Shoreline Evolution and Potential Future Behaviour of the Waikanae Inlet Eastern Shore

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1.0 Introduction

This report examines the Waikanae Inlet in detail based on the information provided in the reports prepared by Dr Shand (2008 (a, b and c) and 2012) and further recent investigations (March and November/December 2013) undertaken by Coastal Zone Management and Planning (CZM and P), including site inspections, examination of aerial photographs and analysis of survey data obtained by Cardno on 22/11/13 and 3/12/13. The report focuses on the evolution of the inlet and on the potential future behaviour of the eastern shore in front of the Kotuku Park subdivision. It is supplementary to a report: CZM and P 2013/2 of March 2013.

CZM and P prepared this report for Cardno on behalf of their client Kotuku Park Pty Ltd.

2.0 Wave Effects on Coasts due to Climate Change

The Ministry of Environment (NZ) has made the following comment (MfE, 2008) in regard to changes to wave interactions with open coasts and estuaries/inlets with increasing water levels resulting from climate change:

"Raised water levels will permit larger waves on high tides to interact with more extensive shorelines and at a more frequent basis - potentially increasing the rate of erosion.....Given the dynamic nature of inlets and the complexity of sand exchange between subsystems, any reliable statement about how individual inlet systems may respond to climate change effects is extremely difficult to make." (provided by Dr Shand, pers. com.).

Yet the Ministry also recommends that in order to assess shoreline retreat of sedimentary shorelines, profile translation techniques should be employed. Clearly this is at odds. If the profile is translated there is no actual increase in water depth on the profile as its translation is both horizontal and vertical so as to achieve the same "equilibrium profile" simply further inshore and hence the wave action at the shore will be the same, for the same wave conditions. Therefore, it is not logical that this will increase erosion, over and above the profile translation. On the other hand wave heights at fixed structures, such as breakwaters or revetments, and on cliff coasts, can increase due to increased water depths, as profile translation cannot take place.

Climate change may result in the generation of larger waves offshore however this will result in an increase in surf zone widths rather than increase the height of shoreline wave breaks.

3.0 Historical Shoreline Movement Behaviour Assumption

In the existing reports (Shand, 2008 (a) and (b) and 2012) Dr Shand has made it clear he made the conservative assumption that where the historical trend of shoreline behaviour was one of accretion he would assume that it was zero. Further that, again for reasons of conservatism, he would apply a measurement uncertainty factor, but only as a negative.

In the general region of the coast adjacent to the Waikanae Inlet, this has had the effect of projecting forward a shoreline recession trend whereas the historical evidence is of shoreline accretion. Interestingly, if the historical accretion trend is projected forward it approximately cancels out the projected shoreline recession due to the forecast sea level rise for the next 50 years.

At the Expert Panel meeting on the 4th and 5th December 2013 this matter was discussed and the view that it was only valid to assume zero accretion after 50 years, was supported by several of the participants, including the writer. If this view is accepted then only the recession due to sea level rise from 50 to 100 years should be taken into account when calculating potential shoreline retreat in areas of the open coast where the above situation holds.

However, within the estuaries the behaviour will be different because sea level rise will also result in inundation of low lying areas and this, and the resulting sediment movements, need to be taken into account.

4.0 Natural Inlet Behaviour

When rivers and streams discharge to the sea through a littoral drift coast they tend to meander just before entering the open sea with the location of their entrances being determined by the net littoral drift at the time. While littoral drift coasts generally have an overall dominant direction of longshore sand transport, there may be short-term reversals from time to time. The net direction of transport is dependent on the net wave energy flux at the time. Climate phenomena such as El Niño and La Nina (ENSO), in the shorter term (1 to 5 years) and the Interdecadal Pacific Oscillation (IPO), in the medium term (30 to 50 years), can change the magnitude, and even the direction of the net wave energy flux and hence the magnitude and direction of the littoral drift.

It is therefore not unusual to find that river and stream mouths can range up and down the coast, to some extent, depending on the prevailing conditions. The stronger the dominance of one direction of littoral drift the more the river or stream tends to be deflected in the direction of that drift, before exiting to the sea. The ranging tends to result in the generation of what can conveniently referred to as an "estuary". This forms immediately behind the longshore drift spit, or bar that develops from the up-drift shoreline. The term "estuary" is being used here to differentiate it from the river or stream where water flow processes dominate, and from the open coast where waves and tides dominate. That is, an estuary is an area of mixed driving mechanisms. The term "Inlet" is taken to

refer to the entire morphological entity, from the open coast to the "throat" where it becomes the river.

The longer it is between floods and/or the stronger the littoral drift, the further the up-drift spit extends down-drift before a new flood breaks through the spit, generally on, or near, the main river alignment. When this occurs the cut-off section of the spit moves down-coast as a "slug" of sediment that tends to partially infill the estuary and/or moves off along the open coast, resulting in short to medium accretion of the down-drift beaches.

After a flood breakout, the longshore drift of sand on the open coast beach again starts to build the spit which, in turn, moves the entrance down-drift as the new spit evolves. The process repeats itself each time there is a break through the spit.

There is considerable experience in dredging estuary and river entrances on littoral drift coasts and on sandy coasts where there is no net littoral drift. The writer has been involved in such projects for several decades. While individual inlets may respond differently, the one thing clearly demonstrated over many years is that the hydrodynamics of inlets are determined by the prevailing tides, river flow, wave action and sediment availability. Even extensive dredging and reshaping of inlet mouths (thereby simulating potential climate change induced increases in depths and changes in morphology) is usually frustrated within months as the inlet rapidly returns to its pre dredged/shaped configuration.

Hence, 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. That is, there is abundant that inlets on sedimentary coasts will rapidly adjust to their 3D "equilibrium" morphology regardless of offshore changes in water depths over the next 100 years.

5.0 The Historical Evolution of the Waikanae Inlet

The scale and resources available for the Kapiti Coast Erosion Hazard Assessments (Shand, 2008 (a) and (b) and, 2012) meant that the 12 inlets of the Kapiti coast had to be analysed using a simple generic model. Shand (2008 (b) and 2012) recognised the limitations of this approach given the simplifying assumptions required and the lack of a robust scientific model for analysis of inlet behaviour. It was therefore considered reasonable for CZM and P to undertake a more detailed analysis of the Waikanae Inlet in order to more fully explore the potential future shoreline behaviour for the part of the estuary fronting Kotuku Park. The analysis utilises the information presented in Dr Shand's reports (2008 and 2012) and discussions and with Dr Shand Shand/Gordon); all gratefully acknowledged. The analysis is also based on the writer's extensive observations and experience with inlet management over

many years, and at various locations, as a coastal engineer and coastal zone manager.

At the Wakanae Inlet, the dominant direction of longshore drift is to the south (Shand, 2012) and hence the river mouth tends to meander south unless there is a flood, or mechanical intervention at which time it shifts back towards the northern end of its range. It has historically ranged further north on some occasions, probably due to medium term reversals in longshore drift. As indicated in the reports, this had a periodicity similar to that of the IPO.

In his reports Dr Shand (2008 (b), 2012) details the history of the estuary and the entrance behaviour. He points to the fact that in the 1800s the entrance to the sea was considerably further south, off Manly Street at the Foreland. Also the river discharge point into the estuary (the "throat") was further south, near the northern boundary of the Kotuku Park subdivision. However both these features have since moved north and there has been considerable infilling of the estuary.

As to whether the northerly movement of the throat since the 1800s was natural or artificial, or as to how much of the infill at north Manly Street was natural or constructed, appears unknown (Shand, pers.com. 6th December 2013). Dr Shand also reports that mechanical intervention in the 1940s, possibly along with some other influences, resulted in a major change to the morphology of the estuary with a substantial infilling phase of the southern portion of the estuary. This in turn created "new land" that was subsequently subdivided (the northern Manly Street area).

The end result has been the throat being stabilized in its current position by the construction of entrance groynes, and other works during the period 1960 to 1970 including the implementation of the Waikanae River Catchment Control Scheme between 1956 and 1964, for flood mitigation purposes. Also, the old (1800s southern) channel has in-filled (Shand, 2008 (b)). In addition, over the past 60 years, the behaviour of the lower Waikanae has been influenced by a number of factors including gravel extraction, channelization and bank stabilization (Shand, 2012). This has also, most likely, had an impact on the behaviour of the river and hence the estuary (Shand, 2008 (b)).

Another interesting, and complicating factor, was the separation of the Waimeha from the Waikanae system. According to Dr. Shand (Shand, 2012) this resulted in additional flow being diverted into the Waikanae. The removal of the natural detention effect of the Waimeha system and the associated floodplains and lagoons meant that flows in the Waikanae would have increased in intensity (reduced time of concentration). This in turn is likely to mean that the breakouts of the Waikanae, across the spit, would be more frequent and longer lasting (more violent breakouts result in larger channels), and hence the opportunity for the mouth to meander as far south as in the past will have been reduced.

Again a factor that also must be taken into consideration are the "trigger conditions" contained within the Wellington Regional Coastal Plan that require mechanical intervention (mechanical breakout) to take place when the channel

outlet (the estuary mouth) migrates either 500 m south or 200 m north of a projected line parallel to the centerline of the southern river mouth groyne, or if the water level increases to 300 mm above normal at the Otaihanga footbridge (Shand, 2008). It is understood that the Regional Council is legally obliged to act on these triggers.

It can therefore be reasonably concluded that shoreline movements within the estuary prior to the 1960s have little relevance to those of today and hence should not be used to determine the Inlet Migration (IM) curve base line for measurement. However it is important to note that the historic behaviour clearly demonstrates that, as the Waikanae has been moved north, stabilized, flow intensified, throat controlled with groynes and placed under a mechanical breakout regime, the southern shoreline has moved north sufficiently far to establish a new subdivision at North Manly Street and now an almost cut-off lagoon to the north of that. In other words the estuary is retreating northward.

Importantly Dr Shand recognizes that the shoreline realignment on the eastern shore (Otaihanga side) that has taken place between the late 1960s and the 1980s reflect a realignment of the shore to the prevailing conditions of the influence of the entrance groyne and the infilling of the southern portion of the inlet. The actual re-alignment of the shore, particularly as a result of the construction of the groyne is very much in keeping with the writer's extensive experience with shoreline re-alignment to such structures. Interestingly the shoreline re-alignment in the southern region is on going. The southern portion of the estuary is currently producing a rapid seaward progradation of the eastern shore in this area. Comparison of the 2007 aerial photographs with the more recent photos indicate a 90m (approx.) seaward movement of the high tide line, with the rate of movement being sufficiently great that the "new land" has not yet had the opportunity to become elevated above the storm inundation level (see Appendix 1, cross section 5).

Dr Shand notes that the shoreline of the central section has, since completing the transitional phase (1960s to 1980s), been "relatively stable" (Shand, 2012). Based on the writer's experience elsewhere, this result is as expected. That is, a seaward building of the shoreline as the local flow regime is altered by the construction of the groyne, with the greatest accretion occurring immediately adjacent to the groyne.

There is another factor that requires further consideration and that is associated with ocean wave penetration into the estuary region. While the estuary entrance still moves with changing littoral drift conditions and river flows/breakouts, albeit within far more constrained limits than it historically could, it still provides a window to allow modified ocean waves to enter the estuary and break against the eastern shore. However, the waves reaching the eastern shore have reduced energy because of both the shoaling losses that occur as they move across the shallow estuary, and through the diffraction and refraction effects due to the morphology of the entrance. The flow velocities within the estuary also impact on the losses and dispersion of the wave energy.

Given that the eastern shoreline is subject to some modified oceanic wave influences a reasonable way to address this potentially complex issue is to recognise that a key indicator of the energy being experienced by a beach, either open coast or within an estuary subjected to modified waves, is in terms of the relative beach widths and slopes. This approach also draws on experience with embayed beaches where the more sheltered end has a narrower, steeper beach than the wider, flatter beaches of the more exposed end.

Measurements taken by the writer, and survey information at Kapiti, in the vicinity of the Waikanae Inlet suggest that the active beach width (taken from mean water level to the location of the back of the active, un-vegetated, beach) on the open coast is between 30 and 40 m and that the slope is 2 to 2.5 degrees. The beach inside the Waikanae inlet, on the eastern shore in front of Kotuku Park, has a width typically varying from 5 to 10 m (the 10 m tends to be in locations where the back shore is low) and has a slope of approximately 6 degrees. That is, the morphodynamics as defined by the relative beach widths and slopes suggest the beach on the eastern side of the estuary, directly opposite the estuary entrance to the sea, suggests an energy condition equal to, or less than one third that experienced by the adjacent open coast. See Photos 1 and 2 for the contrast between the eastern shore beach of the Waikanae estuary and the open coast beach to the immediate south, at the Foreland.

6.0 The Future Evolution of the Waikanae Estuary

The following presents a conceptual model of how the estuary may evolve into the future. It is based on an understanding of the historical evolution to date, and the factors that have molded this development, along with the writer's experience over 40 years of studying the changing characteristics of a range of estuaries and river mouths.

If climate change brings more intense and/or regular rainfall (as seems to be predicted, and demonstrated by the criteria being set for bridges design to cope with significantly increased flow events) then, based on the current performance of the estuary and the river, it could reasonably be expected that breakouts through the spit (both mechanical and natural) will be more regular. The more regular the breakouts, the less distance the estuary mouth has the opportunity to migrate between breakouts and hence the greater the infilling of the southern area of the estuary.

Should the existing groynes be extended to the open coast beach alignment, in order to mitigate increased flooding brought on by climate change, or the mechanical intervention rate was sufficiently high that it significantly limited any meandering, the ability for the estuary to exist at all would be compromised and it would likely totally infill. This is well demonstrated by studying the impacts of breakwaters constructed worldwide. What this shows, is that when the shore parallel ebb and flood flows along the coast from the untrained, or partially trained (as is the current situation driving the morphology of the Waikanae estuary) entrances were cut off by breakwater construction, the flow in and out of the inlet becomes more normal to the shoreline alignment as the training

walls/or breakwater construction reaches the general coastal alignment. Within a very short period of time after breakwaters are extended to the point where they intersect the overall coastal alignment, the down drift beach/estuary experiences rapid infilling.

While currently there is no proposal to extend the groynes at the river entrance, should the ocean shoreline recede as a result of the impacts of sea level rise, a similar situation begins to develop. There are two ways of visualizing what is likely to happen. The first is with a fixed frame of reference, that is, the shoreline retreats. The second is by using a moving frame of reference, that is, the shoreline is held in place but the foreshore area effectively moves seaward at the rate of long term recession. Hence the entrance groyne on the southern side of the river mouth effectively moves westward, progressively becoming a more dominant feature, acting increasingly like an extended breakwater. As its dominance increases it is likely to modify the flow patterns and velocities that currently sustain the dynamics of the estuary. Eventually, as the end of the training wall penetrates the spit, the estuary is likely to totally infill due to the breaking off of the spit. Currently the distance from the overall coastal alignment (taken as the back of the active open coast beach) to the end of the southern groyne is approximately 100 m.

The purpose of the discussion on the topic is to point out the potential implications of general coastal recession on the estuary area. Greater intervention with mechanical breakouts and/or extension of the southern training wall will speed up the process of estuary infilling. Hence, counter-intuitively, long-term coastal recession combined with changes in rainfall may well result in estuary infill and therefore shoreline accretion of the eastern shoreline. Clearly this trend will be offset to some extent by the shoreline recession mechanisms, within the estuary, associated with sea level rise and subsequent inundation of any low lying land. That is, there will be an interesting tension between the forces for estuary in-fill due to the changed morphodynamics of the coast in the vicinity, and including, the Inlet, which will tend to drive shoreline progradation and the mechanisms of shoreline adjustment due to sea level rise and inundation driving shoreline recession.

7.0 Shoreline Recession due to Sea Level Rise – Bruun and Komar

There is an apparent anomaly regarding shoreline response to sea level rise. It has long been held amongst geomorphologists and geologists that the Holocene sea level rise of approximately 120 m between 15,000 years BP and 6,000 years BP was responsible for the accretional feature of many of the present day coastal plains (there was a similar situation during the Pleistocene sea level rise 120,000 years before present). Yet today it is commonly held that the projected 100 year climate change sea level rise, of around 0.9m, will result in shoreline recession. So how can a sea level rise of 120m produce massive accretion and yet a further sea level rise of only 0.9m result in recession? The question is potentially very important when considering the future of the Waikanae Inlet.

It is the opinion of the writer that there is a point of balance between whether a shoreline accretes or erodes as sea level rises. If the rise results in an excess of sediment in the "active profile", that is, the back of shore has a flat slope so as it is inundated by sea level rise, then the subsequent excess of sediment in the profile produces onshore movement. This is a similar mechanism to beach recovery after storm waves have eroded a beach, carrying sediment offshore to form bars and a wider surf zone thereby reducing the overall profile slope across the surf zone. The system responds by moving sand onshore to restore the beach. Further demonstrated evidence of the tendency to move sand onshore as a result of excess sand in the profile is provided by the practice of "profile nourishment". This is when a beach nourishment project, instead of pumping, or dumping sand directly onto a beach, pumps sand into the surf zone, thereby generating an excess of material on the subsurface profile. This material not only builds up the subsurface profile but also moves onshore, under natural processes, to build the sub aerial beach. Hence there is a considerable body of evidence that excess sand in the subaqueous profile produces onshore movement and beach building.

Again, like the opposite, a storm demand situation, if sea level rise encounters a substantial back beach elevation, the apparent surf zone slope is increased and hence the shoreline has to be eroded to flatten the slope to the "equilibrium profile" (or more correctly the "envelope of movement" associated with the "equilibrium profile").

On the eastern shore of the Waikanae estuary area the backshore region is relatively flat but wide (see Appendix 1, and Appendix 2: Photos 3 and 4). Hence it is argued that, while the backshore region will tend to be progressively inundated by sea level rise, this will trigger an onshore movement of material as a rolling over-wash deposit, as well as a beach/dune building mechanism.

Therefore the traditional theories of retreat due to wave action or profile translation can be considered to be of limited applicability, unless suitably modified to also produce beach building on a low lying backshore coast. That is, what is likely to eventuate on the eastern shore of the Waikanae estuary is a new, inland rolling, beach and dune system that will continually increase in bulk as it "feeds off" the excess material in the newly submerged profile region. The rate of progress of its retreat is likely to slow with time as it accesses more material; in the same way artificial profile nourishment builds subaerial beach systems.

Dr Shand has discussed both the Bruun and the Komar equations and has tended to favour Komar because of its simplicity and the fact that the results of using the "Bruun Rule" can be very variable, depending on the offshore limit to the profile parameter. However Komar has indicated that his equation was intended to predict storm erosion of dunes rather than sea level rise induced shoreline retreat (Paul Komar - Kapiti inquiry, 4th and 5th December 2013).

Of significance both approaches are for wave-dominated beaches on open coasts with no littoral drift taken into account. On the open coast at Kapiti the rate of littoral drift can be expected to contribute to the profile shape. Hence both the Bruun and Komar approaches may tend to overestimate erosion due to sea level

rise as material eroded from the subaqueous profile will be, at least in part, replaced through sediments being transported along shore by the littoral processes. Obviously the rates of both processes will determine the actual response.

Arguably, and given the rolling back process described previously, neither the Bruun, nor the Komar approach can be directly applied to the type of estuary shoreline that exists on the eastern side of the Waikanae Inlet. It may be possible to modify each approach by looking at the conceptual model described.

Interestingly, if a modified form of the Komar approach were used, so as to include the subaqueous "equilibrium profile", then it could be projected landward using the rise in water level due to climate change as the base driving mechanism. Such an equation could potentially predict shoreline movement if it assumed that the calculated overtopping of the dunes/backshore resulted in sand deposition equivalent to the excess material in the now inundated coastal profile. That is overtopping of the back beach lands would generate an eastward moving, "rolling", beach/dune system.

8.0 Future Shoreline Behaviour inside the Waikanae Inlet

Taking into account all of the proceeding but, for conservatism, setting aside the likely infill trend for the estuary as per the mechanisms described, the following argues the case for calculating the future shoreline behaviour on the eastern shore of the estuary, fronting the Kotuku Park development.

The equation used by Dr Shand inside the estuary is:

$$IEHD = IM - (LT + SLR + DS + CU) \quad (1)$$

Where:

> IEHD = the inlet erosion distance. In the case of the eastern shore of the Waikanae Inlet fronting Kotuku Park (also referred to as the Otaihanga side) it is argued that this should be the "shoreline retreat distance" since it is likely that this retreat will be by a mechanism of a rolling back through over wash rather than an erosion process.
>
> IM = the inlet migration. That is, the baseline from which shoreline retreat is measured. In his generic approach Dr Shand sets the IM as the landward locus of shorelines over the available period of history and drops the SD term used for the open coast. In the case of the Waikanae Inlet, and based on the history presented by Dr Shand, it is considered reasonable that, due natural and man made disturbances to the river and inlet, shorelines prior to the late 1980s should be disregarded. Further, even after 1980 the evidence is that the back shore in the vicinity of the old river mouth, and in the southern region of the southern portion of the eastern side has continued to build in height due to over wash deposits and hence the shoreline has "firmed up" as a more continuous curve line from the groyne

to the Manly Street area. It is also noted that, Dr Shand comments that the overall shoreline in the central area along the Otaihanga side has been relatively stable since the 1980s. It is therefore argued that the current shore, as defined by the survey data, obtained November/December 2013, and included in Appendix 1, be used as the reference line. This argument is reinforced by the fact that in June 2013 there was a major storm that caused significant erosion on the open coast. However, on the eastern shore of the Inlet only resulted in minor erosion in the area directly opposite the mouth (see photo 1, Appendix 2) and, in keeping with the conceptual model presented previously, also caused over wash and build up in elevation of the lower back shore region adjacent to where the erosion took place. The small (1 to 1.5 m or less) erosion scarps can be seen on the survey plans and in the photo 1 (Appendix 2). This argument is in keeping with the shoreline evolution discussion presented previously. It is noted that the morphodynamics described previously suggest that the eastern shore of the inlet is exposed to approximately one third of the storm erosion energy as the open coast. Hence, if an SD term were to be reintroduced, because of the limited information available to reliably establish an Inlet Migration Curve, the value would be between 4 and 5 m; being a third of the open coast values of 12m to 15m.

On cross section 5 there is apparently an anomalous result. This cross section was purposely selected to pass through an area of extended low backshore where the evidence was that during storm events there had been extensive over wash (debris extending up to 80 m inshore). This is a region currently undergoing rapid infill. Contrasting the 2007 aerial photographs to the more recent photos demonstrated that, in this region, the shoreline has moved approximately 90 m seaward during the past 5 years as a result of infilling of the southern end of the estuary. The “old” shoreline is evidenced on the recent aerial photography as a line of darker vegetation, and on the survey information and as a topographic rise commencing approximately 50 m seaward of the Kotuku Park boundary.

Given the regency of the infill trend (as could be expected by the conceptual model of estuary shoreline behaviour presented previously) it is considered that the incipient vegetation, the debris and the progressive incursion of more permanent vegetation indicated that the region is actively undergoing vertical build up. Interestingly, the top of the current debris line (marking the run up level) at cross section 5 was RL 1.4 m, which is slightly higher than the debris level on most other cross sections (approximately RL 1 m), but is the level of the back of the active beach on those profiles. Under “normal conditions” the beach morphology in the cross section 5 region creates an incipient berm at the “normal” maximum run-up level, but during “storm” conditions this berm is overtopped and debris and sediment is washed further inland.

The lack of escarpments features inshore of the current beach (and current minor scarping at the immediate back-of-beach), on most cross sections, along with the increasingly intensifying permanent vegetation (based on examination of aerial photographs and field inspections) is interpreted as

demonstrating that storm cuts in this region are modest (in keeping with the assessed 4 m to 5 m, above) and confined to the immediate back of beach formation. However the lower back beach areas, as represented by cross section 5, do experience over wash inundation during major events.

Table 1 presents the assessed shoreline locations that it is believed should be used in defining the inlet migration baseline. All "distances to shoreline" are taken from the survey plans in Appendix 1 and are relative to the location of the seaward (Western) boundary of the Kotuku Park property, and the back of the active beach, taken as the base of the escarpment, or where there is no escarpment, the crest of the Back-of-beach berm.

Table 1: Distance of Current Shoreline from Kotuku Boundary

Cross-section No.	Distance from Kotuku boundary to current shoreline	Elevation of rear of active beach (RL)
1	+ 95 m	+ 1.4 m
2	+ 82 m	+ 1.4 m
3	+ 94 m	+ 1.4 m
4	+ 110 m	+ 1.4 m
5	+ 142 m (+ 60 m)*	+ 1.4 m
6	+ 118 m	+ 1.4 m

* The currently very low flat back beach that has been produced by the rapid progradation of this part of the estuary because of the longer term estuary in-filling presents two alternative results. It is considered likely that over time, the over wash build up and other natural processes will elevate this area meaning the 142 m distance will become the singular meaningful value.

LT = the historical long-term shoreline change of the open coast. The use of the LT term in determining the inlet shoreline movements for the future is difficult to reconcile with the very different dynamics that clearly apply. It is relevant to note that the evidence provided in Dr Shand's reports (2008 (a) and 2012) shows that the open coast in this region has been undergoing modest accretion over the historical record, even though there has been an absolute sea level rise trend during this period. Further, the evidence for the eastern shore of the Waikanae Inlet, as presented by Dr Shand, and evidenced by the survey results, has been one of historical accretion followed by a period of relative stability, although, in the southern region the aerial photography demonstrates that rapid accretion is continuing (90m since 2007). Hence, it is argued that to include an LT term in

determining the future shoreline position for the eastern shore of the Waikanae Inlet is unreasonable. Therefore the LT term can conservatively be disregarded in determining the future location of the eastern shoreline of the estuary.

SLR = the shoreline recession due to sea level rise. The use of the open coast SLR calculation in the inlet model is clearly inappropriate as the profile adjustment approach used by Bruun (1983) was developed for shorelines where wave action, and the resulting equilibrium profile, is the determining factor, and that by Komar et al (1999) was for storm wave erosion into dunes. Neither were intended to be applied to estuary bank shorelines, particularly those with low back-shore topography. The mechanism of inundation of low back beach regions and the resulting and rollback of shorelines is a key factor to consider when determining the future trends.

For the purpose of this analysis a conservative shoreline response to sea level rise, on the eastern shore of the Waikanae Inlet, the following assumptions have been made. Firstly it is assumed that the high range IPCC scenario for absolute sea level rise can be adopted as the relative sea level rise (RSLR) for the inlet, that is, the relative sea level rise by 100 years hence will be of the order of 0.9 m (this assumption has been made even though the writer is of the view it probably overestimates the RSLR). Secondly it is assumed that sediment inflow from the rivers and streams will cease (again the writer is of the view this is a very conservative assumption). Thirdly it is assumed that the conceptual model of the estuary infilling processes outlined previously doesn't occur (again the writer is of the view that this is overly conservative).

Hence the simple model used is one of taking the existing profile and transporting it landward, and elevating it in accordance with the 0.9 sea level rise until the top of the active beach profile (current RL + 1.4m) intersects the topography, that is, at a consistent level of RL 2.3m (1.4 m + 0.9 m). Note that for cross section 6 the dune immediately behind the beach has been disregarded as it is felt that it would be redistribute longshore into the lower lying areas. The distances of the resulting SLR induced shoreline retreat for the 100 year sea level rise are presented in table 2.

Table 2: SLR induced Shoreline Retreat

Cross-section No.	Retreat of shoreline from current location, due to RSLR	Distance from Kotuku boundary to shoreline
1	+ 43 m	+52 m
2	+ 28 m	+ 54 m
3	+ 22 m	+ 72 m
4	+ 56 m	+ 54 m
5	+ 61 m	+49 m
6	+ 68 m	+ 50 m

DS = the dune scarp retreat. This is a strange term when applied to inlet banks as there is actually no dune, as there is on the open coast, just a slightly elevated backshore (typically RL + 1.5 to 2 m). However, the “DS response model” used on the open coast may well be appropriate as it is actually based on a simple bank collapse approach and is not altered by the manner in which the collapse is initiated (waves or inlet flows). The only issue is that the use of the bank collapse approach is likely to give a conservative result because, unlike the open coast, inlet bank vegetation is generally far denser and more erosion resistant, hence banks are often steeper. It is recognised however that where shorelines are rapidly prograding the vegetation needs time to develop and therefore should not be taken into account as a dune binder, and hence the equation Dr Shand used to calculate DS is considered appropriate. Therefore, applying the equation: $STR = h/2(\tan \alpha)$, where STR is the landward movement the scarp top must retreat to achieve dune stability (DS), h is the height of the escarpment, on the eastern shore this varies between 1 and 2 m, and α is the stable slope for sand (approximately 34 degrees) then DS is in the range 0.75 m to 1.5 m, say 1.5 m.

CU = the cumulative measurement uncertainty factor. This factor is an artifact of the conservative analysis based on the limited information and resources available to Dr Shand at the time of his reports. Given the now available survey data presented in Appendix 1 it is no longer appropriate to include this factor.

It is therefore argued that the Inlet Migration Curve base line should be based on the offset distances presented in table 1 (as obtained from the survey data in Appendix 1) and that the appropriate equation that should be used to most reasonably calculate the shoreline in 100 years time is:

$$IEHD = IM - (SLR + DS) \quad (2)$$

Where IM is approximately the current shoreline

or, more conservatively, and taking into account the limited period (post 1980s) where the IM approach is meaningfully applicable:

$$IEHD = CS - (SLR + SD + DS) \quad (3)$$

Where: CS is the current shoreline location
DS is 1.5 m and SD is 5 m (⅓ of the 15 m for open coast)

9.0 Conclusions

The application of the above equation (3) leads to the following defining distances for the 100 year shoreline, relative to the western boundary of the Kotuku Park subdivision:

Table 3: 100 year definition of shoreline (assuming a 0.9m sea level rise)

Cross-section No.	Distance from Kotuku seaward boundary to shoreline (rounded down)
1	+ 45 m
2	+ 47 m
3	+ 65 m
4	+ 47 m
5	+ 42 m
6	+ 43 m

It is noted that the cross sections, and the aerial photographs suggest that the above intersections of the shifted profile with the existing topography may well be along the line of a previous shoreline, which existed under different conditions to those that prevail today. It is also noted that landward of these intersection points the elevation of the current profile is generally slightly lower.

It is emphasised that a number of simplifying, very conservative, assumptions were made in developing this model of retreat (see Section 8, SLR). The rolling back of the eastern shoreline will make available a considerable volume of sediment (estimated to be 115 cu m/m run of shoreline – average 46 m retreat by 2.5m scour needed to re-establish profile) to be moved onshore to build a berm and a "coastal plain" in front of Kotuku Park. Further, no account has been taken of further estuary infill due to the processes previously outlined. Finally, by including both and SD and a DS term in equation 3 implies that a storm producing the SD component occurs in the 99th year and at a time when beach recovery has not taken place but full dune slumping has occurred.

Hence it is considered that the figures shown in Table 3 reasonably demonstrate a very conservative estimate of the projected 100 year shoreline, and that the shoreline will be seaward of the Kotuku Park boundary.

10.0 References

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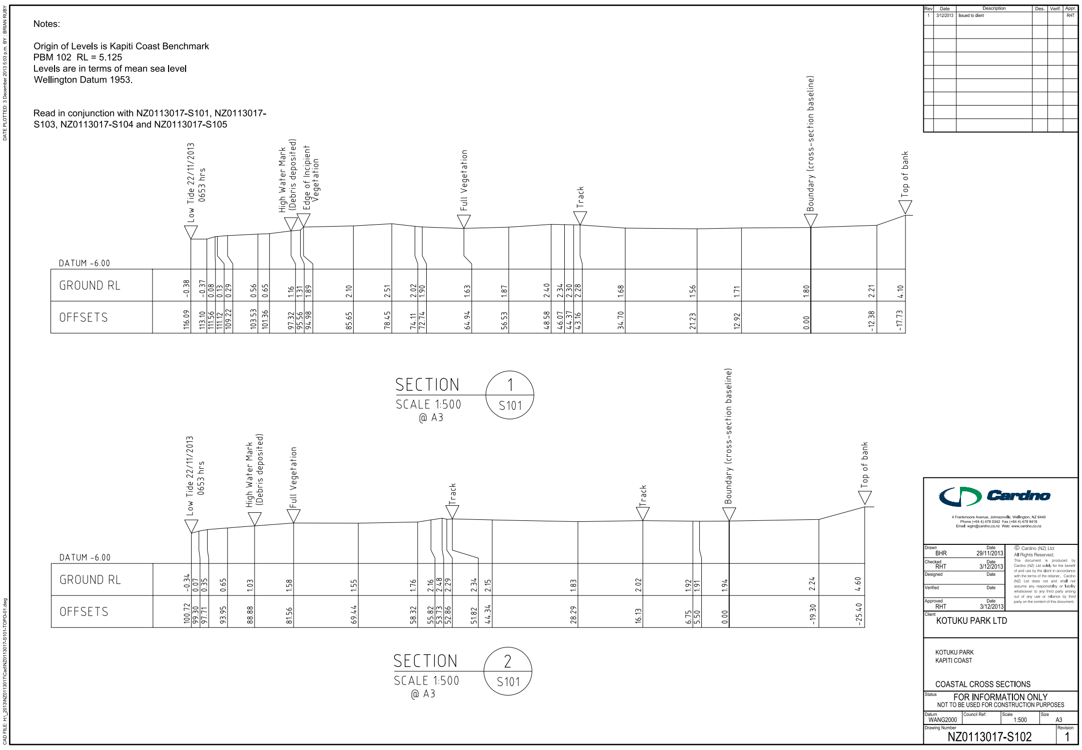
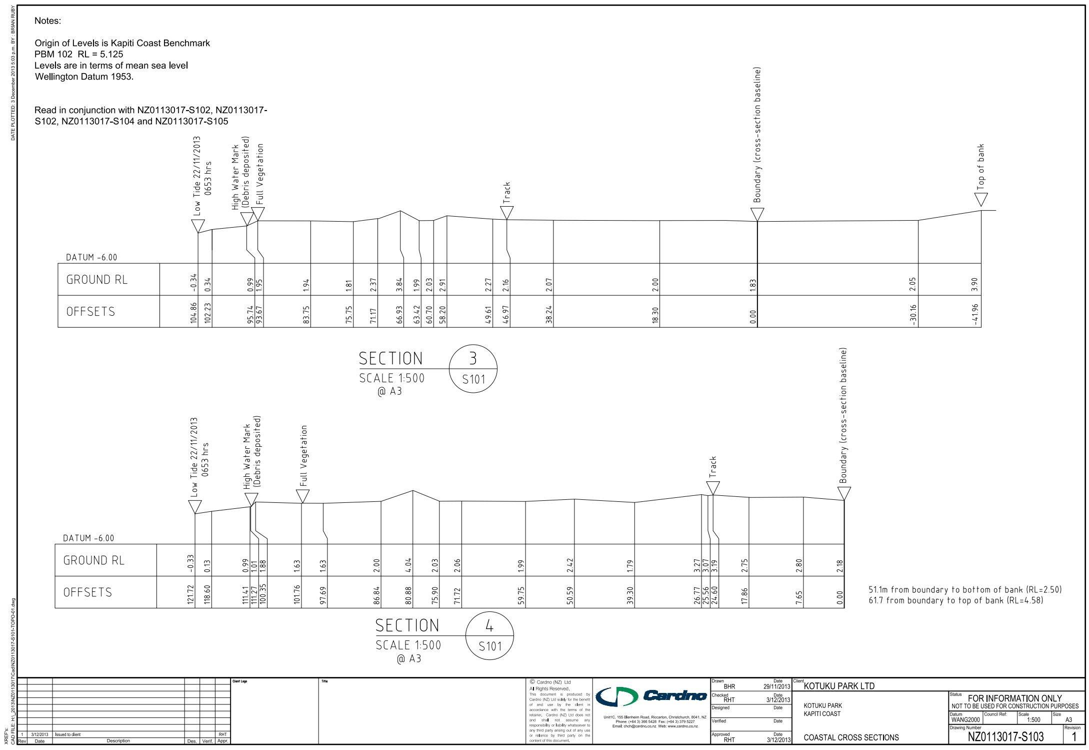
Appendix 1: Survey Data supplied by Cardno

Surveys undertaken by Cardno, 22nd November and 3rd December , 2013

Aerial showing the location of survey lines and spot heights, northern Kotuku subdivision and the location/spot heights of cultural features



Cross sections 1 and 2



Cross Sections 3 and 4

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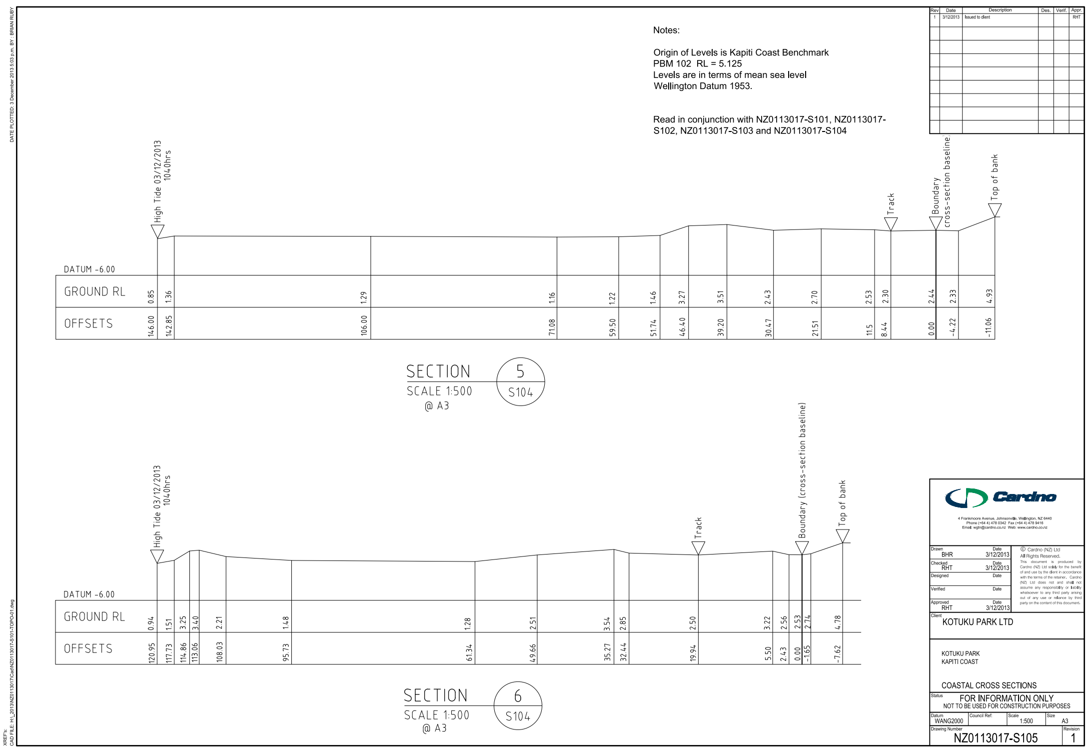
Aerial showing the location of survey lines and spot heights, southern Kotuku subdivision and the location/spot heights of cultural features



Cross sections 5 and 6

Appendix 2: Photos (3/12/2013)

Photo1: Beach of Waikanae Eastern Shoreline (near high tide)

Photo 2: Ocean Beach adjacent to Waikanae Inlet (near high tide)

Photo 3: Region between Kotuku Park and Waikanae Eastern Shore

Photo 4: View across region from Kotuku Park boundary (fence) to Inlet shoreline