSL (2008b) noted that there has been a southward trend which has continued in spite of mouth cutting towards the north, though the dominant southerly littoral drift is likely to contribute to this.

No literature was found regarding assessment of the potential effects of mechanical opening of the Ōtaki River mouth on the morphodynamics of the Ōtaki River Estuary.

Figure 6: Ōtaki River Mouth Estuary Wetland

6 Conclusions

Gravel extraction and flood management activities are necessary to keep the rivers confined in their managed margins to provide flood protection to people and properties and prevent river channel aggradation and reduction in flood capacity.

Previous work had concluded that gravel extraction from the Waikanae River was unlikely to have any significant effect on the rate of coastal erosion on the Kāpiti Coast primarily due to the fine sand portion being extracted (the portion significant to beach composition) being very small compared to the sediment budget contribution from other sources.

Gravel from the Ōtaki River does appear to contribute to the formation of the mixed sand gravel beaches south of the Ōtaki River Mouth to Te Horo. It is plausible that extraction of gravel from the Ōtaki River may at least slow the current measured rate of accretion on the mixed sand gravel beaches to the south of the Ōtaki River mouth. Given that the mixed sand-gravel beaches south of the Ōtaki River have generally been stable or accreting based on historical surveys during a long period of historical extraction, this suggests that the risk of proposed extraction resulting in shoreline retreat is low and the extraction strategy could be adapted in response to measured shoreline retreat if required in the future.

Bank stabilisation and channel maintenance are not likely to alter the rate of supply of sediment resulting in the rate of coastal erosion increasing on the beaches of the Kāpiti Coast as long as the rivers stay in their current form (i.e. a managed state).

Mechanical opening of the river mouths is also considered unlikely to affect the long term supply of sediment to the coast and the rates of coastal erosion.

Cardno (2014) provides a commentary on potential changes in the morphology of the Waikanae River Estuary over time. Cardno (2014) note that changes can result from sedimentation in the estuary and sea level rise. The rate of sedimentation may be affected by the frequency of natural and mechanical cutting, though the dynamics of the estuary are complex and currently not well understood. The frequency of mechanical opening of the river mouth has been rare since the development of the Waikanae River Flood Plain Management Plan with only one cutting in almost a 20 year period.

The effects of mechanical openings of the Ōtaki River Mouth have not been assessed in previous work that was reviewed. The beach in the vicinity of the Ōtaki River mouth has been stable over recent periods despite 5 openings between 1998 and 2011.

Climate change may have some impact on the rate of sediment supply to the coast, though previous work has noted that there has been no clear correlation between sea level rise and shoreline response in the past.

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8 Applicability

This report has been prepared for the exclusive use of our client Greater Wellington Regional Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

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