6 May 2015

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Dear Mike and the Westport Flood Working Group (Buller DC, West Coast RC and Land River Sea consultants).

This letter report addresses the request for advice about proposed floodway cut options between the Orowaiti River/Lagoon and the Tasman Sea at North Beach to alleviate flooding risk to Westport residents (Figure 1 to 3). The scope of this assessment is intended to be relatively high level, and specifically to consider the impact from coastal processes to inform option development and decision making.

A number of options have been simulated using a MIKE Flood model of the Buller River and Westport surrounds by Land River Sea consultants (LRS). The options have been evaluated by comparing flooding extents, hazards as well as comparing the expected damages. Other options also considered by LRS include stopbanks surrounding Westport, increasing the Buller River capacity and various floodway cut options for the Orowaiti River. These are not evaluated in this letter report, but the general coastal processes advice remains applicable to them.

Advice was requested for flood mitigation Option E (Figure 1) and Option B (Figure 2). These options are designed with a curved alignment from the Orowaiti Lagoon, and are 200 m and 120 m wide respectively. Option E provided the best flood mitigation of these options and it was considered that external advice about its functionality and operation was required to assess its realistic flood mitigation potential. The floodway cut options were refined to a straight alignment upon discussion with Michael Allis (NIWA) as a variation with improved hydraulic efficiency (Figure 3).

Figure 1 - Option E

Figure 2 - Option B

Figure 3 - Straight cut alignment

Designing an emergency floodway is a balance between factors of hydraulic efficiency, cost, nearby vulnerability to flooding and coastal processes.

The structure of this Letter Report is to present: (i) background information on the flooding situation at Westport; (ii) describe the major coastal physical processes relevant to the Orowaiti Lagoon/River and North Beach areas; and (iii) discuss the implications of the coastal physical processes in relation to the modelled floodway options.

1. Background

The Buller River discharges into the sea at Westport. The Orowaiti River and Lagoon act as an overflow of the Buller River during large flood events which has been a problem for the life of the town. In 1896 the Orowaiti Lagoon was considered the 'skeleton in the closet' by the resident engineer of the Westport Harbour Board in regard to the flooding potential it exposed to Westport (WCRC 2002). This issue continues today whereby if flood levels are high enough to flow down the Orowaiti overflow channel, Westport effectively becomes an island with problematic public access/evacuation pathways.

Historic river and flood gauging have determined that during a 50 year flood event, the Buller River peak discharge is approximately 8,920 m^3/s at Te Kuha (10 km upstream from Westport) and during a 100 year flood event it is 9,750 m^3/s (Duncan and Bind, 2014). The Orowaiti River discharge for the 50 and 100 year events is approximately 1,200 m^3/s and 1,500 m^3/s respectively. During floods at Westport a substantial portion of the Orowaiti River discharge is spill-over flow from the Buller River breaching its banks at Organs Island (5 km upstream from Westport) and flowing down an old Buller River channel into the Orowaiti River. The maximum recorded discharge of the Buller River is 12,460 m^3/s during a May 1950 flood – a portion of which would have discharged via the Orowaiti River - which caused widespread damage around Westport, however the 1926 flood is considered to have been larger again (WCRC 2002). The Orowaiti River has a relatively small catchment area of its own and functions predominantly as a tidal inlet between flood events when the Buller River overflow comprises a large portion of its discharge. The amount of Buller River spill-over flowing into the Orowaiti River is dependent on the location and orientation of gravel bars, protection groynes and the density of vegetation at Organs Island (Duncan and Bind, 2010).

The primary function of a flood relief cut is to route flood-waters away quickly during extreme events, the rest of the time it lies unused until needed. A floodway provides an additional outlet for floodwaters, and hence increases velocity and decreases stage for some distance above the point of diversion. In its unused state, the floodway should remain in a state of readiness to be opened at short notice and also have minimal effect on the natural environment and introduce minimal additional risk to the area.

At Westport, the floodway options are intended to reduce the water level in the Orowaiti Lagoon in the event a substantial flood necessitates opening of the floodway. The temporary exit-channel would be opened for a period of time sufficient to alleviate flooding around the flood peak. Once the river stage drops below the upstream invert of the floodway, the river should naturally return to its former passage through the Orowaiti Lagoon with no major environmental consequences from the floodway's operation.

The proposed floodway cut options at Westport are suggested to discharge directly into the ocean. This presents some natural coastal processes which are not often incorporated into floodway design.

2. Relevant coastal physical processes

a. Coastal erosion

Coastal erosion is the gradual landward retreat of the shoreline through the action of the sea advancing. The timescales of this erosion are from short-term through storm-driven high waves, winds and currents; or long-term through the gradual movement of nearshore sediments exposing landward areas to higher wave action. Generally, storm-driven erosion occurs at a faster rate and is more dramatic than gradual erosion but intervention measures have greater success at mitigating storm-erosion.

The ability of a beach to resist short-term coastal erosion is primarily a function of the dune barrier composition (height, width and sediment composition). This barrier forms a buffer between the land and the sea which erodes during storm events but rebuild during calmer periods. The beach erosion typically takes place rapidly (hours to days) where the beach rebuilding accretion occurs slowly over periods of weeks to months or years. Long-term and gradual coastal erosion is difficult to manage as it is often controlled by regional-scale sediment transport trends operating on inter-decadal timescales; in this case hard engineering structures are often the only successful defence.

One reason coastal erosion is more severe during storm events is the elevated sea-levels from storm-tides along with wind and wave setup allow the waves to penetrate further inland and expand the potential for damage.

b. Storm-tide inundation

During storms, the base sea-level increases from a number of causes: the inverse-barometric effect increasing water level, wind setup, and wave setup and runup - all of which are super-imposed on the natural tidal oscillations (Table 1). The elevated storm-tides observed at Westport will include components of these coastal effects in their measurements.

Table 1 - LINZ standard tidal elevations at Westport[1].

Datum	HAT	MHWS	MLWN	MSL	MLWN	MLWS	LAT
LVD-37	1.811	1.471	0.791	-0.029	-0.839	-1.529	-1.879

These elevated water levels are known causes of coastal-driven inundation and flooding. In coastal locations the same area of inundation may result from a combination of tide level and flood peaks, although different locations will be flooded with different water depths and velocities. If a large storm-tide coincides with high river flood volumes, the combined effect can be widespread flooding throughout low-lying areas. The 1970 storm event (approximately 50 year river-flooding event) at Westport coincided with a storm-tide of 0.6 m above the natural tidal levels within the harbour even though the Buller River flood peak arrived at low tide which limited the inundation extent. Storm-tide events would occur over only 1-2 hours straddling an elevated high-tide period, but this is still likely to coincide with elevated floodwaters due to the relatively long flood-peak of the Buller River (WCRC 2002).

Wave setup contributes to super-elevated water levels near the coast as the larger waves release momentum as they impact on the coastline, and it is an important factor at open coast locations. However, it is probable that the constrained Buller River entrance is too deep (5-7 m LVD-37) and flat to generate any substantial wave setup. Additionally, the presence of training walls, which extend deeply into the surf zone, may introduce a physical barrier to higher mean water levels from wave setup on the neighbouring sandy beaches.

There is generally a poor correlation of storm-surge peaks accompanying discharge peaks on the Buller River at Westport, except during winter (June-August) floods if the river discharge exceeds 2,000 m^3/s when there is significant correlation (R=0.71) with storm-surge elevation (Wild et al. 2004). By extending this ‘winter’ correlation to the 2% AEP design flood (which was then 8,600 m^3/s) Duncan (2005) calculated a concurrent storm-surge elevation of 0.59 m ± 0.22 m. However, Duncan (2005) went on to show the return period for Buller River floods of 9,100 m^3/s and 8,600 m^3/s *accompanied* by a 2.04 m storm-tide (MHWS tide + 0.6 m storm-surge) have a combined-AEP of 0.04% to 0.07% or return periods of 1300-2700 years. The two phenomena are fundamentally linked, but considering the 2% or 1% AEP flood event coinciding with MHWS and 0.6 m storm-surge is overly conservative for design flood events. **The combination of MHWS and 0.4 m storm-surge resulting in sea-level of 1.87 m which coincide with the flood peak is**

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[1] HAT and LAT are the highest and lowest astronomical tides which occur under average meteorological conditions during the period 1/01/2000 to 31/12/2018 on 18.6 year return period. MHWS, MHWN, MLWN, MLWS represent water levels of the perigean springs and neaps tidal cycle with period of about 7 weeks. MHWS represents the water level exceeded approximately 10% of the time, i.e., MHWS10.

recommended as a reasonable foundation for incorporating tail-water effects and coastal-driven inundation at Westport for the design flood scenarios.

Inundation of low-lying areas by seawater is also caused by infiltration through natural barriers (such as sand dunes, sand-spits and unconsolidated river deposits), particular those of coarse sediment composition (gravels). This form of inundation is likely to result in localised and transient flooding for 1-2 hours around the high-tide period, but will be also be influenced by rainfall ponding and river-water influx.

c. **Geomorphology**

A brief desktop assessment of the natural coastal geomorphology was performed using the Google Earth Engine focused on Westport[2] which creates a satellite image video sequence of the area from 1984 to present and the WCRC/BDC aerial photos. These show the coastline to the east of the Buller River mouth is highly dynamic with a large volume of sediment moving east towards the Orowaiti River mouth. The calculated net transport rate is to the east at 1.0×10^6 m^3/yr with sediment deposition causing North Beach to accrete substantially since the original river training works of the 1880s (Gibb, 1978; Kirk et al. 1987).

The primary source of this sediment is from long-shore drift and circulation occurring around the end of the Buller River breakwaters where 90% of sediment moving along Carters Beach bypasses the river entrance and continues along North Beach. River sand input to the sediment circulation system contributes less than 20% of the littoral drift input. This sediment supply is possibly augmented by wave-current reworked harbour dredge spoil which is periodically deposited offshore (Kirk et al. 1987).

The volume of sediment moving along shore is easily visualised in Figure 4 by the large northward bulge of sand which is absent in 1998, grows through 2007 to be most extensive in 2010 but shrinks slightly by August 2013. The images indicates this sediment bulge formed in 2004-2005 and has subsequently grown to a maximum width of 400 m (2010) and the widest part has migrated east since 2005 by approximately 1.5 km. Overall, the surface area of North Beach and the sand spit has grown by approximately 30 hectares since 1998. The exact generation source of this sediment bulge is uncertain but is likely to have its origins in wave-induced littoral drift and the Westport bar system to which the river exerts a period beneficial disruptive effect while adding to the sediment load of the system (Kirk et al. 1987). Whatever the source, there is clearly a substantial volume of sediment migrating on an inter-decadal basis along North Beach near the proposed exit of a floodway cut.

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[2] https://earthengine.google.org/#intro/v=-41.7545216,171.60589030000006,10.960445181586463

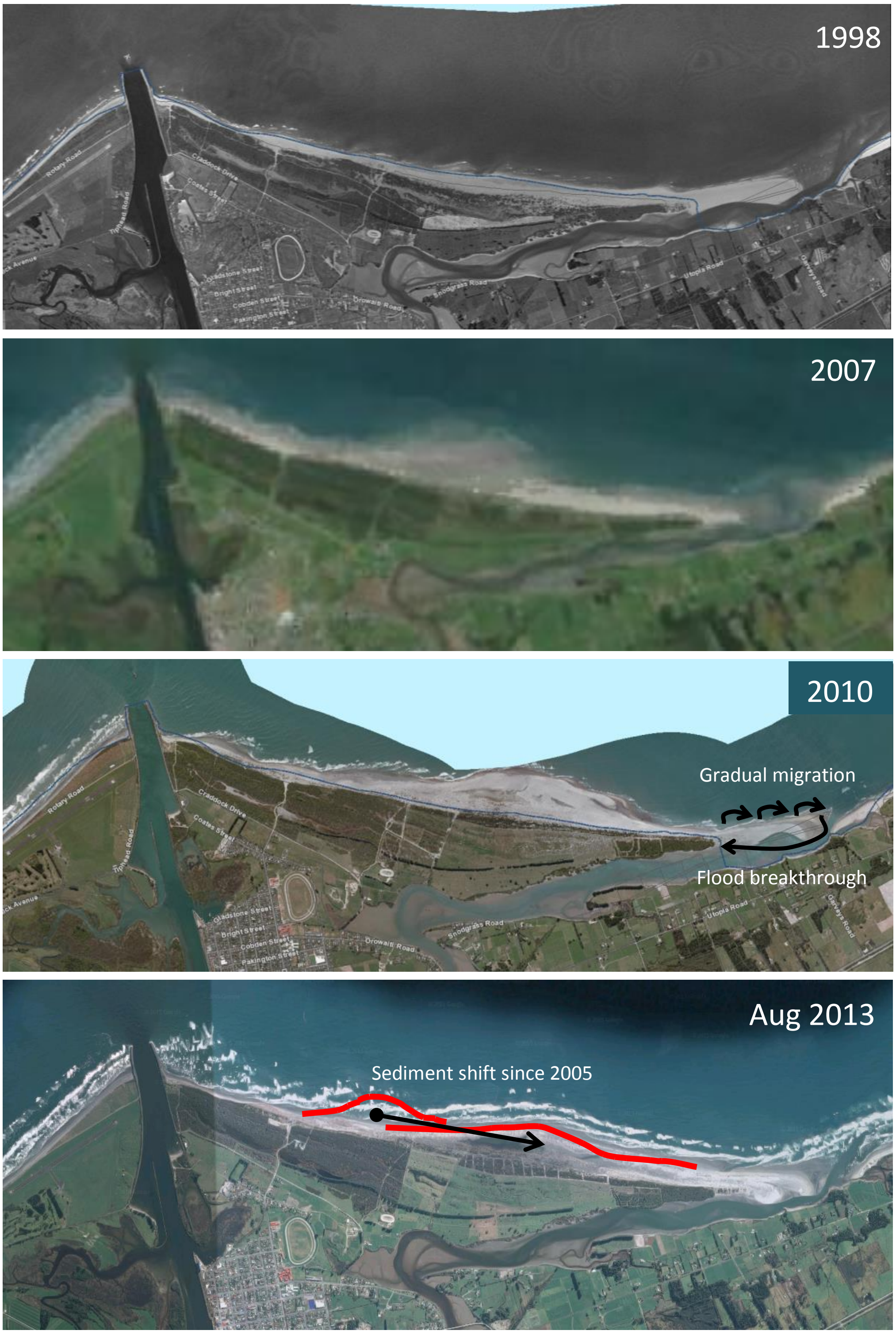

Figure 4 – Historic aerial photo identifying coastal geomorphologic features and processes.

d. **River channel/mouth migrations**

A natural river mouth location is a dynamic equilibrium state between river discharge, wave action and littoral drift. Its location has a cyclic nature as seasonal and inter-annual processes add/detract from the sediment budget and the river mouth moves accordingly. At the Orowaiti River mouth the general sequence is for littoral-action to gradually force the river entrance eastward through growth of the sand-spit tip until a sufficiently large flood event breaks through the barrier somewhere upstream and rediverts the river (Figure 4). After the breakthrough event, the littoral-action begins again to migrate the mouth east. Since 2005 this cycle has been observed three times in the Earth Engine satellite sequence[2] where the river has cut-back up to 400 m through the non-vegetated section of the sand-spit.

Historically, the Orowaiti River is likely to have discharged straight to sea in the approximate location of the proposed floodway. However the relatively recent engineered improvements to the Buller River through training walls, breakwaters and flow diversion have reduced the flood flow volumes through the Orowaiti River channel and caused North Beach to rapidly accrete thereby widening the sand-spit barrier (Kirk et al. 1987) and preventing any major natural breakthrough occurring.

The river itself is actively scouring the outer banks of the Orowaiti Lagoon, particularly at the sharp right turn after the Orowaiti River Bridge. This is an active and natural process of riverbank erosion which, in time, may cause the river to change course. The scour rate becomes greater during bank-full flood events.

e. **Sea-level rise**

The New Zealand Coastal Policy Statement recommends a planning timeframe of 100 years for the analysis of hazards near the coastline (Policies 24 and 27[3]).

Sea-levels in Auckland have been rising at an average of 1.6 cm/decade since 1900 and in the last two decades, have increased to above 3–4 cm/decade, partly due to long-term Pacific climate variability and partly an acceleration in sea-level rise. The latest Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report of Working Group I (Physical Sciences) was released in late 2013, with slightly higher sea-level rise projections than previously, using different Representative Concentration Pathways (RCPs) for carbon emission trajectories. The plausible range of projections is for an increase of 0.5 to 1 m in global-mean sea-level by 2100, with an additional caveat for accelerated ice-sheet contributions.

The most-recent national guidance on sea-level rise values to use is the 2008 MfE Guidance Manual for Local Government on Coastal Hazards and Climate Change (MfE, 2008). The guidance is based around a risk-assessment framework, where the consequences for any project or plan change should be investigated for a range of sea-level rises, starting with 0.5 m (by the 2090s) and at least considering 0.8 m (2090s). Given that the NZCPS stipulates that timelines of at least 100 years need to be considered, the equivalent values start with a rise of 0.7 m and at least consider 1.0 m by 2115 (Section 2 of Britton et al. 2012), which were set prior to the latest IPCC projections.

The predicted sea-level curves incorporating the MfE guidance tie-in points are shown in Figure 5. The gradual rise of sea-level influences all other coastal processes mentioned and potentially introduces longer term and wider scale geomorphic processes.

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[3] Policies 24 and 27 (Coastal hazards, climate change and protection of significant existing development)— Requires assessment of the effect of coastal hazards and climate change over at least 100 year timeframe, taking into account national guidance and the best available information. Policy 27, also recognises that hard protection structures may be only practical means to protect existing infrastructure of national or regional importance, and to meet the foreseeable needs of future generations

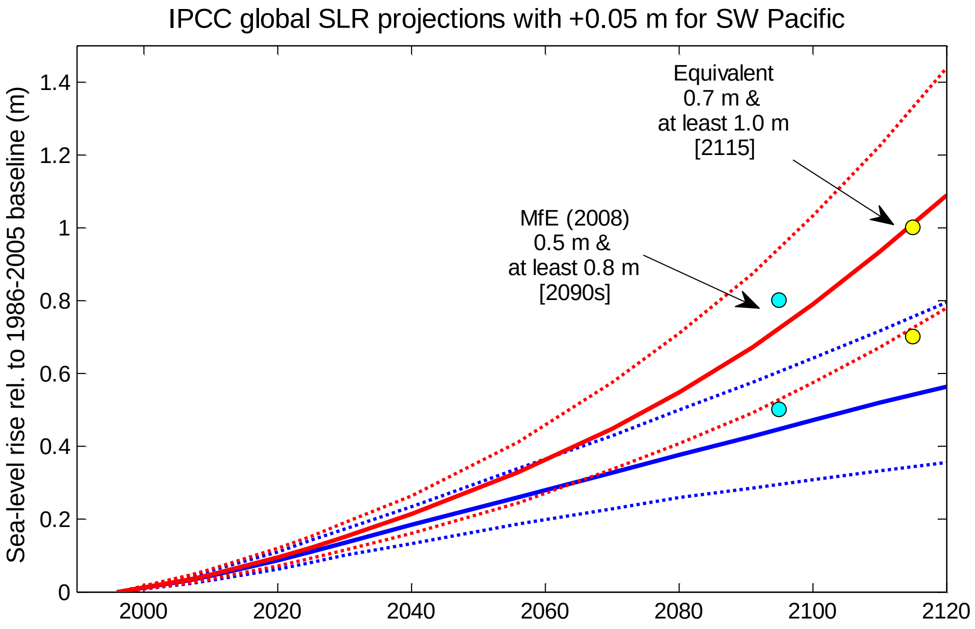

Figure 5 - IPCC (2013) sea-level rise projections out to 2120 that include an additional 0.05 m increase in the SW Pacific over and above the global-average. The blue lines are for the RCP2.6 scenario (severe curbs on emissions and zero by 2100) and the red line for RCP8.5 (business-as-usual global emissions). The two tie-points in the MfE (2008) sea-level rise guidance manual for the 2090s are marked (blue dots) along with the equivalent tie-points extended out to 2115 (100-year period).

3. Effect of coastal processes on floodway cut options

Specific design aspects of a floodway are considered based on the background to coastal processes influencing the Buller and Orowaiti River entrances, North Beach and the proposed floodway exit point. The components discussed are alignment, size (width, depth and slope) and sediment transport, and how each of these coastal processes influence the floodway.

a. **Alignment**

The curved alignment options (Figure 1 and Figure 2) were modelled by LRS on recommendation from an experienced river engineer that any river opening would naturally evolve to such a shape from an equilibrium river-ocean forcing. This alignment is indeed an approximate natural shape for a permanent natural river entrance - such as the Orowaiti River mouth (see historic aerial photo sequence in Figure 4). However, the operational life of a floodway cut is likely to be on a timescale of hours-days around the flood peak, so any long-term morphological equilibrium will not be established. Except in the rare case of simultaneous large coastal-storms and moderate flood events, the short-term river discharge will dominate wave-driven littoral drift for the period the floodway is operational.

The potential benefits of a curved alignment attempting to account for natural littoral drift are unlikely to be outweighed by the decreased hydraulic efficiency or additional costs associated with the cut following a longer (by 700-800 m) curved alignment. For the short-term operation of an emergency floodway cut a curved alignment would not provide any additional benefit over a straight alignment as the wave-current actions would likely be overwhelmed by the floodwater discharge in both cases, and the short operational timeframe means the longshore drift and floodway discharge will not form a stable equilibrium interaction.

To ensure the long-term viability of flood protection provided by the cut, ongoing maintenance is necessary on the containment bunds and banks. However, due to the beach accretion causing shoreline advance, the maintenance activities may require expansion to prevent large dunes and wide sand dunes forming which would prevent efficient drainage of the floodway waters.

b. Width

It is difficult to comment on a suitable width for proposed floodway cut options as this is a topic more relevant to the river engineer in relation to optimising design for hydraulic efficiency, floodwater discharge and cost of excavation and maintenance. One of the key factors to consider for floodway width is whether the flood management authorities are able to maintain a floodway ready for a quick excavation when a large flood is forecast, with a compromise necessary between higher conveyance in a wider channel but a longer time to excavate an opening.

From a coastal perspective, the important factors relating to width are the risk of exacerbating coastal driven storm-tide inundation and the littoral sediment drift acting to close the floodway exit through ongoing beach accretion.

- There is a risk that without proper design the floodway may act as a conduit for floodwaters from the sea and exacerbate the flooding risk to Westport. This risk may be reduced through appropriately sizing the bund blocking the floodway exit as a replica dune (current dunes reach 2.5-3m elevation, see Figure 6). However, a dune-scale exit bund may be too large for engineers to remove in time for the peak flow during emergency flood events.
- The large volume of sediment which actively moves along North Beach will at times make the beach-face very wide at the exit to a floodway (up to 400 m observed in the last decade). A wider channel will reduce the risk of complete blockage, but require greater maintenance to ensure appropriate readiness during storm events.

The presence of a ready-made channel which may act as a shortcut from the ocean to the lagoon heightens the risk of storm-tide driven inundation but it is the floodway depth which primarily controls the level of hazard for Westport.

c. Depth

The design depth or invert level of any floodway should take into account the level of local tides, storm-tides and sea-level rise in addition to the necessary efficient discharge of floodwaters. The level of the surrounding land also impacts the safe discharge depth of the floodway. Present ground surface elevations for the proposed floodway alignments (curved and straight) are shown in Figure 6.

The first stage of the modelling viewed for this report (LRS options report presentation) and the commission for this advice were based on modelling of the temporary floodway cut excavated to an elevation of -0.5m AVD-37, and assuming the offshore boundary at the sea does not impinge on the floodway's ability to convey water. This initial model run suggested up to 50% of the total volume (approx. 1,200 – 1,500 m^3/s) through the Orowaiti River may discharge through the floodway at peak rates of about 600 m^3/s (LRS email to M. Allis 30-3-2015). This depth of excavation would likely result in permanent diversion of the lagoon through the floodway as it represents a more hydraulically efficient discharge pathway than the current path. A stop-bank type barrier at either end (river and beach) would be needed to prevent the river permanently changing course, and after the flood peak subsides the bunds would require rebuilding – which would be difficult if the river has permanently changed the bathymetry to align with the floodway.

The modelling options of LRS addressed the flood-way cut option from a purely river-focused approach whereby the proposed design would convey flood-waters to the sea in the most efficient manner. This approach appears to provide a reduced flood risk to Westport (and stays true to the river-focused rationale), however it does not incorporate risks associated with coastal-driven flooding hazards and a permanent and wide channel up to 0.5m below MSL would bring substantial risk to Westport from storm-tide inundation scenarios of sea-level rise.

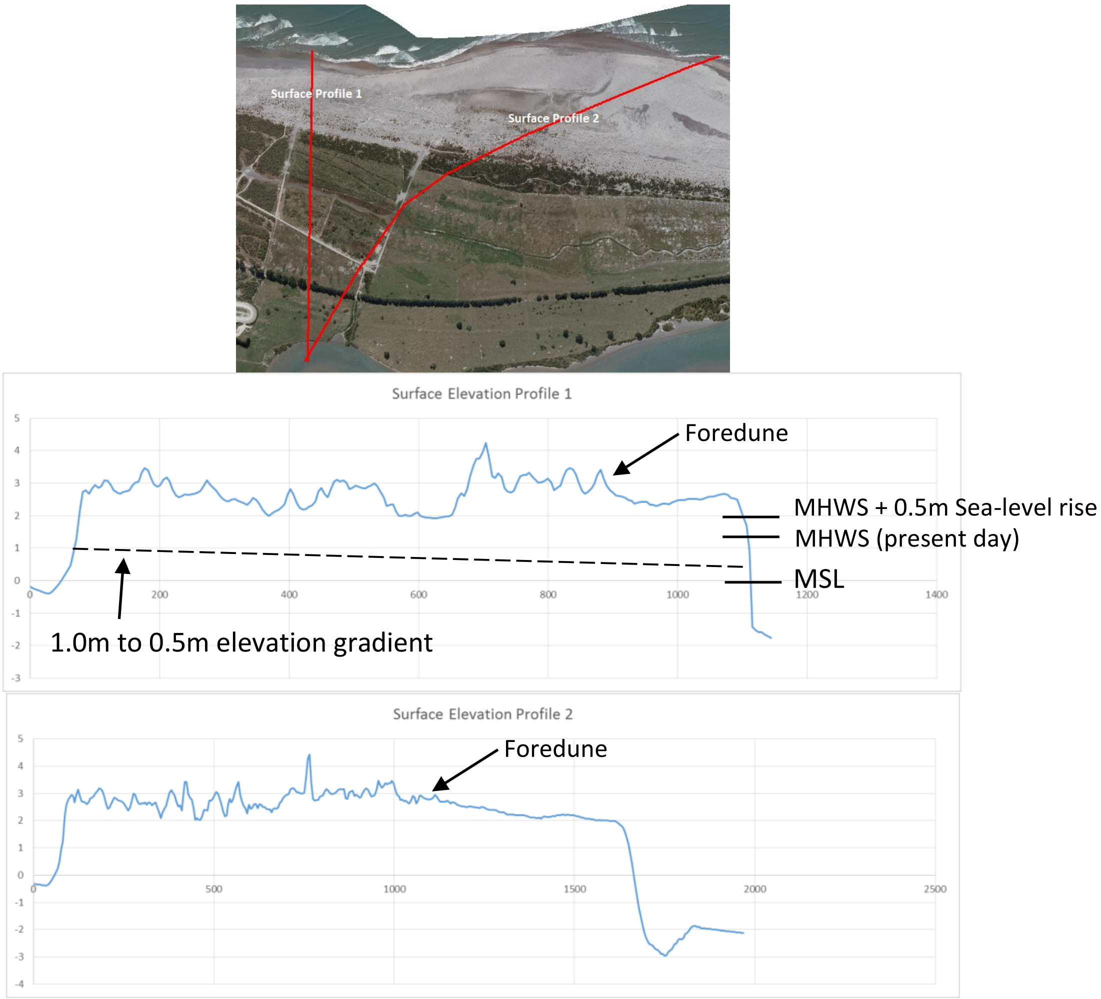

Figure 6 – Ground surface elevation profile along floodway cut option alignment (top). Elevation of 'Straight' alignment (centre) and curved 'Option E' alignment (bottom). MSL is at an elevation of -0.029 m. Lagoon is at chainage 0 m (left) with ocean at right. Elevations in LVD-37 datum. Source: LRS consulting.

Subsequent options modelled revised the invert depth from -0.5 m to +1.0 m, and some included a 0.5 m gradient along the floodway to enhance discharge. However, increasing the floodway invert level also significantly decreases the ability of the floodway to discharge floodwaters. Of the options modelled and sighted at the time of writing, the straight-alignment options of 1 m elevation sloping to 0.5 m elevation at the sea over widths of 100 m and 200 m conveyed approximately 15% and 30% respectively of the total Orowaiti River peak discharge (LRS email to M. Allis 30-3-2015). This is only 2-4% of the total Buller River flood flow. These options provide little flooding relief to Westport town with inundation areas remaining extensive for the costs of excavating 200,000 m^3 to 500,000 m^3 of sediment (estimated from Figure 6 ground elevations). Further increases to elevation of the floodway invert are not expected to be in favour through a benefit-cost analysis if only 10-20% of the Orowaiti River flow is diverted with minimal improvement to Westport flood mitigation for the cost of excavating a floodway.

These scenarios involve pre-excavation the floodway to levels below MHWS (approx. 1.5 m) and there is a risk that groundwater infiltration through the spit and bunds will regularly inundate low lying areas of the floodway. Further, when high-tide coincides with rainfall events, there will be no natural drainage out of the floodway depression. This localised and shallow inundation may have an acceptable loss of serviceability and access through the floodway depression.

In the scenario of storms causing elevated sea-levels with wave action driving coastal erosion, the sediment remaining in the dunes/stopbanks above MSL will act as a buffer to the erosion. Consequently, the action of removing large volumes of this sediment to increase floodway conveyance also increases the risk of erosion and coastal storm inundation.

d. **Storm-tide and sea-level**

These models were tested using 0.4 m storm-surge coinciding with high-tide and the flood peak whereas the 50 year 1970 storm event in Westport had 0.6 m storm-surge observed. This 0.4 m is a good starting point for present-day storm-tide and flood predictions given the statistical improbability of a rare storm-surge coinciding exactly with a rare flood (as discussed in section 2.b above, and in Duncan, 2005).

Inclusion of sea-level rise for modelling future flood scenarios is recommended (MfE, 2008). At Westport, operating the floodway is considered for flood events greater than the 50 year event which is statistically likely to occur once before 2065. Consequently, a minimum sea-level rise of 0.5 m should be included when evaluating performance of floodway cut options, and sea-level rise of 1.0 m considered when evaluating flood scenarios in 100 years.

As sea-level rises to 0.5m and greater, the low invert (relative to the adjacent land) and narrower seaward protection bund (narrower than the adjacent natural dunes) are at heightened risk from erosion, overtopping and inundation. The gradual rise of sea-levels implies that, without further upgrading, any fixed protective structure will provide a decreasing level of protection into the future.

Considering sea-level rises predicted for New Zealand, in approximately 50 years the sea will exceed the present-day Highest Astronomical Tide level (Table 1, HAT occurs every 18.6 years) at least every 7 weeks with a level of MHWS + 0.5m SLR. This means any floodway invert will become increasingly at risk from localised and widespread flooding, and that the sand dunes are more susceptible to erosion being exposed to higher waves on a more regular basis, although these are expected to grow in height as well.

e. **Sediment transport**

In its current form, the LRS model does not account for sediment transport of any sort. This is an important component when considering the stability and through-flow of the natural Orowaiti River channel during high-water events. When in flood, the river naturally widens and deepens its entrance way thereby more efficiently conveying water to sea. The model assumes a fixed bathymetry which is less efficient during flood conditions (but conservative for design), whereby in reality the increased flood velocity will heighten the flood flow bedload and remove large volumes of sediment out to sea.

The velocity of floodway discharge is modelled as typically 1-1.5 m/s and increases further as the flow reaches the beach front (LRS email to M. Allis 30-3-2015). This velocity is high compared to non-flood Orowaiti River and tidal velocities, and may cause localised scour around flow contractions. Floodways are not typically designed for high velocities to ensure widespread bed scour does not occur. Intentionally designing a floodway to self-deepen is inviting the river to form a new, permanent river channel, thereby defeating the purpose of temporary floodway cut (although a permanent diversion may also reduce the flood hazard, but invites substantial maintenance of another river entrance).

Any fixed elevation protection (i.e., stopbanks or floodways) for Westport relies on maintenance, and specifically in the case of the Buller River mouth the maintenance of river bed levels in the face of expected increased bed load volumes and deposition from sea-level rise.

Modelling large scale morphological processes such as river mouth migration is a complex task and many modern models are unable to accurately address the natural morphological sediment transport processes along the riverbed and coastline which are fundamental to the hydraulic discharge during flood events. At this high level stage, with a riverine focus, general incorporation of these coastal-processes to floodway cut design options is sufficient for decision making at this stage. The need to accurately model the interaction of coastal processes and floodwater will increase as options are refined further.

4. Conclusions and Recommendations

Flooding of Westport from the Buller River via the Orowaiti Lagoon is a significant hazard which justifies modelling of flood mitigation options to alleviate the risk levels. NIWA was requested to provide advice and guidance about the suitability of the curved 'Option E' emergency river floodway cut from the Orowaiti Lagoon to the Sea. The original basis of Option E was from a purely riverine focus to maximise efficiency of floodwater discharge. However, the model was unable to account for the important and complex coastal processes underpinning the successful operation of an emergency floodway cut.

The inundation of Westport is complicated by the fact that it can occur as a result of a river flood, a high sea-level brought about by a high-tide, large waves an on-shore wind, or a combination of these factors. The seriousness for inundation of a moderate flood in the river can be exacerbated by a high sea-level and vice-versa.

The key coastal processes and their **implications for floodway options** are:

1. <u>Storm-tides</u> exacerbating coastal flooding risk. A pre-excavated floodway will act as a pathway for coastal-driven storm-tide inundation of the Westport region. The invert level of a floodway is critical to the risk posed by the floodway.

2. <u>Littoral drift</u>. The natural coastal sediment migration is west-east along North Beach with net sediment bypassing of the Buller River entrance. The littoral drift periodically forms sediment bulges which migrate east along North Beach. Such sediment volumes pose substantial operational concern to a floodway as the distance to the sea may be 100-200m longer at any time than modelled. In addition, the wind and wave action may build larger dunes across a floodway exit.

3. <u>Sediment transport and river mouth geomorphology</u>. While the Buller River mouth is laterally constrained with little additional capacity to discharge floodwaters other than through river deepening by bed scouring, the Orowaiti River mouth is unconstrained on its western bank and natural sediment mobilisation during floods will widens the river mouth to increase discharge capacity. This complex process is difficult to model and while it is likely to increase the overall conveyance of the floodwater discharge, the modelling of manually widened river mouths showed little difference to the Westport flooding extent (Pers. Comm. Matthew Gardner 29-4-2015).

4. <u>Sea-level rise</u> in the coming decades will reduce the hydraulic efficiency and the protection offered by the floodway cut by increasing the downstream base level. Sea-level rise also causes an increased flood hazard to Westport through existing river channels and this may be exacerbated by the pre-excavation of a floodway cut to a fixed level. Without future upgrades, any fixed structure will provide a decrease level of flood protection as sea-level rise occurs.

Based on the above assessment and review, the following **recommendations** should be considered for future floodway design options and general coastal processes assessments.

If floodway cuts are to be considered further without more complex modelling:

1. The storm-tide magnitude used for inundation assessment and modelling should comprise Mean High Water Springs (MHWS = 1.471 m at Westport, equivalent to MHWS10) peak tide level coinciding with a 0.4 m storm-surge. Larger values of storm-surge may be considered for even-more extreme situations.

2. Consider only straight floodway cuts which are have greater hydraulic efficiency and are unlikely to be blocked by coastal-processes for the short duration of floodway operation.

3. Pre-excavate floodway cuts to a level not below MHWS and be prepared to accept potential localised flooding within the floodway from coastal-driven storm-tides, and recognise that with future sea-level rises the frequency of this flooding will increase.

4. Consider sea-level rise scenarios of 0.5 m and 1.0 m to investigate the potential consequences of future flood events. Climate change will also have an effect on rainfall patterns and flood hydrographs.

5. Create substantial floodway bunds at the lagoon and sea ends of the floodway to prevent heightened storm-tide inundation risk to Westport. These should be of similar height to the existing frontal dune system. Consider the time taken to excavate these bunds and the relative level of forewarning provided for a large flood event.

6. Consider extending the modelling work to include dynamic wave-driven effects (wave setup/runup and wave-current interactions at the river mouths) on the tail-water levels at Westport. However, a full hydrodynamic model would be numerically complex, costly to run and difficult to calibrate due to the scarcity of West Coast wave data. Further, the effect of wave setup and runup is unlikely to be noticeable as the Buller River mouth water depth is too deep to generate any substantial wave setup, and the dynamic effects of wave breaking and wave runup are only of concern to exposed coastal structures.

7. A site visit by a coastal engineer would assist in refining descriptions and current state of the existing rivers, estuarine and coastal environments.

8. Consider implementation of a coastal monitoring regime at North Beach including short-term instrument deployments (wave buoy, current meter, suspended sediments) and long-term monitoring (beach cross-section profiles, topographic/bathymetric surveys). The combination of sediment monitoring, aerial photos and beach profiles would be useful to obtain volumetric estimates of sediment movement rates. A sequence of cross-shore beach profiles would give a measure of changes in distance from the floodway exit-bund to the ocean as the sediment bulges migrate along the coast. A wave buoy will enable calibration of wave conditions for models to predict shoreline positions, coastal erosion and wave-driven inundation levels for storm events.

To summarise, at this stage of the investigation a floodway cut option from the Orowaiti Lagoon to the sea should not necessarily be discarded based on the potential influence of coastal processes. However, the presence of a floodway heightens the risk to Westport from coastal-driven storm inundation, and the feature will provide a decreasing level of protection as sea-level rise occurs. Further, if the above recommendations about minimum floodway invert levels are incorporated there may be little benefit to flood mitigation within Westport and such a structure would be difficult to justify financially. If such an option is to proceed further, it is recommended that the coastal-driven storm inundation be modelled in conjunction with river flooding to ensure an appropriate level of risk is accommodated within the design.

This guidance is provided at an intentionally high-level for this stage of the flood mitigation investigations and is intended for evaluation and improvement of Option E – Orowaiti Lagoon floodway cut, with general coastal processes applicable for evaluation of other options. It should not be grossly applied as a solution to flood hazard elsewhere. This coastal processes assessment is based on information available at the time of writing with a brief literature review.

Please contact me if you have any queries or follow-up questions about this information.

Yours sincerely,

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