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MEMORANDUM

TO: BAY OF PLENTY REGIONAL COUNCIL

ATTENTION: PIM DE MONCHY AND STEVE EVERITT

FROM: JIM DAHM, ECO NOMOS LTD

SUBJECT: KAITUNA RIVER RE-DIVERSION AND ONGATORO/MAKETU ESTUARY ENHANMCEMENT PROJECT: EFFECTS ON COASTAL AND RIVERBANK EROSION AND MORPHOLOGY

DATE: 11 JUNE 2014

As requested, this memo provides an assessment of the potential effect of the proposed re-diversion on shoreline erosion risk around the estuary margin and along the river edge, including Maketu Spit opposite the marae, Beach Road seawall, foreshore of the township, Papahikahawai Island, the margin of the Corbetts land, Ford Island, the new re-diversion channel and lower Kaituna River.

The assessment is based on the modelling report recently completed by DHI (DHI, 2014), a field inspection conducted on Thursday 24 April, previous reports and historic information, and previous experience working on the earlier Kaituna River re-diversion proposals in the 1980's. All depths and elevations discussed in the report are relative to Moturiki Datum (approximate mean sea level) unless otherwise noted.

1 Coastal Erosion in Lower Estuary

The foreshore of the lower estuary encompasses the shoreline around the landward edge of the extended flood tide delta system – including Beach Road, township foreshore, Maketu Road and the spit from the Maketu entrance to about 1.5 km further north (Figure 1).

1.1 Effect of Original Diversion and Proposed Re-Diversion

The diversion of the river away from the estuary in 1956 significantly altered the lower harbour through both enlargement of the flood tide delta (Burton, 1987) and (further upstream) progressive loss of large areas of rushland (Park, 2014).

Figure 1: Lower area of Ongatoro/Maketu Estuary showing harbour and shoreline areas. The harbour shorelines discussed in Section 1 include the entire shoreline from the entrance to Maketu Road and the landward margin of Maketu Spit. The chenier island features referred to in Section 1.6 are arrowed. (Photo Source: Google Earth imagery – flown 26 July 2013).

Prior to diversion, most of the estuary tidal prism was infilled by river flows which also augmented ebb discharges on outgoing tides. At this time, the flood tide delta was a relatively minor feature (Figure 2).

Following the diversion of the river through Te Tumu Cut, flood tide inflows markedly increased to compensate for the loss of river flows; significantly changing the balance between inflows and outflows and causing significant expansion of the flood tide delta (Figure 3).

The DHI modelling indicates that the proposed partial re-diversion of river flow associated with the Kaituna River Re-diversion and Ongatoro/Maketu Estuary Enhancement Project will significantly increase ebb outflows relative to flood tide inflows; reducing the area dominated by flood tide directed net sediment transport and increasing the area dominated by ebb directed sediment transport (DHI, 2014; see also later discussion in relation to Figure 6). The proposed re-diversion will therefore partly reverse the effects of the 1950's diversion. Over time, this is likely to result in the expanded flood tide delta being reduced in size. The effects of these changes on coastal erosion are briefly discussed below.

Figure 2: Vertical aerial photograph from April 1939, prior to diversion of river from the estuary (see text for discussion).

Figure 3: Aerial photograph of estuary dating from November 1959, shortly after diversion showing the enlarged flood tide delta (arrowed). See text for further discussion

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1.2 Beach Road

In its original natural condition before road construction, a narrow estuarine beach occurred along this area (Figure 4). This beach overlies a shore platform formed by historic erosion of the higher banks to landward; the original cliff faces now vegetated. As the beach formed, it protected the cliffs from further erosion. Rock outcrops sacred to local iwi outcrop in the channel along the seaward edge of the beach.

The formation of the original road encroached over much of the beach area above high tide within the estuary, except at the township and seaward ends. Accordingly, the road was subject to periodic erosion even prior to diversion of the river in the late 1950's – as evidenced by shore perpendicular groynes placed to protect the road shown in historic photos (Figure 5).

Figure 4: View of Beach Road and lower estuary in 1880's.

Figure 5: View of lower estuary in 1955 (Whites Aviation photo, Alexander Turnbull Library).

However, prior to diversion of the river in the 1950's, the channel adjacent to the beach extended only along the outer and central areas of Beach Road - being fronted by shallow intertidal areas at the township end (Figure 5). Following the diversion, the channel extended further landward and around the front of the township due to the increased flood tide inflows (Figure 3). The enlargement of the flood tide delta also tended to push this channel towards adjacent shorelines (Figure 3). These changes in wave and tidal forces on the shoreline aggravated erosion and contributed to the need for early rock sea wall protection evident by the late 1960's.

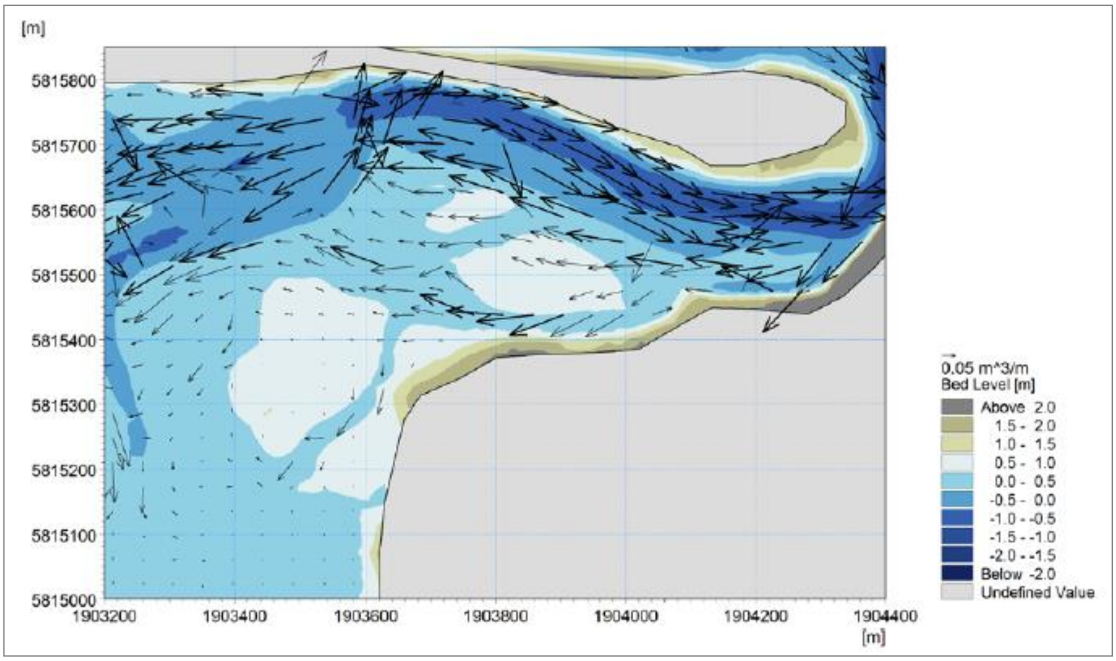
In more recent years, Beach Road has been widened into the estuary, requiring the placement of extensive rock protection which has encroached over much of the beach width and into the adjacent channel.

Modelling by DHI (2014) indicates the proposed Kaituna River Re-diversion will significantly reduce the dominance of flood-tide residual sediment transport in the channel fronting the Beach Road rock wall, with some areas of the channel even becoming ebb-dominated (Figure 6). The changes in the pattern of ebb- and flood-dominated sediment transport predicted by the modelling are significant. These changes are very likely to give rise to morphologic change over time – as the pattern of flood- and ebb-tide dominated sediment transport has a significant effect on the morphology of harbours and flood tide deltas.

As noted by DHI (2014), the exact morphologic outcome is difficult to predict. Nonetheless, the hydrodynamic changes partly reverse the effects of the 1956 diversion of the Kaituna River through the Te Tumu Cut. Accordingly, the direction of morphologic change over time is likely to move the harbour morphology back towards that shown in Figures 2, 4 and 5. The re-diversion is unlikely to completely restore the morphology that prevailed before the 1956 diversion as it only diverts part of the river back through the estuary. However, given the significance of the changes in sediment transport (Figure 6), it is very likely to move the harbour morphology back in that direction and therefore to partly reverse some of the bathymetric changes that followed the 1956 diversion.

While the exact morphologic outcomes are difficult to predict, the changes could include some reduction in the depth and extent of the channel adjacent to Beach Road and some movement of this channel away from the shoreline at the township end. The changes are therefore not likely to increase scour along the edge of the rock protection along Beach Road. In the more seaward areas of the channel, the modelling predicts a change from flood- to ebb-directed net sediment transport (Figure 6). Accordingly, there may be a slight increase in channel depths here but not sufficiently to significantly affect the rock protection. Similarly, any changes in tidal current velocities will have no adverse effect on the stability of the structure; which is designed for the much higher energy wave conditions periodically experienced - associated with refracted storm waves propagating into the harbour through the entrance during storms with elevated sea levels. These storms are the only events likely to damage the rock wall and they will be unaffected by the Project.

The existing rock protection works are only of moderate engineering standard and could suffer severe damage during a major wave event. Upgraded rock protection has been



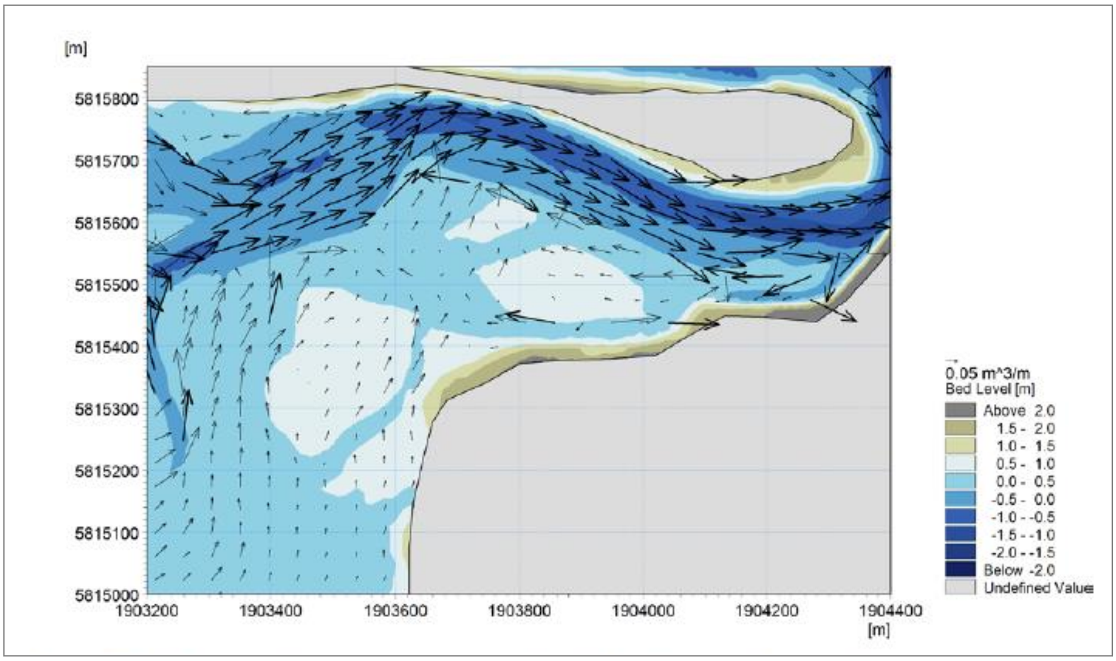


Figure 6: Residual sediment transport rates (m^3/m) over flood tide delta area for mean river flow and a neap-spring tidal cycle – showing existing situation (top) and predicted situation following the proposed re-diversion (bottom). (Figures provided by DHI from modelling reported in DHI, 2014).

designed and consented for this area, but has yet to be constructed (Mr Steve Everitt, Waterline Ltd, pers. comm.). Design drawings indicate that the upgraded rock protection includes improved rock sizing and grading, as well as a toe extending 2.5 m below the channel bed. This protection, once constructed, will provide a much improved level of protection against extreme wave events. Changes accompanying the proposed diversion are not likely to compromise the performance of the structure.

1.3 Foreshore of Main Township (Park Road Area)

Prior to the diversion of the river from the estuary in the late 1950's, the main township foreshore was fronted by a wide sandy beach and shallow intertidal areas (Figure 5). The wide sandy beach underwent minor dynamic shoreline changes over time but is evident in all available aerial photos prior to the diversion (including vertical and oblique aerial photos dating from 1939, 1948, 1953 and 1955).

The relative stability and permanence of the wide high tide beach area led to the local community raising and grassing the area to form a reclamation registered in October 1955 (DP 37678) - though the term reclamation only applies accurately to a small part of the area, as most of the area was already landward of high tide (Figure 2) and simply raised. Photos from before the diversion clearly show a wide vegetated area fronted by a gently sloping sandy beach, with no protection works required (e.g. see Figure 2 and Figure 5).

Following diversion, the increased flood tide inflows formed a channel along the foreshore and this channel also moved landward as the flood tide delta expanded (Figure 3). This resulted in rapid erosion of the foreshore in the years immediately following the 1956 diversion at Te Tumu. This erosion, caused by the effects of the diversion, eventually led to rock protection being placed to protect the eroding foreshore and township – rock protection being evident in aerial photos dating from at least 1963. The erosion and the placement of the rock protection resulted in loss of the beach along the foreshore.

The DHI modelling notes that the proposed re-diversion will significantly reduce flood tide directed sediment transport in this area (Figure 6). Over time, this is likely to reduce the expansion of the flood tide delta which pushed the channel close to the shoreline. While the final morphology is difficult to predict, the direction of change is likely to be back towards the gross morphology which existed prior to the diversion (see Figures, 2, 4 and 5). The changes are likely to lead to some shallowing and reduced erosional forces along the foreshore.

It is not clear if the reduction in the flood tide delta and accompanying changes will be sufficient to restore a sandy beach seaward of the present rock protection – particularly as the existing rock protection is close to the seaward edge of the high tide beach that existed prior to diversion of the river from the estuary. However, the changes may increase the potential for softer protection options and enhanced beach amenity – though full restoration of a high tide beach (if desired by the community) might still require some retreat of the rock protection.

The potential shallowing over time could affect the present boat ramp and, depending on the changes experienced, it may need to be moved. These changes should be monitored.

1.4 Town Foreshore – 733 Maketu Road to Marae

This foreshore area extends from the northern end of the Park Road parking area to the sports field.

Prior to the diversion of the river from the estuary, this shoreline was characterised by a sandy beach fronted by a shallow intertidal flat, with shallow low tide channels located further offshore (see black arrow in Figure 7). This morphology is consistent in all aerial photos pre-dating diversion of the river (e.g. Figure 2).

Figure 7: View of marae and southern township foreshore in 1955 (Whites Aviation photo, Alexander Turnbull Library). See text for discussion of arrows.

Following diversion, aerial photographs indicate that ongoing expansion of the flood tide delta into the estuary (accompanying the marked increase in flood tide inflows) gradually pushed a tidal channel close to the shoreline (e.g. Figure 1 and arrowed Figure 8).

This interpretation is supported by the DHI modelling which indicates that the intertidal areas immediately offshore are presently strongly dominated by flood tide sediment transport (see top figure in Figure 6 – a copy of Figure 7.6 from DHI, 2014). It is also supported by field inspections of bedforms and gross morphology conducted during this study - which indicate that shoals dominated by flood-tide sediment transport presently hold a narrow ebb-dominated tidal channel close to the shoreline.

The increased nearshore tidal currents and depths that occurred following the diversion appear to have exacerbated shoreline erosion during wave events, resulting in protection works being placed along much of the shoreline. Field inspections suggest that coastal erosion along this foreshore is primarily controlled by combined wave and tidal action. At present, various forms of erosion protection (some of poor engineering standard) are visible along the shoreline eastwards to about the marae.

Figure 8: 1988 aerial photograph showing growth of flood tide delta has pushed small channel (arrowed) hard against the foreshore fronting the marae and adjacent areas – as also occurred in the area fronting Park Road.

The DHI modelling indicates that the proposed re-diversion will significantly reduce flood-tide directed sediment transport in the areas immediately offshore from this shoreline (see bottom map in Figure 6 – a copy of Figure 7.7 from DHI, 2014). This is likely to markedly reduce the forces which presently hold the channel against the shoreline. Therefore, while the final morphologic outcome is difficult to predict, the direction of change is likely to be back towards the morphology that prevailed before the 1956 diversion. Over time, it is probable that the channel will move further offshore over time and that erosion forces along the shoreline will reduce.

Accordingly, the re-diversion is likely to provide increased opportunities in the future for beach and dune restoration and for the use of soft approaches for the management of coastal erosion – should relevant land owners/managers wish to pursue this. Depending on the scale of the natural changes, it may be possible to even remove some of the existing hard protection structures over time following the re-diversion.

1.5 Town Foreshore – Southern Areas

Prior to the diversion, this area of shoreline was extensively protected by large areas of rushland located immediately offshore (see Figure 2 and orange arrows in Figure 7). Little to no loss of this rushland is evident in aerial photographs pre-dating the 1956 diversion (Park, 2014).

Following the diversion, significant progressive loss of rushland occurred over time. There are now only minor isolated remnants left along the area immediately offshore from the shoreline; primarily a small offshore remnant associated with chenier island features (Figure 1; Figure 9) and small remnant areas along the shoreline (particularly either side of the small stream discharging from the township). However, significant rushland remains further landward within the embayment where the estuary directly abuts Maketu Road (Figure 10). A new equilibrium now appears to have been reached with no further significant loss of rushland in recent years (Park, 2014).

The processes responsible for the loss of rushland and other wetland vegetation in this area are not fully understood. Observations during the period of loss suggest the rushland was being progressively lost to erosion along the exposed seaward side of the remnant (Bergin, 1991; 1994) with an erosion face often 10-15 cm high along the seaward edge of the rush (David Bergin, pers. comm.). This tends to suggest a change in the sediment budget leading to bed lowering following the diversion. It is probable that this sheltered area received large inputs of suspended fine sands and silts during major river floods, much of which is likely to have settled in this sheltered area. With diversion of the river, this source of sediment was lost altering the sediment budget. Combined wave and tidal action then resulted in net sediment loss and bed lowering over the outer intertidal flats until a new equilibrium was reached. Park (2014) suggests that the increase in salinity following diversion may also have played a role; killing some marsh plants which then led to substrate erosion.

The loss of the rushland offshore from the shoreline has exposed most of the shoreline to wave action at higher stages of the tide. However, this area of shoreline is only exposed to locally-generated, fetch-limited waves and field inspection indicates that present-day

Figure 9: Chenier island features off from the southern shoreline of the township – with saltmarsh remnants and other maritime wetland and riparian vegetation communities. .

Figure 10: Rushland remnant adjacent to Maketu Road to south of township.

erosion processes are relatively minor. Over most of the shoreline, the limited erosion can readily be accommodated without the need for erosion protection works. It would also be possible to restore sand trapping vegetation over a suitable width of the shoreline margin to facilitate sand trapping and repair after erosion should relevant landowners desire. There are already isolated patches of spinifex and pingao along this shoreline from past restoration work.

The only moderate erosion occurs towards the extreme southern end of the township where concrete and other rubble has been placed along the boundary of residential properties (Figure 11). In this area, the stream discharging from the township flows directly along the seaward edge of private properties and appears to exacerbate wave erosion.

Figure 11: Extreme southern end of township showing concrete and other rubble placed as shoreline protection

The impact of the partial re-diversion on coastal erosion along this shoreline will primarily depend on whether or not the re-diversion encourages rushland recovery. The DHI modelling suggests the re-diversion will result in some minor lowering of salinities in this area. There is also likely to be increased input of suspended sediment, particularly during high river flows (floods and freshes). However, it is not clear whether these changes will be sufficient to promote rushland recovery in this area. In particular, field inspection suggests that bed levels may now be too low for saltmarsh and other higher elevation wetland vegetation (e.g. sarcocornia, salt meadow) over significant areas of the intertidal flats. Even if the re-diversion encourages some recovery of elevation over the intertidal flats (which is not certain), this may take some time to occur. Therefore, significant natural recovery of rushland following the re-diversion seems unlikely.

Field inspections suggest that there is potential to use sand placement to form more chenier island complexes similar to the natural islands which currently occur offshore. These features require only small volumes of sand and provide useful wave-sheltering to help reduce erosion. The features also provide a range of elevations enabling diverse wetland sequences ranging from riparian vegetation (e.g. saltmarsh ribbonwood, taupata) through salt meadow and sarcocornia to oioi and then sea rush (e.g. Figure 9).

If it is desired to also encourage recovery of the lost saltmarsh over adjacent intertidal flats, sediment placement to elevate bed levels is likely to be required. This placed sediment would need to be protected from erosion. It is possible chenier islands could also be used to provide wave shelter for such work – though trials would be required to confirm this. The strategy could therefore include provision for trial restoration of these features to provide increased habitat for a range of vegetation and provide enhanced shelter to adjacent shorelines.

It is also possible to restore relatively low chenier islands which rise only small elevations above high water and therefore remain unvegetated. These features could be used to provide enhanced shelter as well as safe high tide roosting areas for waders and other sea birds – important with increasing human use and disturbance along the shoreline.

Overall, any effect on coastal erosion along this shoreline is most likely to be neutral (i.e. no net change). However, some positive effect would occur if the Project resulted in rushland recovery; but this seems unlikely. However, there is potential for human intervention to assist recovery of wetland vegetation communities and natural values through use of appropriate sediment placement to raise bed level elevations in selected areas and to create additional chenier island features.

1.6 Eastern end of Maketu Sand Spit

This area encompasses the sand spit within 1-1.3 km of the Maketu entrance (Figure 1).

Examination of historic vertical and oblique aerial photography dating from 1939-1955 indicates that prior to the diversion the spit in this area was consistently wide, with no sign of any severe erosion along the landward margin despite the full river flow through the estuary (e.g. Figure 2).

However, following the diversion, expansion of the flood tide delta has periodically caused severe erosion along the landward margin of the spit, leading to breaching of the spit on at least two occasions (1979 and 1994). The spit breaches cause significant but temporary changes to the pattern of channel and banks in the lower estuary (e.g. Figure 12).

Following the breaches, the entrance slowly migrates eastwards back to its original position and the pattern of channel and banks inside the estuary recovers; with this process taking at least 4-5 years following the breaches in 1979 and 1994.

The history of spit breaching and subsequent eastwards migration of the entrance back to its original position has significantly lowered the dunes at the distal end of the spit. The entire spit was also reworked by erosion from Te Tumu to Maketu between 1907 and 1927 – accompanying eastwards migration of the entrance following the breach at Te Tumu in 1907. Accordingly, the present dunes (generally <100 years old) are much lower than the high features evident seaward of the township in photos from the 1800's.

Figure 12: 1979 aerial photo showing changes following a spit breach.

A further period of flood tide delta expansion is presently occurring, causing severe erosion and narrowing of the spit in the area approximately 600-800 m from the entrance (Figure 1). This may lead to further breaching of the spit in the next few years. Any breaching is most likely to occur during a severe storm event with elevated sea levels and storm-wave overtopping.

The location of the present erosion is further upstream than any of the other breaches since the river was diverted. Accordingly, a breach in the present area of severe spit erosion may cause more significant disruption of inner harbour morphology than has occurred previously. It may also take a longer time for the estuary entrance to migrate eastwards to its original position following any breach in this location. The reason the flood tide delta is presently causing spit erosion much further upstream is not clear but it may indicate progressive ongoing expansion of the flood tide delta up the harbour over time.

Modelling by DHI indicates the present dominance of flood tide directed sediment transport over the flood tide delta (e.g. top map in Figure 6), which is the cause of the ongoing growth and expansion of this feature. This map of residual (i.e. net) sediment transport directions also indicates cross-channel vectors at the apex of the delta opposite the present spit erosion. This reflects the current growth of the delta across the channel increasing currents in the main channel close to the landward margin of the spit and probably moving the channel closer to the spit over time. These increasing currents exacerbate the wave erosion which is occurring along the landward margin of the spit.

The modelling indicates that the proposed partial re-diversion will markedly reduce flood tide directed sediment transport over most of the flood tide delta and will reverse net sediment transport directions (i.e. give rise to ebb-directed net transport) along the main channel margin of the flood tide delta (see bottom map in Figure 6). Accordingly, it is likely that the proposed re-diversion will stop the current expansion of the flood tide delta and, over time, will gradually erode this feature. The likely reduction in size of the flood tide delta over time is difficult to predict - but the reduction in the areas and strength of residual flood tide directed transport before and after the re-diversion (compare top and bottom plots in Figure 6) suggests the reduction is likely to be significant.

Given the serious nature of the present spit erosion, it is not clear whether the proposed re-diversion will occur in time to prevent the present erosion causing a spit breach. DHI (2014) note that the proposed re-diversion may also slightly exacerbate erosion for a period immediately following implementation – as there will initially be a small increase in both flood and ebb velocities adjacent to the spit. However, these slightly increased velocities will probably also reduce over time as the channel and flood tide delta dimensions adjust to the altered sediment transport residuals.

Overall, the proposed re-diversion is likely to have a significant positive effect on erosion of the spit –reducing the frequency of future spit breaches (and possibly even preventing these) due to the marked reduction in flood tide delta expansion and size (due in turn to markedly reduced flood tide directed residual sediment transport).

If the present erosion led to a breach before (or even during) the Project, this would not significantly affect implementation or exacerbate any short-term effects of the Project. In fact, given the increased ebb tide directed sediment transport and decreased flood tide directed transport predicted by the modelling, it is possible that the Project would increase the rate of recovery and sediment flushing following the breach.

2 Coastal Erosion in the Upper Estuary

2.1 Papahikahawai Island

Field observations and LiDAR data (Figure 13) indicate that Papahikahawai Island can be broadly subdivided into two geomorphic units:

- **An area of elevated sand dunes** – occurring along the seaward side of the island (Figure 13 and Figure 14). The dunes extend along most of the seaward side of the island (separated from the spit by Papahikahawai Creek) but are most notable at the northern end where they commonly rise to elevations of 3-5 m above mean sea level, with maximum elevations up to about 7.5 m (Figure 13). In central and southern areas of the island, the dunes are much lower – with typical maximum heights of about 1.5 m above mean sea level.

- **A low-lying area of peaty soils and sands** along the landward half of the island (Figure 13 and Figure 14), where elevations are typically 0.5-1 m above mean sea level (Figure 13). This area is the modified (i.e. drained and grazed) remains of an extensive area of wetlands that occurred prior to diversion (Figure 15). A human-constructed sand bund (stopbank), vegetated largely (though not exclusively) in pampas, lies along the landward and estuary margin of the island, separating the low-lying area of the island from the estuary (Figure 16).

Figure 13: LiDAR survey data for Papahikahawai Island and adjacent areas (The arrow points to a small remnant patch of rushland (largely oioi) discussed in the text).

Figure 14: View of Papahikahawai Island looking north from near centre of the island – showing high dunes to seaward and the low lying land bordering the estuary.

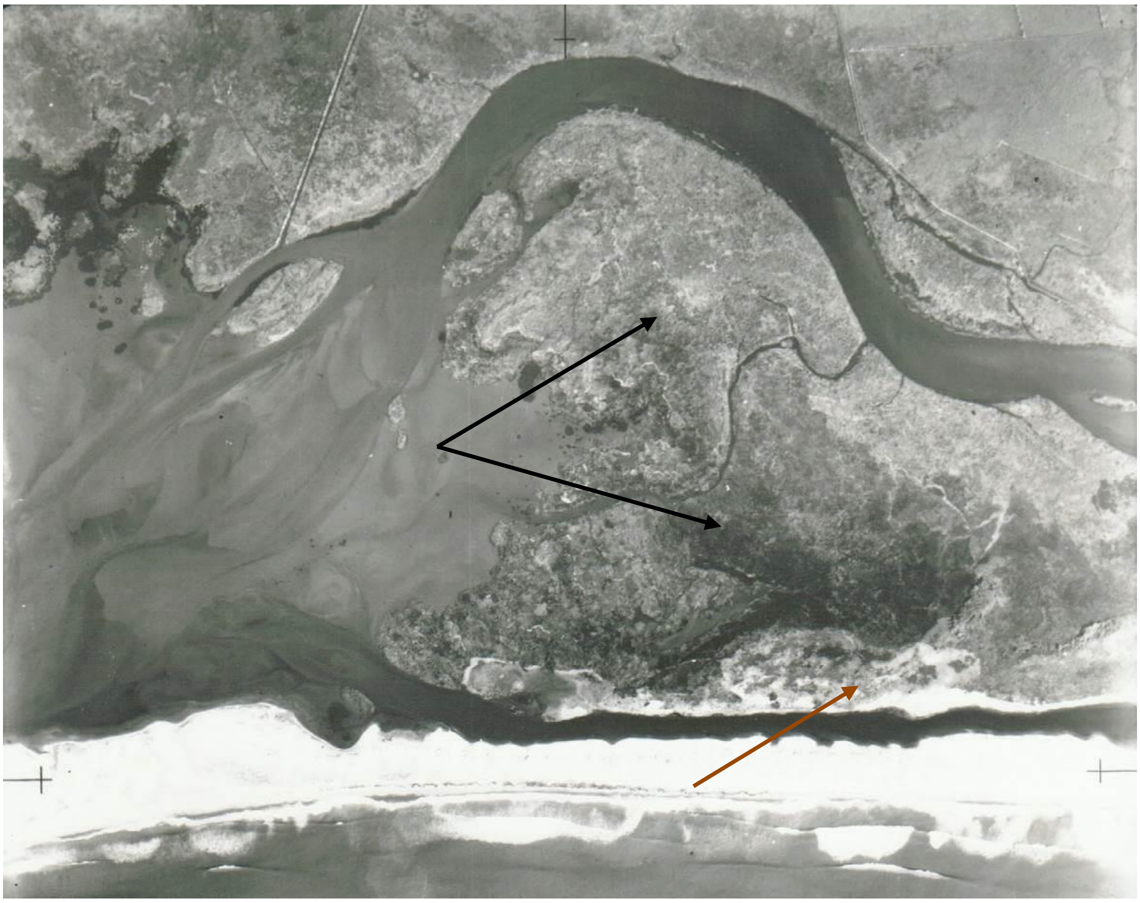


Figure 15: View of upper estuary in April 1939 prior to diversion of the Kaituna River from the estuary - showing the sand dunes of Papahikahawai Island (orange arrow) and the large area of wetland vegetation on the estuary margin of the island (black arrows).

Figure 16: View of large sand stopbank (vegetated largely in pampas) along the landward margin of Papahikahawai Island. The view shows the island side of the stopbank.

The dunelands were probably part of the original Maketu sand spit and separated from the spit by ancient eastwards alongshore migration of the Kaituna River entrance following periodic natural spit breaches at Te Tumu.

The low-lying areas of the island were originally part of the extensive rushland and other wetlands that occurred prior to the river diversion in 1956; extending from the sand dunes of Papahikahawai Island southwards to the main river channel (Figure 15).Following the diversion of the river in 1956, these large areas of vegetated wetlands were progressively lost (Park, 2014). This extensive loss of rushland is likely to have been caused by various mechanisms but increased salinity following diversion is believed to have been a major factor, causing die-off of freshwater and possibly other rushland and vegetation (Park, 2014). Once the plants died off, the peat soils would have been broken down not just by physical erosion but also by oxygenation, microbial actions and other physical and biological changes which sped up erosion (Stephen Park, pers. comm).

There is also evidence that bed level lowering causing erosional retreat of the rushland was a factor in some areas. In particular, a small isolated remnant of rushland (largely oioi) remains out in the estuary directly south of Papahikahawai Island (Figure 13 and Figure 17). The remnant has survived as sand levels around it are higher than the surrounding intertidal flats. However, even within the remnant high area the elevated sand levels are lower than the sediments in the rushland and the remnant is being gradually eroded (Figure 17).

Figure 17: Small remnant of oioi in estuary off Papahikahawai Island associated with remaining high area. Note that the sand levels around the remnant are lower than the peaty sand sediments in the rushland clumps and the rushland is gradually eroding. The intertidal flat elevations away from this high area are much (probably at least 0.2-0.3 m) lower.

Away from this high remnant, the wider intertidal flats which once supported extensive areas of wetland are now at least 0.2-0.3 m lower. This bed level lowering suggests a change to a negative sediment budget in the wetland area following the diversion. The original wetlands south of Papahikahawai Island lay on the inside bank of the river channel in the upper estuary (Figure 15) – an area similar to a point bar deposit in a river. During river floods, it is likely that significant volumes of fine sand and coarse silts carried in suspension would have flowed over this area. Much of the sediment would be deposited among the wetland vegetation as velocities decreased (e.g. due to expansion of the river as it entered the estuary and to the effects of flow resistance associated with the wetland vegetation) – contributing to forming the peaty sands and silts which underlie the rushland remnant.

Following diversion, this sediment supply would have been lost – leading to slow lowering of the wetlands as waves and currents removed sediments until a new equilibrium bed elevation was established. In general, the bed elevations now occurring are too low for the native maritime rush species such as sea rush and oioi.

The progressive die-off and/or erosion of the rushland and other wetlands following the diversion eliminated most of the original rushland south of Papahikahawai Island over the 1960's and early 1970's. The remaining low-lying areas of Papahikahawai Island were only protected by the placement of the sand bund (Figure 16) in the 1970's. Aerial photography from 4 February 1977 indicates that most of the wetland south of the bund had been lost by that time, apart from small isolated patches (which have now reduced to the remnant partly shown in Figure 17). If the sand bund had not been placed in the 1970's, it is probable that the erosion would have continued - eliminating much of the low-lying wetland (possibly even right back to the high sand dune component of Papahikahawai Island) and converting this area to other forms of estuarine habitat (e.g. open intertidal flats).

The sand stopbank is fronted by a low beach formed from erosion of the bank (Figure 18). This elevated sand provides habitat for limited areas of saltmarsh (largely sea rush and oioi but also spartina) and, in higher areas, saltmarsh ribbonwood and (above high tide) occasional native shrubs (e.g. taupata). There are occasional short lengths where the saltmarsh rushland forms a band up to about 10 m wide (e.g. bottom photo in Figure 18), though in most areas the rushes are limited to isolated plants and provide little to no erosion protection. It is probable that existing bed levels are generally too low for the key maritime rush species (i.e. sea rush and oioi) and/or that the environment is too exposed.

Wave washed algae deposits also occur in a band along the front of the shoreline (Figure 18), typically underlain by anoxic muddy sediments (Figure 19).

Field observations indicate that the sand stopbank is subject to periodic wave erosion along most of its length, with a scarped face underlying the pampas. This erosion occurs during periods of elevated sea level (e.g. large high tides or storm surge) accompanied by wave action. Over time, this slow erosion will progressively erode the stopbank unless it is maintained.

The modelling indicates that the proposed re-diversion will very significantly increase ebb oriented sediment transport over the intertidal flats adjacent to Papahikahawai Island (Figure 20).

Figure 18: Estuarine shoreline of Papahikahawai Island - showing typical views (top) and isolated areas fronted by rushland (bottom).

Figure 19: Anoxic muddy sediments which typically underlie the wave washed algal accumulations along the estuarine shoreline of Papahikahawai Island.

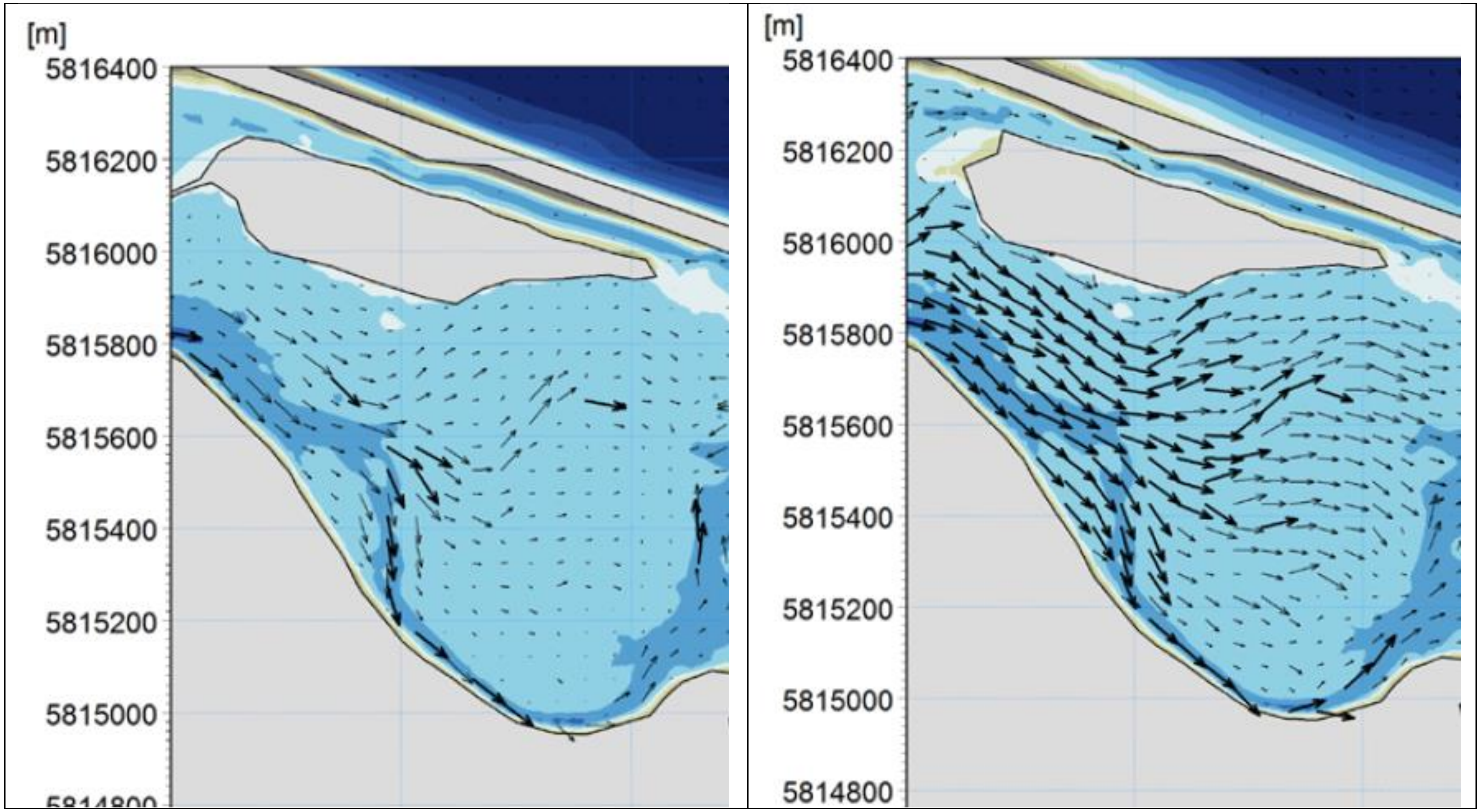


Figure 20: Residual sediment transport rates and directions within the estuary for the existing situation (top) and with the proposed re-diversion (bottom). The sediment residuals are those that occur during mean river flow over a neap-spring cycle. (Figures provided by DHI from their modelling reported in DHI, 2014. Transport rates are low and arrows have been scaled so that differences can be seen).

Hamill (2014) considers in some detail the effect of the increased currents and argues they are likely to substantially increase the flushing from the estuary of algal accumulations and associated anoxic, organic mud. I concur with these conclusions. Wave stirring associated with fetch-limited, locally-generated wind waves will also aid entrainment of the algae aiding dispersal by the increased currents. Over time, the reduced algal accumulations over the intertidal flats should also reduce (and possibly eliminate) the supply of wave-washed algae to the Papahikahawai Island shoreline (Figure 18). The increased currents, together with wave stirring should also assist in the dispersal of the band of algae accumulated along the shoreline and the underlying anoxic muddy sediments.

In most areas, existing bed levels over the intertidal flats are too low for either sea rush or oioi - except for elevated beach areas close to the stop bank and the eroding remnant noted above.

DHI (2014) note that the proposed re-diversion may increase sediment supply from the river to the estuary, particularly during floods – which they believe could lead to some deposition. However, even if this occurs, it is not clear that this sediment supply will raise bed levels over the intertidal flats sufficiently to restore maritime rushland. For instance, the proposed re-diversion is not likely to carry anything like the volumes of suspended sands and silts that used to occur during floods when the entire river flowed through the estuary. The increased sediment transport that is likely to accompany the diversion might even further lower bed levels.

Accordingly, while not certain, it is unlikely that the proposed re-diversion will encourage natural restoration of rushland along the estuary side of the sand stopbank. Appropriate human intervention is likely to be required if it is desired to restore saltmarsh and other wetland and riparian vegetation in this area.

The ecologists have identified that removal of the bund over time would be ideal to better reconnect and restore wetlands in the low area behind the bund (Opus, 2014). However, if the sand bund were to be removed as part of the re-diversion works, significant erosion of the low-lying "land" (mostly former wetland) behind is likely to occur. Estuarine wetlands would be restored, but these would probably largely be open intertidal flats, with elevations too low for rushland. Consultation with the landowners indicates this would be unacceptable to them (Mr. Pim de Monchy, pers. comm.). Therefore, the bund will need to be retained until alternative erosion protection can be provided.

There are therefore essentially two alternatives for the management of erosion along the estuarine shoreline of Papahikahawai Island:

- Adopt the bund as the shoreline and maintain this feature by ongoing placement of sediment as required
- Human intervention to restore rushland along the seaward edge of the bund to provide natural protection to areas further landward.

These options will require more detailed consideration but are briefly discussed below.

Adopt the bund as the shoreline

This option essentially involves adopting the bund as the shoreline and maintaining this feature as required by ongoing placement of sand along the seaward margin. Any rushland restoration along the seaward edge of the bund would be left to natural processes accompanying the re-diversion – with available evidence suggesting extensive rushland recovery is unlikely to occur in the near future.

This option could involve the following different approaches:

- **Status quo and improved hydrological connectivity**: Maintaining the existing bund by periodic ongoing placement of sandy sediment to balance erosion along the estuary margin, but including more breaches to improve hydrological connections between the estuary and the wetlands behind the bund.

- **Status quo with native revegetation:** As above, but replacing the pampas with native riparian vegetation to improve natural character of the margin

- **Lowering and reshaping the bund to form chenier islands**: This approach would enhance natural character and diversity of habitat by transforming the bund into more natural appearing chenier islands. As with the other approaches, gaps of appropriate width and spacing would be created to improve hydrological connection between the estuary and areas further landward.

These options would maintain protection of the low-lying areas behind while also sufficiently improving hydrological connections to restore natural rushland and other wetland ecosystems on the protected side of the bund. Periodic sand placement seaward of the bund would be required to balance erosion or (with chenier islands) possible landward migration.

Human intervention to restore rushland seaward of the bund

This option involves human intervention to restore saltmarsh and other natural features seaward of the bund (and possibly well seaward) to provide natural erosion protection. If successful, this option would eventually enable the bund to be significantly lowered or removed without leading to erosion of areas further landward.

The best means of human intervention to restore saltmarsh on the estuary side of the bund will need further investigation and, ideally, small trials. However, the work is likely to require:

- Sediment placement to restore the bed elevations required by saltmarsh, and

- Placement of suitable protection to retain the placed sediment and restored rushland.

The option would involve retaining the bund until appropriate methods had been developed to successfully restore and maintain alternative natural protection to seaward. However, as with the earlier option, the bund could be breached in appropriate areas to improve hydrological connectivity.

In tidally inundated areas, sea rush and oioi are limited to a narrow elevation range near high tide – with minimum bed levels (and other requirements) necessary for successful and sustainable establishment. The minimum bed levels required vary with tidal range and exposure (e.g. Graeme and Dahm, 2006) but in meso-tidal harbours with ranges similar to Maketu are typically at least 0.8-1 m above mean sea level and sometimes higher (Phleger, 1977; Graeme and Dahm, 2006; Jupp, 2007). The minimum bed levels required in Maketu Estuary are best assessed by field levelling of existing remnants.

Field observations suggest that bed levels are now too low for the successful restoration of sea rush or oioi over much of the area where saltmarsh and other rushland once existed. Accordingly, sediment placement to elevate bed levels is likely to be required in many areas if it is desired to try and restore some of the original rushland.

Natural protection of the placed sediment and restored saltmarsh could potentially be provided by constructing small chenier island features along the margin of the restored area, similar to those which exist in the lower harbour (Figure 9). Small scale trials of this this approach would be useful. Use of these features would also significant enhance natural character and provide habitat for a range of vegetation species or (with lower features) useful bird roosting habitat (see earlier discussion in Section 1.5).

However, construction of cheniers requires care and design and is not simply a matter of dumping sand. Careful consideration has to be given to both the cross-sectional shape and maximum elevations. If the features are built too high, they can be subject to rapid erosion and movement. If they are built too low, they can be rapidly dispersed. Appropriate design is best undertaken using measurements of similar features and small scale trials.

Other natural maritime vegetation might also be a possibility to help protect areas of restored saltmarsh and placed sediment. For instances, in many other harbours mangroves provide useful protection along the seaward margin of saltmarsh communities. This estuary is close to the southern limit of mangrove colonisation and further work would be required to assess the potential for restoration of this species. Community discussion would also be required as the spread of mangroves accompanying human accelerated sedimentation has caused controversy over the species in some areas.

Field examination of the largest existing area of native saltmarsh along the estuary side of the Papahikahawai Island bund (see lower photo in Figure 18) indicates that spartina patches towards each end may be acting as a groyne and helping to retain the native saltmarsh. However, use of this very undesirable species to provide natural protection is not likely to be favoured unless there are no other useful options. Spartina is listed as an Eradication plant in the Bay of Plenty Pest Management Plan 2011-2016 – with objectives of control leading to eradication (Andrew Blayney, Land Management Officer, BoPRC, pers.

comm). While it might be possible to get an exemption for small areas if use of the species offered significant benefits in restoration of saltmarsh, the hurdles to this are significant. It is also probable that even minimal use would require active ongoing management to prevent expansion of the spartina – and a requirement for eventual replacement by a more appropriate long term solution, with total eradication of the remaining spartina. .

In addition to the above and other natural features, there are also a range of engineering approaches for saltmarsh restoration/enhancement. In the case of Maketu Estuary, such structures could include a low armoured bund along the seaward margin of the restored saltmarsh to retain the placed sediment; though elevation would have to be set low enough to allow hydrological exchange. The capital costs and ongoing maintenance of such structures can however be expensive. The structures also generally involve visible engineering works with some adverse effect on natural character. There may also be difficulties with allowing hydrological exchange while retaining placed sediment – particularly during extreme sea levels with wave stirring. Nonetheless, such structures may be an option for further investigation if trial of more natural features (e.g. cheniers, mangroves) is not successful.

If restoration of rushland (using natural and /or engineered approaches) is possible on the estuary side of the sand bund, then the bund could eventually be removed or otherwise extensively modified (e.g. to form isolated chenier islands or redistributed to raise bed levels to assist with saltmarsh and other restoration). If limited areas were retained (e.g. as lower chenier islands), these would nonetheless be widely spaced with significant openings between to ensure a high level of hydrological connectivity between the estuary and areas landward of the bund.

Total removal of the bund is not likely to be desirable in early years even if rushland restoration proves practical on the estuary side of the bund - as the bund provides a useful second line of defence for the areas further landward. Total removal would only occur once it is certain that any restored rushland (or other natural features) further seaward can be maintained and will provide sustainable long term protection to areas landward of the bund.

Summary and recommendation

Removal of the bund prior to successful establishment of alternative natural protection would risk serious erosion of the low-lying areas behind the bund – probably converting a large part of this area to open intertidal flats; which landowners have indicated is not acceptable to them.

The most appropriate options to manage erosion will require further work and will need to be resolved in active consultation with the landowners of Papahikahawai Island.

It is recommended that initial work focus on maintaining the bund but (subject to landowner approval) include appropriate breaches to improve hydrological exchange – while trials are conducted to assess the best long term method of providing alternative natural protection. Experience with wetland restoration elsewhere in similar estuarine environments indicates that small trials of the various options are often the best approach to prove concept before operational scale implementation. Sand and other suitable sediment that could be used for restoration could however be stockpiled in suitable locations on the island with landowner approval.

Any initial breaches will need to be closely monitored and closed if undesirable effects (e.g. erosion) arise.

The trials of alternative protection should initially emphasize natural features (e.g. cheniers) and vegetation (e.g. saltmarsh and mangroves), with sand placement to lift bed levels to suitable elevations where required (e.g. for saltmarsh restoration).

Extensive or even total removal of the bund should only be undertaken once it is clear from long term trials (probably at least 3-5 years) that alternative natural or appropriate engineered protection can be established and maintained.

Given the large accumulation of algae and anoxic muds along the estuarine margin, it may be desirable to allow time for this material to disperse before commencing work on restoration. However, it would probably also be practical to scrape these areas clean using excavators if required.

2.2 Stopbanks along Southern Estuary Margin

The stopbanks along the southern estuary margin encroach close to the estuary and are therefore vulnerable to erosion.

Historically, the stopbanks have been periodically subject to severe erosion.

In particular, file notes record severe stopbank erosion during the Wahine storm of 9-10 April, 1968 in which sea levels in Maketu were higher than had previously been recorded. A report by the (then) Tauranga County engineer dated 24 April 1968 records serious erosion of the stopbank face reducing the top width to an average of only “2 feet” (i.e. about 0.6 m) over a length of “58 chains” (i.e. about 1.1-1.2 km). Diagrams accompanying the file notes indicate the damage extended from the middle to the upper estuary.

Murray (1978) also notes stopbank erosion in some areas in May 1977 resulting in various “corrective” measures including dumping of rocks and logs and the planting of spartina. He also notes that spartina had been planted next to another area of stopbank in the mid-estuary in 1972 to prevent erosion.

It is probable that serious erosion such as the Wahine storm relates to the combination of extreme sea levels and the penetration of some storm wave energy into the estuary (probably in the form of longer period infragravity waves or surges). It is not known if the present stopbank protection works have been designed to accommodate any such future events.

The increased river/tidal velocities accompanying the proposed re-diversion are too low to cause any significant erosion of the banks and therefore the diversion is not likely to aggravate any erosion of the banks. Therefore, regardless of the standard of the existing protection works, the proposed diversion will not have any significant adverse effect on the severity of the erosion accompanying future storm events.

In the longer term, there would be benefit in setting the stopbank further landward from the estuary margin and restoring saltmarsh and other natural vegetation or features to enhance erosion protection, However, this is outside the scope of the present Project.

2.3 Diversion Channel

This area includes the banks along the full length of the re-diversion channel (i.e. the new cut, Ford Island, the bend adjacent to the Corbett land, and the enlarged Ford’s Cut channel).

Modelling of water velocities through this channel by DHI indicate that velocities are relatively low even during flood situations, with peak velocities in the new diversion channel and the enlarged Fords Cut averaging less than 1.5 m/s (except immediately downstream of the culverts). The highest velocities also occur near the channel centre rather than the margins, except near bends. These velocities are unlikely to promote significant erosion of the channel banks.

Nonetheless, as a precaution the construction report proposes that that rock protection is placed along the southern bank of the new channel to protect the stopbank, with a 5 m berm also placed between the top of the channel and the stopbank (see Section 2.6 of Waterline, 2014). In my opinion, this is appropriate risk management as while the risk of serious bank erosion is low, the consequences of stopbank failure during a major event would be very significant.

The construction report (Waterline, 2014) also proposes the placement of rock protection on the outside banks of the minor bends in the new channel – including:

- The northern bank at the upstream end of the channel (i.e. where water flows from the river into the diversion channel) (see Figure 6 of Waterline, 2014)
- Part of the Ford Island shoreline (Figure 11 of Waterline, 2014). In my opinion, this protection more than adequately covers the area potentially at risk. (Note: It is possible that a small counter-clockwise eddy will form in the open water adjacent to Ford Island between the 1983 river channel block and the new channel. However, these secondary flow velocities are likely to be weak and not likely to cause any erosion or pose a significant risk for water users such as waka ama).
- Part of the Corbett shoreline (see Figure 11 of Waterline, 2014). Fill will be placed on the bench between the channel and the stopbank and the fill margins will be

rock-protected. The rock protection will extend to the channel invert where the fill borders the channel. The outside of the bend will remain unprotected. In normal circumstances, higher nearshore velocities would be expected around the bend and rock protection would be placed. However, in this situation it is envisaged that the fill placed immediately upstream will shelter this area, though there may be some secondary flow in the lee of the fill. The area will however be monitored following the diversion and rock protection placed if there is any evidence of stream erosion. I concur with this approach.

Rock protection is also proposed along both the northern and southern banks immediately adjacent to the culvert structure (see Figure 8 of Waterline, 2014), important given the turbulence and high velocities that can occur in these areas.

The unprotected areas are unlikely to suffer significant erosion provided the proposed batter slopes (of variable gradient – largely 1:2 but as little as 1:20) are day-lighted to the top edge of the banks or to at least 0.5 m above the highest likely extreme water level.

2.4 Kaituna River – Te Tumu to Kaituna Wetland

The modelling indicates that Kaituna River flows upstream of the diversion channel are not significantly changed. Accordingly, there is not likely to be any aggravation of erosion in this area.

In the areas downstream of the diversion channel, the river flows are decreased due to the partial diversion. Accordingly, any existing river erosion issues in this area are likely to be either unaffected or decreased – probably the former as most erosion occurs at high river flows when the effect of the diversion will be less significant.

It is important to note that the Kaituna River stopbank is rock armoured upstream from the river mouth and this area has suffered damage in past extreme events, due to storm waves penetrating up the river. Particularly serious damage occurred during the Wahine storm of 9-10 April 1968. Files notes report that the rock works slumped at numerous locations between the mole and a distance of about 140 m upstream, as well as several “very minor” slumps beyond that. These events relate to the combination of extreme sea levels and storm wave action and the proposed diversion will have no significant adverse effects on this risk.

2.5 River Mouth Behaviour

The depths over the bar at the river entrance depend primarily on the balance between river outflows (which tend to scour) and wave action (which tends to shallow the bar). Periodically, sand moving alongshore is also bypassed across the entrance (usually in significant “clumps”) and the movement of this sand across the entrance results in various complex bar and channel changes.

The majority of bar problems occur during low and mean flows, particularly when accompanied by significant wave action.

The modelling of low flows with significant adverse wave conditions indicates no significant difference in bar depths or channel morphology with the proposed re-diversion (see Figure 7-33).

The modelling also indicates that the proposed re-diversion has little to no adverse effect on outflows during mean flows – outflows decreasing by only 2% (spring tides) to 6% (neap tides) (see Table 7-3 of DHI, 2014). The reason for this is that the increased salt water inflows during the flood tide largely balance the loss of freshwater. These minimal changes in outflows will have no significant effect on depths over the bar. Wave conditions and bypassing events will be the primary influences on bar depths during low and mean flows. The minimal changes in outflows also confirm there is no danger of entrance closure.

The modelling indicates that while there will be significant increases in flood tide inflows into the lower river with the Project, sediment transport in the lower river and entrance will remain markedly dominated by outflows (see Figures 7.2 and 7.3 of DHI, 2014). Accordingly, as DHI (2014) conclude, there is unlikely to be any significant sediment accumulation formed in the lower river as a consequence of the Project.

The one-year simulation of river entrance change indicates no significant changes in bed levels between the existing situation and the proposed re-diversion (Figures 7-17 to 7-22). The modelling does suggest that the scour of the bar that occurs during major flood events may be slightly reduced by the proposed diversion (see Figure 7-20), though they note this is likely to be an artefact of the model scaling. It should be noted that even if the reduction is real, the bar will continue to be significantly scoured during flood events. As is the case with the existing situation, flood improvements will only persist until significant wave events.

Overall, I concur with the view of DHI (2014) that any effect of the project on the Kaituna River entrance will be minor.

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