Avon-Heathcote Ihutai Estuary Edge Condition Inventory

Christchurch City Council

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IZ128500-A.CS.EV.1-NM-RPT-0001 IZ128500-NM-RPT-0001| B

12 August 2019

Estuary Edge Condition Inventory

Project No:	IZ128500
Document Title:	Avon-Heathcote Ihutai Estuary Edge Condition Inventory
Document No.:	IZ128500-NM-RPT-0001
Revision:	B
Date:	12 August 2019
Client Name:	Christchurch City Council
Client No:	Client Reference
Project Manager:	Ian Wiseman
Author:	Kate MacDonald, Derek Todd
File Name:	J:\IE\Projects\02_New Zealand\IZ128500\21 Deliverables\IZ128500-NM-RPT-001_A Estuary Edge Condition Inventory_ 20190812.docx

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Document history and status

Revision	Date	Description	By	Review	Approved
A	12 August 2019	Draft Report for CCC staff review	K. MacDonald	D. Todd	C. Redmond

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Executive Summary

This condition inventory presents information on the current location, extent and condition of built structures, soft barriers and natural shorelines along the eastern edge of the Avon-Heathcote Estuary from Evans (north of Bridge Street) to the southern tip of South Brighton Spit. The position and elevation of the current estuary edge, as surveyed in June 2019 in this study, was compared to 2011 aerial imagery and 2003 LiDAR to assess the changes following the Canterbury Earthquake Sequence (CES) to present day. The inventory comprises of a database of edge and structure information, along with maps of structure location and condition, elevations, and change on shoreline position. For mapping and analysis the study area is divided into six areas of: North of Bridge Street, South of Bridge Street, South New Brighton Park, Ebbtide Street to Godwit Street, Southshore from Godwit Street to South of Tern Street, and the natural shoreline within the Spit Reserve.

Methodology

An in-depth review of literature and council records was undertaken to obtain information on the age and condition of estuary edge structures prior to the CES. Key resources in this review were previous inventories of edge structures undertaken by Walter (1995) and ECan (2002). The information from these inventories has been added to information collected from the June 2019 field surveys to form an up-date inventory of the history and changes to the estuary edge and the structures located along the edge.

A GNSS survey and subjective condition assessment was undertaken in June 2019 to determine the current state of the eastern estuary edge. As well as the GNSS survey of current structure position and elevation, an 'estuary edge' line was surveyed to represent the physical edge of the estuary. For this analysis the estuary edge is defined as being either 1) the erosion scarp or vegetation line where there is no structure or 2) the inland boundary of any structure, or 3) evidence of erosion scarp beyond a structure. A 'high ground' line associated with the edge was also surveyed to include 1) the highest elevation of the top of any structure present, or 2) the top of any bank/erosion scarp behind the structures.

The surveying of these lines allowed for the current edge position to be compared to the estuary shoreline digested from 24th February 2011 aerial imagery to determine change in shoreline position since the February 2011 earthquake. For land elevation change due to the CES the elevation of the 2019 surveyed 'high ground' was compared to the highest ground elevation from the July 2003 LiDAR survey across a 5-10m buffer width around the 2019 position. Unfortunately, the direct comparison of structure elevations was not possible due to non-ground structures being removed during post processing of the 2003 LiDAR. However, where possible use of information from previous inventories of estuary structures were used to aid the assessment of elevation changes.

A current condition ranking was applied to each structure in the field and adjusted based on findings from the field survey and literature/records review, and a review by a coastal engineer. A similar ranking of the current condition of the land immediately behind the structures was given to each section of shoreline which indicated evidence of erosion and loss of vegetation due to dieback from overtopping.

Structure Condition Results

In total the 7.1km of shoreline surveyed was categorised into 145 sections, of which 117 were structures covering a length of 4.5km. Shoreline sections represent lengths of similar condition, hence an individual structure could have multiple sections covering different conditions. Approximately 3km of the structures (60%) were graded as being in a good condition ranking of 'A' or 'B' (no or limited evidence of damage), predominantly being council stopbanks that have had repairs post-CES north of Bridge Street (Area 1) and at Ebbtide Street (Area 4), and repaired gabion baskets and reno mattress in the South New Brighton Park (Jetty to Pleasant Point Yacht Club and the Jellicoe Marsh Boardwalk). Additional estuary inundation protection structures not on the estuary edge, being the stopbank around the eastern side of Jellicoe Marsh and the LINZ bund along the Southshore RRZ were also graded as condition 'B' and 'A' respectively, although the Jellicoe Marsh stopbank was being upgraded following the survey.

Approximately 1.3km of the shoreline, making up 28% of length of structures were given a condition ranking of 'D' or 'E' (severe or extensive damage resulting in significant loss of functionality). These structures were

predominantly found in Area 3 - South New Brighton Park and Area 5 - Southshore. Within Area 3 half of the 600 m of unrepaired reno mattress between the Yacht Club and Jellicoe Marsh, is ranked Condition 'D' and 'E'. The worst section RM2-I, covering a length of 186m to the north of the South Brighton Holiday Park has slipped down onto the estuary bed with lateral spread to now sit below MWHS level, and the land behind has suffered the greatest post CES erosion over the whole study area (average -8.5m, maximum -13.4m).

In Area 5, there is 1km of former private structures, being a collection of still standing concrete walls, informal revetments and informal fill (many from collapsed former walls), that have been graded as being condition 'D' or 'E'. These structures make up 70% of the length of structures within the Southshore area. Conversely, none of the structures in this area have been graded condition 'A' and only 6% (83m) have been graded condition 'B'.

One 40m of the stopbank in Area 1 (fronting Kibblewhite Street) was also given a condition 'D' rating due to the significant erosion occurring on the front face of the stopbank. No structures with 'D' or 'E' rankings were found in Areas 2, 4 or 6.

Land Conditions Results

The 2019 survey assessed 46% of the 7.1km surveyed as having a land condition behind the edge as being condition 'A' or 'B' (no or mirror evidence of erosion or vegetation die back), while 24% (1.65km) was ranked as condition 'D' or 'E' (significant to extensive erosion, scarping and vegetation dieback). Approximately 1.3km of the land behind the edge was not assessed for condition due to the presence of roads (areas 1 & 4) or marsh (Area 3) being located immediately behind the structures.

Areas 3 and 5 have the greatest lengths of poor condition land behind the edge (e.g. condition 'D' and 'E'), with 467m and 876 m respectively, which is 42% and 50% of the total shoreline length in these areas. However, both areas also include over 200m of condition 'A' and 'B' land behind the edge. Area 2 has the least evidence of erosion, scarping or vegetation dieback along the edge, with 97% (1031m) of the edge in this area being graded condition 'A'.

Elevation changes

The analysis of elevation changes from pre to post CES has been complex. However, the following points have been identified for each area:

- For Area 1, the comparison of pre- CES to current stopbank elevations shows that the current stopbank elevations are higher than the pre-earthquake elevations.
- For Area 2, the change in elevation, assumed to be a result of subsidence in the CES, has generally in the order of -0.2m across the whole area, however in some locations it is up to -0.5m.
- For Area 3, for the northern part of the area the 'high ground' feature is higher in 2019 than 2003 by up to 0.2m due to the construction of new structures. However, for the 600m of unrepaired reno, the combination of subsidence and lateral spread has resulted in the current elevations being on average 0.25m lower than in 2003, with the maximum change in the order of -0.5m.
- For Area 4, the whole length of the rebuilt stopbank except for the southern section is generally the same or slightly higher elevations that pre-CES levels.
- For Area 5, a combination of RRZ land clearance, the varying degrees of edge structure removal, the way the 2019 'high ground' has been defined and the limitations and uncertainty around the 2003 LiDAR elevations at the structures made the analysis of pre to post CES level very complex. However, comparison of structure and ground levels against the corresponding information presented by Walter (1995), indicated the following points:
    - Although the removal of seawalls has resulted in an average drop in effective edge elevation in a number of locations, there were gaps where former walls were below 11m and boat ramps, which did not produce a continuous level of inundation protection pre CES.

- Nearly equal numbers of properties have lower 'high ground' elevations that ground levels in 1995 as have higher levels. It is uncertain how much these levels have been influenced by RRZ land clearance activities and how much is due to earthquake effects.

- At a number of the properties the remnant wall structures are higher than former natural banks, therefore still produce a greater level of erosion benefit that would occur with the natural banks alone.

- For Area 6, there is a variable pattern, with the northern and central areas showing the current 'high ground' being around 0.2m lower than the corresponding 2003 elevation, and southern area showing wide fluctuations in the relationship with differences greater than 1m.

Shoreline Position Change

These results of the DSAS show that the 40% of the study area shoreline (2.3 km) is stable (changes ± 1m), and 34% (1.9km) has eroded over the 8-year period since 24th February 2011. The majority of this erosion has been by less than 4m (e.g. rate of < 0.5m/yr), with only 330 m having erosion distances for greater than 4m.

The greatest erosion distances (e.g. > 12m, >1.5m/yr) have occurred in Area 1 at Bridge Reserve (-32.5m), Area 3 in the centre of the un-repaired reno mattress section 9-13.4m), and on the spit reserve natural shoreline in Area 6 (-20m).

Shoreline advance has been recorded in Area 1 and Area 5 in relation to shoreline repairs and revetment construction respectively, and along the natural shoreline at the tip of the South Brighton spit in Area 6

For areas with structures (e.g. excluding Area 6) Area 3 (75%) and Area 5 (37%) have suffered the greatest spatial extent of erosion. For Area 3 this erosion includes 400m of the un-repaired reno mattress, with an average retreat of -3.5m and a maximum of -13.4m. This is the worst eroded area of structures in the study area. Further analysis of changes in erosion rate over the 8-year period showed no clear trend, with 40% of the available transects having a decrease in in rate since 2016, and 40% showing an increase.

In Area 5 the erosion distances are less, predominantly being limited to under 4m, due to the remnant structures still providing some degree of erosion protection along this shoreline. This is an important consideration in any decision to remove or modify the existing remnant structures.

There also appears to be a relationship between the presence of extensive salt marsh on the upper estuary bed and the magnitude of erosion experienced, particularly at locations without edge structures. This relationship should be examined further for evaluating future edge erosion protection options.

Relationship of Erosion Distance to Structure Elevation

The results from the condition assessment and survey data indicated a relationship between the elevation of a structure, and the magnitude of erosion behind the structure. Key points of further analysis of this relationship included:

- Of the 7 structure sections which have minimum elevations below the MHWS, approximately 85% had erosion behind their structures
- The occurrence of larger erosion distances was highest for low elevation structures below MHWS elevation, with 187m (42%) of shoreline erosion behind these low elevation structures being by more than 8m.
- Although the occurrence of larger erosion distances decreased with higher structure elevations, erosion was still experienced over all structure elevations.
- The likelihood of any erosion occurring decreased with increasing structure elevation.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to identify the current location, extent and condition of the eastern shoreline of the Avon Heathcote Estuary in accordance with the scope of services set out in the contract between Jacobs and Christchurch City Council ('the Client'). That scope of services, as described in this report, was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Client and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

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1. Introduction

1.1 Background

As part of the South Brighton earthquake legacy project, Jacobs have been commissioned by Christchurch City Council (the council) to provide factual information of the current location, extent, and condition of built structures, soft barriers, and natural shorelines around the eastern edge of the Avon/Heathcote Ihutai Estuary shown in **Figure 1** (Evans Ave to the southern tip of South Brighton Spit) to be compiled into a single comprehensive inventory comprising of maps, tables and a summary report.

It was hoped that the current condition of the 'edge' in terms of elevation and position could be compared to the condition present prior to the start of Canterbury Earthquake Sequence (CES)[1] in September 2010. For elevation this was possible by comparing surveyed 2019 elevations with those from a July 2003 LiDAR survey. However, due to issues with pre-CES aerial imagery limitations and availability it has not been possible to do this for estuary edge position. Instead, comparisons have been made between the surveyed 2019 edge position and edge position determined from aerial imagery flown on the 24th February 2011, two days after the devasting 7.1 magnitude earthquake on 22nd February. Hence the assessment is of post-February 2011 earthquake position changes due to estuarine processes rather than of changes due to combined earthquake and estuarine processes from a pre-CES position.

This inventory consisting of report, maps and database is stage 1 of a larger project. The assessment on the reasons for change in estuary edge condition, differences in the level of risk of inundation and erosion, and potential options to remedy the shoreline back to the pre-earthquake condition may be considered in a subsequent Stage 2 report.

For reporting purposes, the eastern estuary edge has been divided into the following 6 areas, as shown in **Figure 1** and **Figure 2**:

- Area 1: North of Bridge Street
- Area 2: Bridge Street to north end of South New Brighton Park
- Area 3: South New Brighton Park including Jellicoe Marsh. Area divided into 3 sub areas for mapping as shown in Figure 2.
- Area 4: Ebbtide Street to Godwit Street
- Area 5: Southshore from Godwit Street to south of Tern Street. Area divided into 5 sub areas for mapping as shown in Figure 2.
- Area 6: Natural shoreline with no structures within the Spit Reserve from south of Tern Street to the southern end of the spit.

[11] The Canterbury Earthquake Sequence commenced on 4th September 2010 with lasted through out 2011 with four major earthquakes, including the devastating 22nd February 2011 event, and thousands of aftershocks.

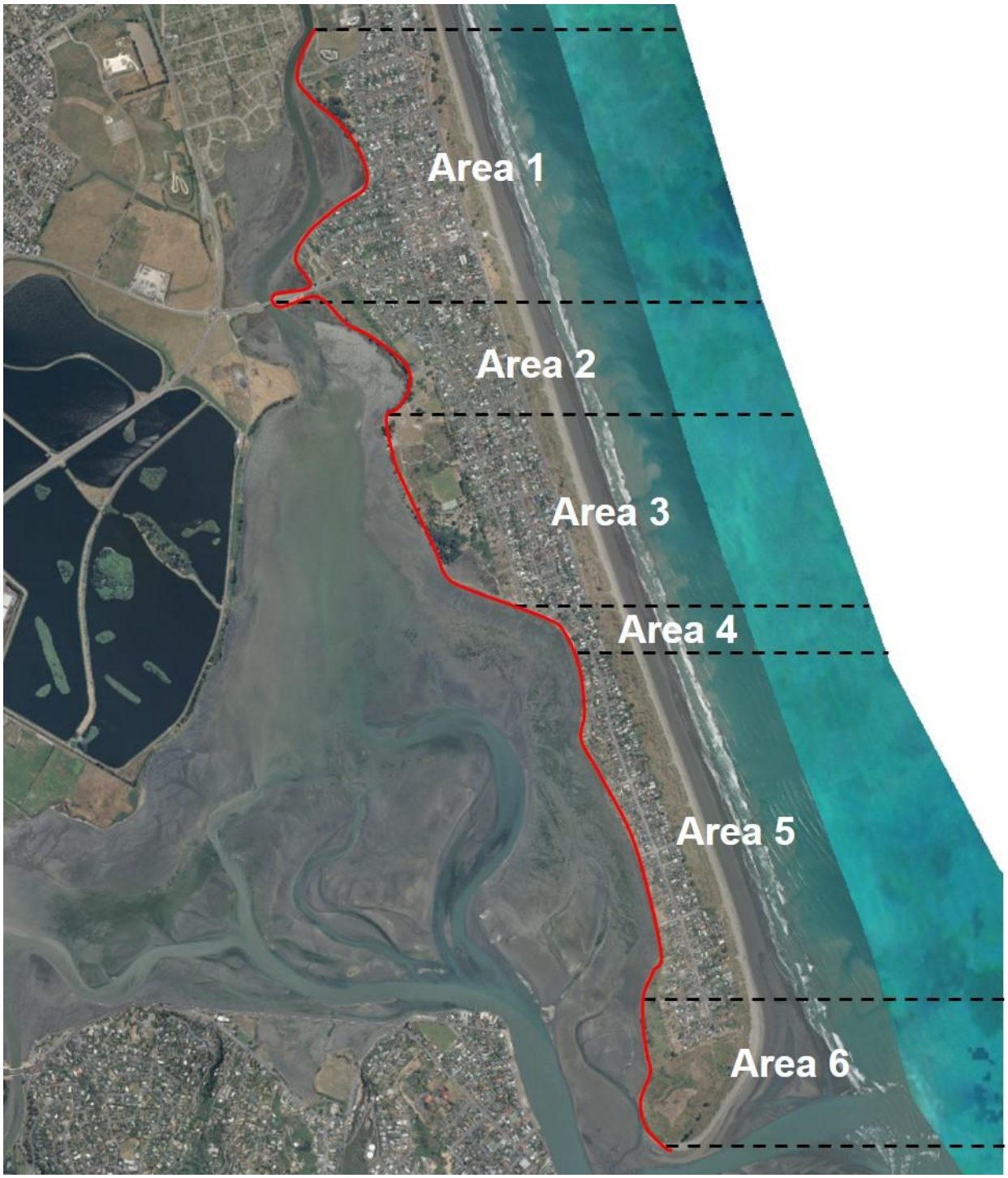

Figure 1: Eastern estuary edge

Figure 2: Eastern estuary edge broken into Areas for reporting

1.2 Condition Inventory Report Outputs

The information presented in the condition inventory include the following:

1. **Inventory of current condition of the eastern estuary edge:**
   This consists of summary database (**Appendix A**) and mapping **(Appendix B)** of the current shoreline and structure type, footprint area, elevation, structure failure/weakness, and evidence of erosion scarps. This information is presented for each section of structure or shoreline with common conditions and was largely collected in the field during June 2019. An over-all 'current condition ranking' was applied to each structure which was attributed in the field and adjusted based on findings from the field survey and literature/records review. A similar ranking of the current condition of the land immediately behind the structures in terms of evidence of erosion and inundation was also applied.

   Further detail on the survey and current condition methodology is included in section 2.1.

2. **Assessment as far as possible of the pre-CES eastern estuary edge condition (e.g. elevation and position):**
   This assessment relied on information obtained from a literature and council record review, and analysis of LiDAR survey surfaces from July 2003, and vertical aerial imagery from 24th February 2011[2], and information obtained from a literature and council record review. We recognise that for the assessment of shoreline position from the aerial imagery, this does equate to condition pre the whole CES from 4th September 2010, but we are constrained by data availability and limitations (see section 2.3). However, for ease of description the combined elevation and position are termed to be a 'nominal pre-CES condition'. Where possible the elevation and position data for this 'nominal pre-CES condition' has been checked against information obtained from the literature and records review. We also recognise that there is gaps and uncertainty in this information, hence have developed a "certainty" rating for the pre-CES condition for each structure section of the estuary edge.

3. **Assessment of the differences in the condition of the eastern estuary edge from the 'nominal' pre-CES condition to the current 2019 condition.**
   This assessment is largely presented the following map forms:

   - Change in elevation of the 'high ground' around the estuary edge between the July 2003 LiDAR and the 2019 survey. The definition of 'high ground' includes the highest elevation of the top of any structure present or the top of any bank/erosion scarp present at any location around the estuary edge. For preliminary interpretation of change in inundation risk, these changes are mapped against four design return period water levels (ARI of 10 years, 20 years, 50 years, 100 years).
   - Change in position of the estuary edge from comparison of the 24th February 2011 and May 2019 aerial photographs. For this analysis the estuary edge is defined as being either:
     - The erosion scarp or vegetation line where there is no structure,
     - The inland boundary of any structure, or evidence of erosion scarp beyond a structure.

Further details on the methodology for determining these changes in elevation and position are presented in Section 2.3.

The mapping associated with this inventory are presented in the following appendices, presented in a separate volume in A3 size for ease of viewing:

- **Appendix B**: Base maps of 2019 estuary edge structure location, type, footprint and condition, as well as condition of land behind the structures.
- **Appendix C**: 2003-2019 elevation comparison and design flood levels
- **Appendix D**: 2011-2019 shoreline position change

[2] Feb 24th 2011 was two days after the Feb 22nd 2011 magnitude 6.3 earthquake. The quake was centered 10km south-east of the city at a depth of 5km.

The May 2019 aerial imagery is used as the base for all these mapping products.

As well the written material included in this report, the condition inventory includes the following digital information supplied to council:

- Detailed database on current and historical structure condition from all records and literature.
- Photograph database from 2019 survey and historical images from various sources
- GIS database including structure type, 2019 surveyed location and elevations, and structure photographs.
- Full results of DSAS analysis of shoreline position change 2011 - 2019.
- Listing of council records and literature reviewed to gather information on estuary edge and structure history.
- Drone survey of the eastern estuary edge flown by ECan on 8th July 2019.

1.3 Estuary Extreme Water Levels

The most relevant water level records for the eastern estuary edge are those collected at Bridge Street by the council since 1997. These records have synthetically been extended back to 1960 to give a longer-term record. Although there is some doubt about the actual level, the highest water level at Bridge St prior to the CES is commonly accepted as being on 28 August 1992 in combination with the large snow event in the city. Walter (1995)[3] reported a water level of 10.95m CDD[4] (All elevations in this report are in terms of CDD) at the mouth of the Avon River, and Mulgor (2010)[5] estimating the level at Bridge St to be 10.941m. The corresponding water level at Ferrymead was recorded (records at this site since 1974) as 10.77m, with the difference being because of strong SW winds blowing across the estuary towards the eastern shoreline. It is noted that for hydraulic modelling of the estuary, a design wind of 10 m/s (36 km/hr) from the south-west is applied, which produces a 0.11m increase in water levels from Ferrymead to Bridge Street.

The August 1992 water level appears to have been used as an approximate design level for eastern estuary edge structures constructed during in the 1990's and early 2000's.

For hydraulic flood modelling required for hazard management requirements, Mulgor (2010) generated an extreme storm tide[6] probability distribution for the estuary, with standard return period levels presented in **Table 1**. From this distribution, the August 1992 water levels had a return period of 114 year. The design height for stopbanks and bunds around the estuary since 2011 has been 11.2m, being based on the 1 in 50-year water level from Mulgor (2010) (est 10.9 m) plus a 0.3m freeboard. On the eastern edge this freeboard is required to accommodate wave set-up and run-up along the edge during strong south-west wind events.

Table 1: Extreme Water Level Statistics for Bridge Street

Return Period	2011 Water level (CDD)	2018 Water level (CCD)	Frequency that 2018 levels exceeded since CES (up to 1/8/2019)
2-years		10.682	15
5-years	10.780	10.804	5
10-years		10.885	3
20-years	10.869	10.963	1
50-years	10.910	11.063	1
100-years	10.936	11.139	

[3] Walter J.L (1995) Estuary Eastern Foreshore Protection. Report for Water Service Unit, CCC.
[4] CDD: Christchurch Drainage Datum, is +9.043m above Lyttelton Vertical Datum 1937 (LVD37).
[5] Mulgor (2010) Downstream Hydraulic Boundary Conditions for Avon and Heathcote Rivers. Report to CCC.
[6] Stor tide: Combination of high tide with storm surge to produce extreme tidal water levels.

In the eight years since the CES, there has been record high water levels in the estuary and the occurrence of extreme levels have become more frequent. For example, under the 2011 extreme water level distribution levels on 4th March 2014 (10.90m) would have been a 100-year event, on 21 July 2017 (10.96m) would have been an 800 year event, and on 2nd February 2018 (11.08m) a 15,000 year event (Harrington & Parsons (2019)[7]. Images of the inundation around the estuary edge at South New Brighton Park and Southshore in the February 2018 highest recorded water level are presented in **Figure 3a** and **3b** respectively**.**

Figure 3: Inundation of estuary edge in highest recorded water levels on 2nd February 2018. a) South New Brighton Park, b) Southshore south of Penguin Street. (Images supplied by CCRU).

These levels prompted council to review the distribution due to 2011 statistics no longer being relevant, with (Mulgor 2018)[8]. calculating new extreme water level statistics as presented in **Table 1**. These changes are partly due to using a longer data record therefore a greater range of events and tidal conditions, partly due to sea level raise over the period of the record, and most likely partly due to changes in estuary bed levels as a result the CES. Under these updated statistics, the March 2014 event has a return period of around 12 years, the July 2017 around 20 years, and the February 2018 event around 60 years.

The frequency of water levels since the end of the CES above each of the 2018 return period levels is also presented in Table 1, showing that there have been 15 events within the 8 years with water levels greater than the 2-year return period, with the above 3 most extreme events having water levels above the 10-year return period. During 2019 there have been 2 events (23rd Jan and 1st Aug) with water levels above the 10.68m threshold.

Under the 2018 statistics, new stopbank and bund design elevations will have to be to 11.4m to maintain protection for a 50-year event with a 0.3m freeboard.

1.4 CES Ground and Estuary Elevation Changes

During the CES, the southern part of the estuary lifted whilst the northern part subsided resulting in elevations changes of the land around the eastern edge and the bed of the estuary. **Figure 4a** presents the vertical land changes from EQC mapping, while **Figure 4b** presents the changes to the estuary bed from NIWA 2011 and Measures 2015.

[7] Harrington & Parsons (2019) The stormwater and tide Interface in Christchurch. 2019 Stormwater conference.
[8] Mulgor (2018) Extreme Sea levels at Christchurch sites: EV1 Analysis. Report for CCC LDRP.

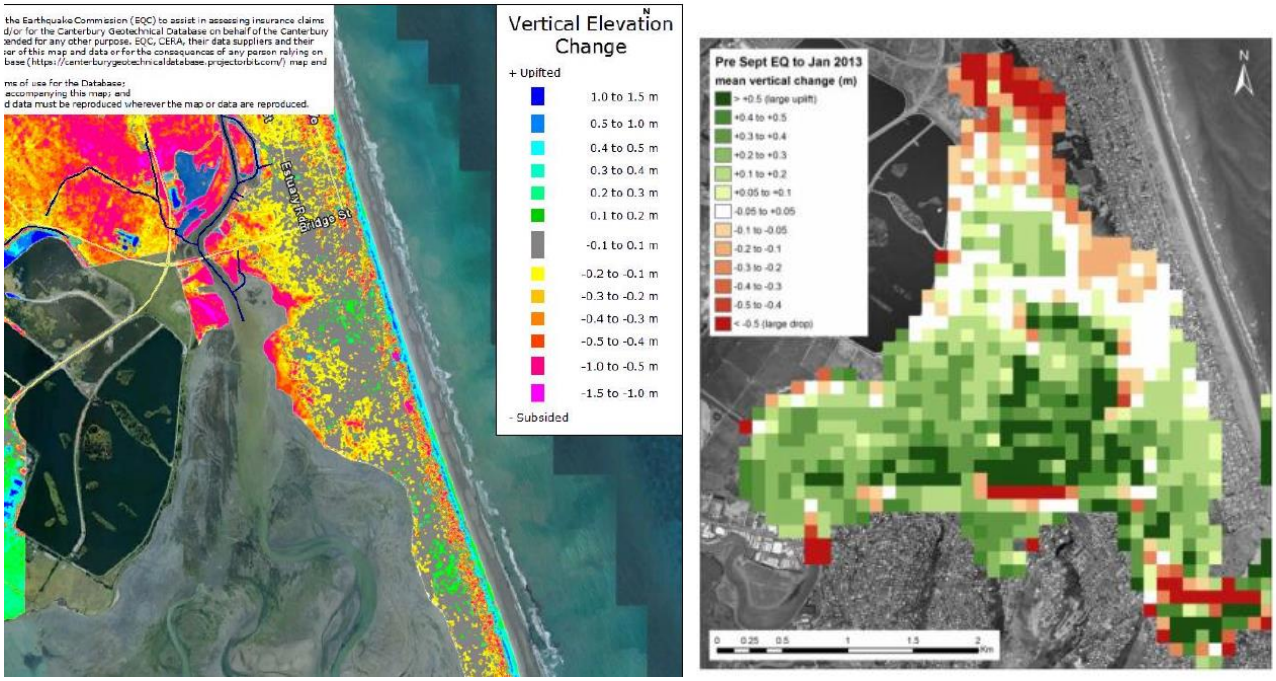

Figure 4: Elevation changes as a result of the CES: a) Vertical land elevation changes from EQC mapping; b) Estuary bed elevation changes from NIWA (2011) and Measures (2015).

2. Methodology

2.1 Literature Review and Record Search

2.1.1 Literature Review

A major source of reference material was the Avon- Heathcote Estuary Ihutai Trust bibliography (AHEI Trust, 2018), a reference list of material related to the AEHI estuary from scientists, schools, local body researches and community groups. The bibliography was reviewed, and relevant material was obtained online and from CCC sources. In total 38 published and unpublished reports were reviewed, which included information about the age and purpose of built structures, as well as information about as-built elevations and alignments that may have changed as a result of the Canterbury Earthquake Sequence (CES). Key references included Walter (1995) which included in appendices an inventory of private structures in Area 5, and CH2M Becca (2019) which included a visual condition assessment of all estuary edge structures and adjacent land condition south of Bridge Street (e.g. Areas 2 to 6).

The full record of reviewed literature is included in the separate digital listing of reference material.

2.1.2 Council Records Search

A search of council TRIM records and archived hard copy historical material was undertaken for relevant documents which described works and conditions of the estuary edge. In total 143 records were identified and reviewed to obtain relevant information on structure condition and design. Following completion of the field survey, this information was tied to a structures unique identifier to determine the specific structures history. A narrowed search was undertaken to fill any gaps in the record about structures which had been identified in the field survey but had no historical or recent records associated with them.

The full record of reviewed records is included in the separate digital listing of reference material.

2.1.3 ECan Estuary Edge Inventory 2002

An important historical record was a 2002 inventory of estuary edge structures and infrastructure undertaken by ECan, which included information of structure elevations, subjective condition assessments, and photographs of the structures. Information from this inventory forms the main source of pre CES knowledge on structure condition and is included along with the inventory photographs in the separate digital listing of reference material.

2.1.4 Past Estuary Edge Surveys

Since 2000 ECan have undertaken periodic annual position surveys of the shoreline around the Spit Reserve in Area 6. Surveys are available from 2000-2006, 2010, 2014-2017, and 2019. For this project the April 2010 and February 2016 surveys were used to compare position with the May 2019 survey undertaken for this project.

The Council hold survey information from 2014 and March 2016 of the estuary edge at the road ends in Area 5 (e.g. Heron, Penguin, Plover & Tern Streets) prior to the extension of the LINZ bund across these areas in July 2017, and of the shoreline erosion scarps around the South Brighton Holiday Park in Area 3. The information from these surveys has been included in has been in digital database on current and historical structure condition.

2.1.5 Interview Knowledgeable Technical Personal

Interviews were undertaken with identified key coastal professionals of John Walter (Christchurch City Council), Justin Cope (Environment Canterbury), Deirdre Hart (University of Canterbury) and Martin Single (Shore Processes and Management Ltd) to gather any additional information about structures and the purpose of structures which may not be found in council records or literature. The interviews were also used to identify past

activities which may not be noticeable on the surface in current conditions (e.g. Nourishment activities, buried structures). A site visit was also undertaken with a long-standing resident and community board member Tim Sintes, who was able to provide anecdotal evidence about the land elevation changes following the CES due to the clearance of the Residential Red Zone (RRZ).

2.1.6 Christchurch Coastal Residents United Photo Inventory

Christchurch Coastal Residents United (CCRU) provided a series of images of the estuary edge both pre and post 22nd February 2011 earthquake with the GPS locations of each photo. The majority of photos were taken when a large storm tide event occurred, and therefore their primary use of this information was to confirm the failure or loss of functionality of a structure to protect the coastline from inundation. Where images could be associated with a structure identified in the survey, the image was included in the Estuary Edge Inventory Photo Database and are listed with the structure in the digital structure database.

2.1.7 Pre-Earthquake Sequence Condition Certainty Ranking

Information from the literature review, record search and 2002 ECan inventory provided an insight to the condition of structures prior to the CES (e.g. pre- Sept 2010). However, since there is a temporal component to the information sources, the footprint and condition of some of the structures may have been different from the records at the time of the start of the CES. Therefore a 'Certainty Ranking' was developed following the literature and records review to determine how certain we can be about the condition of the structures at the time of start of the CES. The certainty rankings and criteria are shown in **Table 2**.

Table 2: Certainty ranking of the pre-2010 condition of the structure

Certainty Rating	Criteria
Certain	2008-2010 As built design report
Almost Certain	2008-2010 Design report 2008-2010 Resource consents
Some Certainty	2002-2008 Design reports 2002 Estuary inventory (ECan, 2002) with condition ranking
Limited Certainty	1995 Survey of structures (Walter, 1995) 1990-2002 Design reports 1990-2002 As built reports
Uncertain	No information found about the structure

It is assumed that when a structure is constructed it would be given a certainty grading of 'A'. If a source from 1990 indicates the design dimensions of a structure, it is likely that the condition of that structure may have changed over the 20-year period to 2010. The legitimacy of a document was also considered when determining the pre-earthquake condition of the structure. Design documents had lower certainties unless it could be confirmed that the structures were built to these levels. Anecdotal evidence (e.g. email correspondence to the council from the public) also had low certainty given the source could not be checked for reliability, and the information could not be reliably quantified.

The 2002 ECan Estuary Edge Inventory was given a ranking of "some certainty" as to what state the structures were before 2010. This ranking recognises that there were no tectonic land change events between 2002-2010 which would have contributed to the change in the structures, however there may have been some deterioration or change of the structures between 2002 and 2010.

2.2 Assessment of Current Condition

2.2.1 GNSS Survey

A GNSS (Global Navigation Satellite System) walk over survey was conducted of the eastern estuary edge from 17th-25th June 2019 (approximately 6.7km) which also included the collection of photos, and qualitative data about the condition of the structure and the land immediate behind the structure.

The GNSS survey was undertaken by ECan using a Trimble GPS system which had an anticipated horizontal accuracy of ±100mm and a vertical accuracy of ±50mm (A Rabe 2019, pers. comm., Senior Surveyor Environment Canterbury). The GPS survey collected a series of points to establish the location and dimensions of built structures (e.g. walls, gabion baskets, stopbanks etc) and infrastructure (e.g. stormwater outfalls, jetties, boat ramps etc), as well geomorphic features along natural shorelines where there were no structures (e.g. vegetation line, erosion scarps, top of bank etc). The data was collected in Mount Pleasant 2000 horizontal projection and Lyttleton Vertical Datum 1937 (LVD37), the latter of which was converted to Christchurch Drainage Datum (CDD) in post-processing for consistency across council documents. All elevation data presented in this report is in terms of CDD.

Each structure along the coastline was given a unique identifier based on the type of structure (e.g. SB for stopbank) and a numerical value based on its occurrence from south to north (e.g. SB2 was the second stopbank from south to north). The structure types used in the unique identifies are listed in **Table 3**.

Table 3: Structure Type Codes

Structure	Code	Structure	Code
Boat Ramps	BR	Wall	1. W
Gabion baskets	GB	No structure	NS
Informal Fill	IF	Reno Mattress	RM
Jetty	JT	Revetment	RV
Other (e.g. LINZ Temporary bund, Bridge protection)	O	Stop banks (e.g. located on the estuary edge)	SB

Each structure was further divided into sections, reflecting a change in condition of the structure (see 2.2.4.1 for structure condition gradings). These structure sections were also incorporated into the unique identifier with the first section from the south being section 'A' (e.g. SB2-A), and any sequence change in condition being section B, C, etc as required.

In locations where the estuary edge was defined by a single structure, these were identified as 'Primary structures'. When two structure types were acting as a single form of protection, the structure acting as the main protection structure was defined as the primary structure, and the subsequent structure was identified as the secondary structure, and a unique identifier was developed accordingly (e.g. GBRM for Gabions overlaid on top of reno mattress). Codes were assigned to each survey point taken to identify the feature of the structure or coastline being collected (e.g. PFBE for the primary structure front bottom edge).

A more detailed description of the naming conventions for structure types and feature codes is presented in **Appendix E.**

To assist with recording images and qualitative data in the field, an electronic form was developed using Fulcrum Mobile Collection App. The unique structure identification codes were generated in this form and given to the surveyor, and therefore qualitative data could be attributed to the GPS survey data in post-processing. Information gathered in the electronic form included:

- A general description of the structure

- The condition of the structure (further explanation in **2.2.4.1**)
- The condition of the coastline behind the structure (further explanation in **2.2.4.2**)
- Any damage points in the structure
- Presence of stormwater outfalls and pedestrian access
- The land-use behind the structure
- Images of the general structure and sections

The data from the GNSS survey and the associated qualitative data has been processed and presented in the form of the digital database and spatial maps presented in this report, and the information has been used to inform the current condition inventory for the eastern estuary edge.

The 'estuary edge' was surveyed as a continuous feature along the total length of the survey area, being the vegetation line or erosion scarp if no structure was present, and for where structures were present – the most landward of the back edge of structure or the top of any erosion scarps located behind the structure. This 'edge' is defined to be the 2019 shoreline position for comparison with the February 2011 shoreline.

An estuary edge elevation was also continuously surveyed along the length of the survey area, which represented the maximum elevation of the ground or structures immediately adjacent to the edge. This line was determined as being the highest elevation of either; the top edge of a structure, the top of any bank located in close proximity behind a structure, or the top of any scarp or bank if no structure was present. This elevation is defined to be the 2019 'high ground' elevation for preliminary comparison with design flood levels, being the first defence against inundation from high estuary levels. However, a detailed inundation risk assessment is not included in this report, but may form part of the Stage 2 assessment.

2.2.2 Photographic Record

During the GNSS walkover survey, photographs were taken from the ground of the structures including points of damage, failures, stormwater outfalls and pedestrian access. These photographs have been exported from the survey form database and presented in a digital file, with file names stating the structure name, section, date and source (e.g. W4-A_2019_Jacobs). Photo file names associated with the structure are listed in a column in the digital database, and the corresponding file name can be searched for in the Estuary Edge Inventory Photo Database.

Drone imagery was collected on 8th July 2019 to capture high resolution (5cm) oblique aerial photographs of the estuary edge and adjacent bed to show the oblique view and broader scale of structures, vegetation and land use. This imagery was used to display any discontinuities and issues with boundaries between shoreline types, the relationship between shoreline types, the relationship of shoreline type to estuary bed vegetation, and the connection between shoreline structures and land uses and assets (e.g. roads, residential area, parks etc). The imagery was also used to check for consistency of structure condition and coastline condition rankings (section 2.1.4) after fieldwork was completed.

2.2.3 2019 Aerial Imagery and LiDAR

High resolution (0.3m) aerial imagery from May 2019 was obtained from ECan to map the current estuary edge position. The estuary edge line and vegetation line collected in the GNSS field survey was overlaid on the 2019 imagery to confirm areas where the vegetation line and erosion scarps cannot be identified on the imagery due to tall vegetation cover, shadows, and boundaries between saltmarsh and terrestrial vegetation. High resolution LiDAR from May 2019 was also obtained from ECan, however we relied on the GNSS survey data for the elevation of structures due to the higher degree of certainty in both elevation and location.

2.2.4 Condition Grading

2.2.4.1 Condition of Structure

A qualitative five point condition 'grading' of the structure from 'A' (best condition) to 'E' (worst condition) was assigned to each structure based on its physical condition in 2019, and ability to perform a protection function along the edge against both erosion and inundation. The condition criteria presented in **Table 4** used subjectively assigned in the field to each section of structure. The condition grading was subjectively assigned in the field and recorded in the electronic field survey form. It was then revised if necessary following consideration of field photos, drone imagery, the findings from the records and literature review, and a second field assessment from an experienced inundation coastal engineer to ensure gradings were consistent across the study area.

Table 4: Assessment criteria for condition grading of a structure

Grade	Criteria
A	No evidence of structural failure or loss of functionality. No evidence of foundation exposure, material failure, overtopping, or outflanking/end effects. OR Any minor defects have no significant effect on the visual or functional element of the structure.
B	Limited evidence of small damage or deterioration of structure occurring on approx. 5-10% of structure, **which** doesn't reduce the structures functionality. OR Likely to require only a minimal degree of maintenance in the short term (e.g. Up to 5 years) under current conditions to retain functionality.
C	Evidence of deterioration of structure occurring on approx. 10-20% of the structure, resulting in some loss of functionality. AND Likely to require some maintenance in the short term (e.g. Up to 5 years) under current conditions to restore functionality.
D	Severe damage affecting 20-50% of the structure resulting in significant loss/lack of functionality. OR The element is close to failure/collapse (e.g. Leaning, bowing) AND Likely to require major maintenance or replacement in the short term (e.g. up to 5 years) under current conditions to restore functionality.
E	Structure has failed OR Extensive damage affecting more than 50% of the structure with significant loss of functionality. AND Will require major maintenance or replacement immediately to restore functionality.
	'*' Assigned to a structure in which primary function is not protection of the edge from erosion inundation e.g. Boat ramps

For functionality, damaged structures where there was evidence that they were still providing some protection function against erosion, but not inundation due to loss of elevation, were graded higher than a structure which did not appear to be functional for providing protection against either inundation or erosion. An example of this can be seen in **Figure 5** where the low concrete wall structure was assigned a Condition grading of 'D' due to damage and failure, rather than an 'E' due to the structure still providing some functionality in protecting the land behind it from erosion.

Figure 5: Structure IS10 - low lying concrete wall, condition graded 'D' rather than 'E' due to still providing some functionality against erosion (Jacobs, 2019)

A Superscript '*' is included in the condition grading for structures when their primary function was not to provide protection against erosion and inundation, however as a result of their location on the coast were subsequently acting as shoreline defence structures. There were two circumstances where this occurred:

1. The presence of concrete and wooden boat ramps along the coastline in Areas 3 and 5, where their primary function was to provide access.
2. Structures IS46-IS42 in Area 3 which are low lying staggered detached breakwaters in front of the Jellicoe Marsh boardwalk (**Figure 6**), where the primary function of these structures is to break up wave energy before it reaches the boardwalk and saltmarsh, not to protect from inundation and erosion.

Figure 6: IS45-IS43 low lying revetment graded B* which have been put in place to break up wave energy to protect the boardwalk and saltmarsh (ECan, 2019).

For comparison, it is noted that the condition assessment presented in CH2M Becca (2019) is '4 point' criteria, with the following descriptive categories:

- Minor defects only (Minor maintenance required, 5%)
- Maintenance required to return to accepted level of service (Significant maintenance required).
- Requires renewal (significant renewal/upgrade required, 20-40%)
- Asset unserviceable (over 50% of asset requires replacement).

It is noted that this the 3rd and 4th condition categories from the CH2M Becca (2019) are similar to the 'D' and 'E' grading used in this current assessment.

2.2.4.2 Condition of Land Behind Structure

A qualitative condition 'grading' of the land behind the structure was also recorded in the electronic field survey form. Gradings ranged from 'A' (best condition) to 'E' (worst condition) was based on field observations and was reviewed after the survey was complete using the drone imagery to confirm grades were consistent across the study area. The assessment criteria used to assign the gradings is shown in **Table 5**. Similar to the condition of the structure, the condition of a coastline behind a structure was considered worse if there had been erosion of the land, as opposed to vegetation die back due to salt water inundation, which could be more easily be rehabilitated. This information was used to help interpret the relationship between failing/failed structures and their ability to protect the coastline from inundation and erosion.

Table 5: Assessment criteria for condition of land behind structure

Grade	Criteria
A	No evidence of scarping, smooth interface between estuary edge and shore region OR No evident recession of shoreline, no tree roots exposed, extensive grass/vegetation cover
B	Minor recession of shoreline evident behind structures (<0.2 m horizontal) OR Small scarping (<0.1m vertical), OR Some grass and vegetation dieback but no tree roots exposed.
C	Moderate recession of shoreline evident behind a structure (0.2-1m), OR Moderate scarping (0.1-0.2m). OR Some grass and vegetation dieback, exposure of tree roots but not extensive.
D	Significant recession of shoreline visible both with or without a structure (1-5m) OR Significant scarping (0.2-0.3m), OR Tree roots totally exposed and extensive dieback of vegetation.
E	Extensive recession of shoreline visible both with or without a structure (>5m) OR Significant scarping (>0.3m) OR Total loss of vegetation and trees have toppled.

For comparison, the land condition assessment contained in CH2M Becca (2019) has the following '5 point' descriptive grading of: Excellent, Good, Moderate, Poor, and Very Poor. No criteria for these gradings were given.

2.3 Assessment of 'Nominal Pre-CES' Estuary Edge Condition.

2.3.1 Shoreline Elevation

The elevation of the 'nominal' pre-CES estuary edge was determined from the May 2003 LiDAR survey, which has an average horizontal point separation of 1.8m (0.22m laser footprint, 0.2m vertical accuracy) and has been reprocessed for ground elevation only (Leanne Banks, CCC pers com). This is the most recent LiDAR survey prior the CES, and has been used as the base for mapping CES changes in a number of other council and EQC projects. A LiDAR survey from 5th September 2010 is also available but was rejected as was after the 4th September major earthquake, and there is some uncertainty on the vertical datum of this data.

To determine a comparable 'high ground' elevation to the 2019 survey, a polygon was created in ArcGIS along the estuary edge to form a 'buffer' 5-10m wide around the 2019 'high ground' position. Maximum elevations over the controlled buffer area were extracted every 1m perpendicular to the shoreline from the 2003 LiDAR surface to form the 2003 'high ground' elevation and position. However, given the resolution of the LiDAR data and the data being post processed to remove non-ground structures, the extracted elevations may not include the tops of sea walls in Area 5. Also, due to lateral land displacement during the earthquake series, the 2003 elevations do not necessarily correspond to the current structure locations and therefore elevations are likely to be a combination of assumed ground level at the structures and actual ground levels behind the structures (the exact LiDAR post-processing algorithm is unknown and it could not be determined whether the sea wall structures were retained in the DEM). Further analysis of the origin of the maximum elevations could be included in the Stage 2 assessment.

The elevation comparison of the 2003 and 2019 'high ground' lines as well as 2019 structure elevations (including the LINZ temporary bund in Area 5) and flood design levels are presented in **Appendix C**.

2.3.2 Shoreline Position

The 24th February 2011 aerial imagery was used due to the previous imagery from 5th September 2010 not covering the whole study area and having too low a resolution to accurately determine the shoreline position with the required level of certainty. The most recent pre-CES imagery available is from April 2004, which unfortunately also has too low a resolution to accurately determine the shoreline position with the required level of certainty. Therefore, the 24th February 2011 aerial imagery is the most appropriate to use for determining the position of the shoreline around the beginning of the CES. However, due to the likely impact of lateral spread on the estuary edge in both the 4th September 2010 and the 22nd February 2011 earthquakes and the uncertainty in the magnitude of these impacts, it would be inappropriate to consider the mapped February 2011 position as being representative of the a pre-CES position (e.g. prior to 4th September 2010). Hence, the assessment of change in position is termed to be from a "nominal' pre 22nd February 2011 earthquake position to the current position as surveyed in June 2019.

As with the June 2019 survey, the same combination of features was used to represent the alongshore edge of the estuary in the images including; the vegetation line where there is no structure, and the front edge of a structure when a structure is present. There are gaps in the shoreline of the 2011 shoreline mapping where high elevation vegetation created too much uncertainty surrounding the actual position of the shoreline in these areas. This was particularly an issue in Area 2 and 3.

For the Spit Reserve in Area 6, the ECan survey of the 'dune bottom' from April 2010 was used as pre-earthquake estuary edge rather than the February 2011 aerial imagery. Hence for this area, the presented shoreline is from total pre-CES period.

The position of the February 2011 digitised, and 2010 surveyed shoreline (Area 6 only), along with the survey June 2019 shoreline are presented in the maps in **Appendix D**, overlaid on the May 2019 aerial photographs.

2.4 Assessment of differences from the 'nominal' pre-February 2011 earthquake condition to the current 2019 condition

2.4.1 Shoreline Elevation

The 2003-2019 elevation comparison involved overlaying the 2019 'high ground' elevations from the GNSS survey with the 2003 maximum elevations extracted from the controlled buffer area. This comparison is included in the maps in **Appendix C**. Due to the way the 'high ground' has been defined and the limitations and uncertainty around the 2003 LiDAR elevations at the structures, no analysis change in the elevation of the structures themselves was possible.

To undercome this limitation, a second analysis was undertaken comparing the 2019 average structure elevations to the following database information in Walter (1995) on individual property ground level, floor level, bottom of bank, top of bank, and wall height. The following assumptions were made about the information presented by Walter in order to use this data in a comparative analysis to the 2019 survey data:

- The bottom of the bank is the bed of the estuary adjacent to the edge.
- The top of bank elevation was the top of the bank directly on the estuary edge, which may have been a natural bank or revetment/fill material. Hence this feature is may or may not be the same as the 'high ground' feature collected in the 2019 survey.
- The types of walls had not changed between 1995 and the start of the CES in September 2010.
- If a top of bank measurement was present with a wall height measurement, it was assumed that the wall was sitting on top of the bank, and therefore by adding the wall height to the top of bank elevation a top of structure height could be obtained.
- When there is no top of bank measurement, but a bottom of bank measurement was given along with a wall height, it was assumed that the bottom of bank was the elevation of the bottom of the wall.
- The ground level elevation was assumed to be the ground elevation of the land behind the structure, therefore similar to the 2019 'high ground' line where this was higher that the elevation of any structure present.

For the analysis, where possible the former physical street addresses were attributed to each structure in ArcGIS and average elevation data from the 2019 survey was matched to the 1995 survey data, resulting in the survey data from 38 different structure sections being able to be compared to the 1995 data. The elevations from both sets of data for these e structure sections were then plotted to determine the overall trend of the changes in elevation of the ground and the estuary edge between 1995 and 2019. It is important to note that this analysis excluded boat ramps and 'no structure' settings', and therefore the results did not spatially represent the entire 1.7km Southshore estuary edge.

2.4.2 Shoreline Position

For accuracy of the analysis of shoreline position change presented in the **Appendix D** maps, both the 2011 and 2019 imagery needed to georeferenced using infrastructure located in the same place in both sets of images. In doing this, any horizontal movement in earthquakes post February 2011 are removed. This implies that the shoreline position change results are totally due to estuarine processes rather as a result of horizontal movement since February 2011. However, following the georeferencing there was still an offset of up to 1m in the imagery overlays near the shoreline in some locations due to the tilt of the imagery. Therefore, any measurements of shoreline change of ≤ ±1m were considered to be less than the error margin, and not included in the analysis.

The Digital Shoreline Analysis System (DSAS) tool was used in ArcGIS to determine the total magnitude of shoreline position which occurred between February 2011 (April 2010 in Area 6) and May 2019 shorelines. The analysis is undertaken at 10 m spaced transects shown on the maps in Appendix C, and numbered from north (1) to south (624). These transects are referred to in the interpretation of the results in each area.

For Area 3 (South New Brighton Park) an intermediary January 2016 shoreline digitised previously from aerial imagery for another project (Jacobs, 2019) was used in the DSAS analysis to determine any temporal trends in

shoreline retreat in this area. A similar analysis was undertaken in Area 6 using the February 2016 ECan surveyed shoreline as the intermediately position.

3. Results Area 1: North of Bridge Street

3.1 2019 Condition

3.1.1 Area Description

Area 1 is defined as the eastern estuary edge in the upper estuary north of Bridge Street, extending the lower Avon River channel at Evans Ave as shown in **Figure 7**. The base map for structure type, footprint, and condition is presented in **Appendix B1**.

Figure 7: Area 1 Overview Map

As shown in Figure 7, over the majority of the area the estuary bed comprises of a primary single thread channel 60-70 m wide with extensive salt marsh covering the intertidal areas on both sides of the channel. On the upper eastern side of the area between Shackleton and Jervois Streets is a 25- 30 m wide secondary channel separated from the main channel by Naughty Boys Island, a small low island approximately 400m long and 120m wide covered with marsh and scrub.

The eastern estuary edge in Area 1 is around 1.7 km long with two stopbank structures (SB4 & SB5) being present along 95% of the total length. The edge undergoes considerable changes in orientation along this length, therefore is exposed to different wind and water level conditions. The upper westerly facing section along Evans Ave (SB4-I to SB4-K) is more exposed to river processes in the lower Avon River, while around 500 m length of shoreline facing to the WSW to the east of Naughty Boys Island (SB4-F to SB4-H) is largely protected from wind effects on high tide water levels by the island. The Kibblewhite Street section (SB4-A to SB 4-F) is exposed to north-west winds blowing across a maximum high tide fetch of 500m. However, the majority of the edge along this section is protected by salt marsh beds up to 50 m wide. The southern most section of Area 1 (SB5A) is orientated to the WSW along Bridge Reserve and to the north along Bridge St.

The hinterland of the estuary in Area 1 comprises predominantly of residential area along Kibblewhite Street and around Union St - Jervois Rd (SB4-B to SB4-F), with houses set back around 25 m from the estuary edge behind the stopbank and road along the former and around 15 m behind the stopbanks at the latter. A small area surrounding Evans Ave (SBI to SB4-K) are Residential Red Zone (RRZ) having been cleared following the 2011 earthquake, while there are reserve areas behind the stopbanks at Blighs Garden (SB4-G & H) and Bridge Reserve (SB5-A).

3.1.2 Structure History

As presented in **Appendix A** and shown in **Appendix Map B1**, the only type of estuary edge structure present in Area 1 are stopbanks, with the exception of the Bridge Street bridge protection (O2). The stopbanks have varying length and size of revetment present on the on the estuary side of the bank in some locations where the channel is closest to the shoreline (e.g. SB4-K, SB4-B, SB4-A). Stopbank SB4 from Evans Ave to the west end of Kibblewhite St is assumed to have been originally constructed between 1984 and 1990 with a crest elevation of 11.1m. The stopbank sections fronting Kibblewhite St (SB4-A to part of SB4-F) were relocated landward to their current position in 1997 with an elevation of 11.2m elevation. Evidence from the consent hearing to relocate the stopbank acknowledged that the stopbank had experienced 12m of erosion in the previous decades, highlighting that this edge has experienced erosion prior to the CES.

An extension of stopbank SB4 south along Bridge Reserve to Bridge Street (SB5-A) was constructed in 2008, where the ground was levelled to 11.2m to join the Kibblewhite St stopbank. It is noted that in the 2019 GPS survey this section of stopbank was not identified as a structure due to the highly vegetated and natural looking front edge of the bank, hence was recorded as a 'no structure area' in the survey. However, information from the council records review revealed that this was the 2008 stopbank, and therefore an estimated footprint of the structure using the top of bank line as the front edge of the structure was developed to show it as a recognised structure.

Stopbanks SB4 and SB5 suffered damage in the 22nd February 2011 earthquake, resulting in temporary repairs post-quake as emergency works to restore the stopbank levels to 11.2m. In 2012 there was concern from residents along Kibblewhite St about the temporary nature of the protection and about erosion occurring on the stopbanks. In 2017 a resource consent was granted to repair, reconstruct or replace all the stopbanks in Area 1 to an elevation of 11.4m. This repair work has been carried out.

Further information from the individual structure sections survey notes and history is presented in the summary database in Appendix A, and more detailed notes for each structure section are included in the digital database.

3.1.3 Current Structure Condition

As shown in Table 6, the stopbanks throughout Area 1 are predominantly graded Condition 'A' (65% of total shoreline length) or 'B' (27% of total shoreline), with Condition 'B' being stopbanks with small lengths of minor erosion or undercutting of the estuary face of the bank (e.g. SB4-C, G, I). The general high condition grading of these stopbanks reflects that they have been recently repaired post the CES. The bridge protection (O2) is also graded as condition 'A' given its recent installation as protection beneath Bridge Street, installed in 2014. Other condition rankings for structure sections are presented in the base map in **Appendix B1**.

Table 6: Summary of structure conditions and shoreline length for Area 1

Total number of structures sections	Total shoreline length	Total length of structures	Total length Condition A	Total length Condition B	Total length Condition C	Total length Condition D	Total length Condition E
14	1699m	1615m (95%)	1117m (65%)	458m (27%)	0m (0%)	38m (2%)	0m (0%)
Notes: Percentages are of total shoreline length							

As shown in Table 6, only 2% of the total shoreline of Area 1 had a structure condition grading of 'D' (severe damage affecting 20-50% of structure), being a 38 m length of stopbank along Kibblewhite St (SB4-E) suffering significant erosion on its front face, with large boulders having been sporadically placed to try to halt the erosion (**Figure 8**). It is notable that this section of stopbank is an area where extensive salt marsh is absent from the estuary edge, and is exposed to the longest wind fetch within Area 1, therefore, this is exposed to greater energy at the shore. The only other Kibblewhite St section exposed to the longest fetch without the presence of salt marsh along the estuary edge are sections SB4-A & SB4-B, where the front face of the bank is protected by rock revetment preventing any scour of the front face. Further consideration of the relationship between the structure (and shoreline) condition and the presence of salt marsh could be examined in Stage 2 of the project.

Figure 8: SB4-E Structure condition 'D' where front edge of the structure has shown significant erosion.

3.1.4 Current Land Condition

The grading of the condition of the land behind the estuary edge in Area 1 is presented in **Table 7**.

Table 7: Summary of land condition behind the estuary edge for Area 1

Total number of shoreline sections	Total shoreline length	Total length N/A due to Infrastructure	Total length Condition A	Total length Condition B	Total length Condition C	Total length Condition D	Total length Condition E
15	1699m	529m	729m	430m	0m	0m	10m
Note: In Bridge Reserve the analysis includes land behind the estuary edge rather than land behind SB5							

As can be seen from Table 7, for 31% of Area 1 no assessment of land condition (e.g. erosion or die back) could be made due to the presence roads (e.g. Kibblewhite St and Evans Ave) directly behind the stopbank.

For other sections where the land behind the stopbanks is reserve land, the condition was graded as good, being either 'A' - no evidence of recession (42% of the area) or 'B' - minor recession <0.2m horizontal (25%).

The only section of land erosion in Area 1 was recorded at the grass bank on the north side of Bridge St (NS17-A), where 10 m of erosion scarp up to 0.6m in height, as shown in **Figure 9.**

Figure 9: NS17-A Land condition 'E' – 0.6m erosion scarp on grass embarkment north side of Bridge St.

3.2 Change in Elevation 2003 - 2019

The maps presenting the comparison of the 2003 LiDAR elevations to 2019 survey elevations and design flood levels for Area 1 are presented in **Appendix C1**. The mapping confirms that stopbank (SB4) which extends most of the estuary edge in this area was repaired/reconstructed in 2017 to a general level of 11.4 - 11.5 m, hence are at least 0.35m above the current (2018) 50-year ARI flood (11.06m), and at least 0.25 m or more above the 100-year ARI flood level (11.14 m).

From the 2003 LiDAR data, the mapped 'high ground' elevation would be the stopbank elevation, which for the Kibblewhite St sections (SB4-A to SB4-J) would be the elevation following the 1997 rebuilt. As such, the mapping shows the general elevation of these banks, as well as sections further north to Evans Ave (SB4-F to SB4-K) are in the order of 11.2m or higher, as per the design (except for sections SB4-B & SB4-C which are slightly lower than 11.2 m).

For comparison of pre- CES to current stopbank elevations, the mapping clearly shows that the current stopbank elevations are higher than the pre-earthquake elevations.

It is noted that stopbank SB5-A current elevation data is not included in the Appendix C1 mapping due to it not being collected in the field. However, the comparison of the 'high ground' levels from in front of the bank between 2003 and 2019 suggests that the land in this area subsided on average around 0.2m as a result of the earthquake. This is consistent with observations of the vegetation in front of the stopbank at Bridge Reserve reverting from terrestrial woodland in 2011 to estuarine in 2019 as shown in **Figure 10**, although this has been assisted by the removal of trees from the estuary side of the stopbank.

Figure 10: Comparison of vegetation cover from Bridge Reserve from February 2011 (left) to May 2019 (right).

3.3 Change in Edge Position February 2011 - May 2019

The location of erosion scarps identified in Area 1 during the June 2019 survey are shown in **Appendix B1** and maps for the estuary edge position change between 2011 and 2019 are presented in **Appendix D1** (DSAS analysis), with summary of results presented in **Table 8**. Full results for individual transects within the area are available in digital form.

Table 8: Summary of DSAS results for Area 1 shoreline change 2011-2019

	Total shoreline analysed	+8 to +4m Advance	+4m to +1m Advance	± 1m Change	-1 to -4m erosion	-8 to -4m erosion	-12 to -8m erosion	>-12m erosion
Area 1	**1480m**	**300m**	**570m**	**320m**	**160m**	**30m**	**20m**	**80m**
Note: change of ±1 m is within the margin of error for determining change, hence is interpreted as 'no change'. Distances are from the sum of DSAS transects spaced every 10m alongshore, so may not match shoreline distances in previous tables.								

The results show that the shoreline over the majority of Area 1 had advanced by 1-8m, especially around the stopbank SB4 north of Bridge Reserve. This advance could be termed a reclamation of the estuary edge, being the repair of the stopbanks as emergency works in 2011 and/or reconstruction in 2017 to raise the banks to 11.4m elevation. Therefore this accretion is not due to natural processes. Average shoreline advance was 2.5 m over the 1 km length of stopbank, with maximum advance mapped as 7.4 m at transect 123 (section SB4-C).

The main area of erosion within Area 1 is 130 m length of Bridge Reserve in front of SB5 (transects 135 – 146). For this section, the current estuary edge has been determined to be the edge of the terrestrial vegetation line 10-40 m west of the stopbank, a position in the range of 10-60 m east of the similar vegetation line determined from the 2011 aerial imagery. The average retreat of the terrestrial vegetation edge over the 8 year period is in the order of -32.5 m. Post-earthquake terrestrial vegetation clearance has been carried out in this area (e.g. chopping down of trees), and the area is reverting to salt marsh vegetation (Figure 6). Unfortunately, due to the transition between estuarine and terrestrial vegetation being difficult to determine, and the presence of trees

covering part of the 2011 shoreline, the DSAS analysis could only be carried out in the northern part of this section of shoreline (transects 138-146).

The DSAS results also indicate isolated areas of erosion along the stopbank (transects 60 - 64, 79, 83, 106 – 107). However, these areas are where small headlands of land extending a short distance into the estuary in front of the stopbank have been eroded by nature estuarine processes. As shown in Appendix B1, of these isolated locations only at Transects 106-107 (structure SB4-D) was there observed scarping in the 2019 survey. It is noted that the significant erosion scarp along the front face of the stopbank at SB4-E (transects 101-104) has not been picked up in the DSAS analysis due to steepness of front slope of bank and lack of horizontal shift of estuary edge.

4. Area 2: Bridge Street to South New Brighton Park

4.1 2019 Condition

4.1.1 Area Description

Area 2 is defined as southern part of Bridge Reserve from Bridge Street to the car park in northern end South New Brighton Park as shown in **Figure 11**. The base map for structure type, footprint, and condition is presented in **Appendix B2**.

The estuary edge within Area 2 is largely naturalised bank and has extensive saltmarsh cover on the intertidal estuary bed. South of Bridge St the estuary bed increases in width from around 400 m to maximum of 750 m at Beatty St. The majority of the edge within the area is orientated to a general south-west direction, therefore is exposed to winds blowing from this direction, but is protected from more southerly conditions by South New Brighton Park.

Figure 11: Area 2 Overview Map: southern part of Bridge Reserve from Bridge St to South New Brighton Park

The closest residential houses are located on Seafield Place, which is setback at least 50 m from the estuary edge. The main asset close to the estuary edge within Area 2 is the carpark for the community centre at the end

of Beatty St, which is setback approximately 25-30m from the estuary edge. A walking track is situated parallel to the estuary edge through the Bridge Reserve, which is frequently used for walking and cycling.

4.1.2 Structure History

Council records and literature review showed that there has not been any recorded structures in this area before the earthquake, however the records showed that residents both pre and post earthquake have been concerned about flooding of the low lying land in the area. Possibly as a result, construction of a 185 m extension of the lower Avon River stopbank immediately south of Bridge St began in July 2019. This structure is not recorded in the June 2019 survey. A decision on a bund over the whole distance of Area 2 was deferred by Council in April 2018.

4.1.3 Current Structure Condition

As shown in **Table 9**, the June 2019 survey indicated that Area 2 has a total shoreline of 1061m, of which only 3m consisted of a structure (IS47-A). However, as indicated above, and shown on **Appendix B2**, a 185 m extension of the Avon River stopbanks is currently being constructed immediately south of Bridge St.

Table 9: Summary of structure conditions and shoreline length for Area 2

Total number of structure sections	Total shoreline length	Total length of structures	Total length Condition A	Total length Condition B	Total length Condition C	Total length Condition D	Total length Condition E
1	1061m	3m	0m (0%)	3m (0.2%)	0m (0%)	0m (0%)	0m (0%)
Notes: percentages are of total shoreline length							

Structure IS47 is a small (3 m shoreline length) informal rock revetment consisting of small angular rocks (**Figure 12),** which are not naturally occurring in estuarine environments, hence the definition as a structure. The age of this revetment is uncertain but is thought to be a similar age as the adjacent 2014 bridge repairs. It is located in a small area where salt marsh is absent from the estuary edge, but it is unknown whether the rock has been placed in-situ or has relocated to this position from placement as part of the bridge protection works. The revetment is has been graded condition 'B' due only to the minimal degree of maintenance required due to its low-lying nature.

Figure 12: Informal rock revetment (IS47-A) south of South Bridge Street

4.1.4 Current Land Condition.

The grading of the condition of the land behind the estuary edge in Area 2 is presented in **Table 10**.

Table 10: Summary of land condition behind the estuary edge for Area 2

Total number of shoreline sections	Total shoreline length	Total length N/A due to Infrastructure	Total length Condition A	Total length Condition B	Total length Condition C	Total length Condition D	Total length Condition E
3	1061m	0m	1031m	3m	28m	0m	0m

The 2019 survey only found one section of erosion within Area 2, located at the grass embarkment (NS16) adjacent the Bridge St bridge protection works (O2) This scarp **(Figure 13)** is similar to the corresponding scarp on the grass embankment in Area 1, being approximately 10 m long and up to 0.6 m in height, resulting in a land condition grading of 'E'.

The land condition behind the small informal revetment IS47 was graded 'B' due to limited evidence of inundation impacts on vegetation above the structure.

All of Area 2 without edge structures (e.g. NS15) was graded land Condition 'A' - no evidence of recession or vegetation impacts, being well protected by the extensive areas of inter-tidal salt marsh and the well vegetated edge bank. By comparison, the CH2M Beca (2019), also gave this area of natural shoreline a 'good' rating for land condition.

Figure 13: NS16-A Land condition 'E' – 0.6m erosion scarp on grass embarkment south side of Bridge St.

4.2 Change in Elevation 2003-2019

The Area 2 map showing 2003 LiDAR 'high ground' elevations along the estuary edge compared to 2019 surveyed 'high ground' and design flood levels is presented in **Appendix C2**. The change in elevation, assumed to be a result of subsidence in the CES, is shown to be generally in the order of -0.2m across the

whole area, however in some locations it is up to -0.5m (e.g. around chainages 1850, 2125, 2250, 2450, 2550-2625).

For nearly the whole length of Bridge Reserve (e.g. chainage 2000 - 2500) the 2019 'high ground' is generally below the current (2018) 10-year flood level (10.89 m), which as presented in **Table 1** been exceeded 3 times since the CES (4/3/2014, 21/7/2017, 2/2/2018). For approximately 150m around the northern end of Seafield Place (chainage 2225-2375) the current 'high ground' elevation was surveyed as being below the current (2018) 2-year return period flood level (10.68m), which has been exceeded 15 times since the CES. In contrast, the higher 2003 LiDAR pre-CES 'high ground' elevations around the edge were at, or above the current (2018) 20-year return period flood level (10.96m), indicating a higher level of natural inundation protection was present prior to the CES.

4.3 Change in Edge Position February 2011-2019

The location of erosion scarps identified in Area 2 during the June 2019 survey are shown in **Appendix B2** and maps for the estuary edge position change between 2011 and 2019 are presented in **Appendix D2** (DSAS analysis), with summary of results presented in **Table 11**. Full results for individual transects within the area are available in the DSAS digital data supplied to council with this report.

Table 11: Summary of DSAS results for Area 2 shoreline change 2011-2019

	Total shoreline analysed	+8 to +4m advance	+4m to +1m advance	± 1m Change	-1 to -4m erosion	-8 to -4m erosion	-12 to -8m erosion	>-12m erosion
Area 2	**320m**	**0m**	**20m**	**200m**	**60m**	**30m**	**10m**	**0m**
Note: change of ±1 m is within the margin of error for determining change, hence is interpreted as 'no change'. Distances are from the sum of DSAS transects spaced every 10m alongshore, so may not match shoreline distances in previous tables.								

As shown on the mapping in Appendix B2 the majority of shoreline in Area 2 could not be analysed accurately using DSAS Analysis due to the dense and tall vegetation cover along the naturalised shoreline in this area, which therefore made it difficult to determine the transition from estuarine to terrestrial vegetation. The only areas where this could be determined was at the northern extent of the area.

Transects 180-186 show a range of accreting and erosion with no particular trend. It is likely that this area has undergone anthropogenic changes when the bridge was repaired in 2014, and erosion control structures were put in place beneath the bridge (e.g Structure O2). However, the location of the small informal revetment (IS47 – transect 185) where there is no salt marsh shows erosion of 10 m. It is uncertain what impact the revetment has had on this retreat. A small area of erosion was also mapped from transects 203 to 210, with average retreat in the order of 1.7m over the 8 years considered to be due to natural processes.

5. Area 3: South New Brighton Park

5.1 2019 Condition

5.1.1 Area Description

Area 3 is 1.1 km of eastern estuary edge between the northern extent of South New Brighton Park (taken as being the Jetty Carpark) to the southern extent of the Jellicoe Marsh Boardwalk, as shown in **Figure 14.** The base maps for structure type, footprint, and condition are presented in **Appendices B3a, B3b,** and **B3c**.

Figure 14: Area 3 Overview Map – South New Brighton Park Overview map.

The estuary frontage of the park faces south east over the majority of its length, and nearly due south along the Jellicoe Marsh frontage. As such the estuary edge within the park, particularly the southern end is exposed to among the longest wind fetch lengths on the estuary, being in the order of 3.2 km from the south west and 2.5 km from the south. Since these directions have the highest frequency of high winds, this edge is likely to be more affected by wave impacts operating on top of extreme high-water levels than other areas along the eastern side of the estuary. It is also noticeable that there is an absence of salt marsh vegetation over the majority of nearshore estuary bed of the park, expect for a small area in the most sheltered section immediately north of the jetty (e.g. in front of structures RV1-A & GB5-A).

Structures occur along the estuary edge over the majority of Area 3, being primarily 1993/1994 reno mattress (RM4) from south of the Pleasant Point Yacht Club boat ramp to Jellicoe Marsh, with a collection of recent post-earthquake gabions and reno's north of this ramp. Along Jellicoe Marsh at the southern section of the park, is a broken line of detached rock breakwaters on the estuary bed (IS45 – IS41) along the frontage to Jellicoe Marsh to provide protection to the boardwalk and allow water flow into the marsh, while a stopbank (SB3) is present on the landward side of the marsh, on which repairs started in July 2019 – after the condition survey for this project. Two boat ramps are present at the northern end of the park, the small public ramp (BR9) and the larger Pleasant Point Yacht Club ramp (BR8).

The estuary edge hinterland within the South New Brighton Park includes walking/biking tracks, the Jellicoe Marsh boardwalk, the Pleasant Point yacht club complex (under construction), tennis courts, and the South Brighton Holiday Park. The Holiday Park and the Pleasant Point Yacht Club are the two main locations with buildings close to the estuary edge in Area 3, with the Yacht Club being set back approximately 25-30m from the edge, and the Holiday Park being set back a minimum of 65m.

5.1.2 Structure History

A resource consent (CRC930700) for 174 m of reno mattresses from the tennis courts south towards Jellicoe Marsh was granted to council Parks in July 1993 to deal with "*substantial erosion along this length of estuary shoreline, some inundation has also occurred where existing stopbanks have been breached"* (from the consent application). It is assumed that this erosion became an issue in the 28th August 1992 high estuary water level event (10.94m) that occurred in combination with significant snow fall in the city. The wording above also suggests that there was some stopbanking, or at least some form of mound (natural or man-made) along the shoreline prior to the construction of the reno mattress. Although the presence of this bank has not been able to be confirmed, a raised mound is present behind the reno at the southern end of the structure (sections RM2-D & E)

Unfortunately, the consent documents contain no information on the actual location of the reno or the structure design, apart from consent conditions that filter cloth was to be installed beneath the reno mattress and that the shoreline and estuary bed were to be restored to original condition following construction. It is also uncertain when this reno was constructed, and when it was extended to cover the total 600 m length of reno's present along the edge of the park from the Pleasant Point Yacht Club south to Jellicoe Marsh (RM2, RM3 & RM4). In the structures inventory (**Appendix A**) it is assumed that this total length of reno was constructed in 1993/1994 as this extent of the reno mattress was recorded in the 2002 Estuary Edge Inventory (ECan, 2002). This 2002 inventory noted that the reno was in the order of 0.7 m to 1.3 m high, although it is uncertain what this relates to – but most likely is in reference to the rise in elevation from the bottom to the top of the sloping structure, and that the structure was generally in a satisfactory condition. However, as shown in **Figure 15** (2008 photo), pre-CES erosion behind the reno had occurred in some locations, indicating that it was not of sufficient elevation at these locations to prevent overtopping in extreme water level events (9 events above 10.68m threshold between July 1994 and July 2008, with highest 10.81m in June 2000. It is considered likely that Figure 15 was taken after extreme water level event on 5th July 2008, with level = 10.74m), and appears to the same location as the February 2018 inundation shown in Figure 3. Although, the exact location is unclear, and it is unknow whether any changes to the structure to increase elevation or rehabilitation of this erosion was carried out prior to the onset of the CES in September 2010, this image indicates that there was some issues with the functionality of the reno mattress to prevent erosion from time to time.

Figure 15: 2008 erosion behind reno mattress in South New Brighton Park (Image Supplied by K Hansen)

In the northern end of the park, the shoreline from the jetty car park to the Yacht Club boat ramp was redeveloped in association with the redevelopment of these facilities in 2015 (boat ramp) and 2017 (jetty). Around the jetty was a 1 m high masonry wall for which there are plans for construction in the 1930's, which was recorded as being in excellent condition in the 2002 ECan condition inventory **(Figure 16a**). However, by 2017 it had failed resulting in considerable erosion of the land behind the wall **(Figure 16b),** although **i**t is uncertain whether this failure occurred during or post the CES. A replacement gabion wall (GB3 & GBRM3) was constructed in 2017 **(Figure 16c)**.

At the southern end of Area 3, the boardwalk across Jellicoe Marsh is thought to have been constructed around 1995. It is reasonable to assume that the raised bank and track at the northern end of the Marsh and reno (RM1) was constructed at the same time. As shown in **Figure 16**, repairs to this reno appear to have been carried out circa 2009. There is reference to a small bund being placed on the western side of the boardwalk to protect it and the salt marsh, with a continuous low rock wall revetment or breakwater also being described in 2002 as being in front of this bund (see **Figure 17**). There were concerns about erosion of the bund prior to the CES as noted in the South New Brighton Reserves Management Plan 2010, and council records post the CES report that the bund had eroded away. The boardwalk and detached rock breakwaters (IS46 to IS42) that act as a wave trip and incorporating gaps for water passage into the salt marsh, were rebuilt in 2017.

Figure 16: a) Masonry wall south of jetty in South New Brighton Park in excellent condition in 2002 (ECan 2002); b) wall failed and erosion behind in 2017 (Jacobs Image); c) replacement gabion wall (GB3-A & GBRM3-A) in June 2019 (ECan drone image)

Figure 17: Reno mattress (RMRV1, RM1-A) in good condition at north end of Jellicoe Marsh Boardwalk in 2009 prior to the CES (Image Supplied by A Crosslands, 2009)

The stopbank (SB3) around the eastern side of Jellicoe Marsh was constructed in prior to 1995 to address the flooding of residential properties behind the marsh. Repairs to this bank are currently (July 2019) being undertaken by council.

More in depth details on the history of structures, including reference to the photograph database, can be found in the digital database on structure condition.

5.1.3 Current Structure Condition

Following the CES, repairs have taken place throughout Area 3 to restore recreational infrastructure (jetty- JT1, boat ramps – BR8 &BR9, and the Jellicoe Marsh boardwalk) as well as repair heavily damaged coastal protection in the northern and southern parts of the area. Unfortunately, design criteria of many of the post CES structures and repairs in Area 3 are not well documented they did not require resource consents due to being considered as repairs to existing structures. A summary of the post CES works undertaken on each structure is included in the **Appendix A** inventory, further details and photographs are available in the digital inventory and photograph databases.

The 2019 condition survey determined that within Area 3 there were 27 structures broken into 42 condition sections covering a total length of 1389m (note more than the shoreline length due to structures on both sides of Jellicoe Marsh). Mapping of the structure conditions is presented in **Appendix B3a** to **B3c**, and a summary of structure condition by shoreline length is presented in **Table 12**.

Table 12: Summary of structure conditions and shoreline length for Area 3.

Total number of structure sections	Total shoreline length	Total length of structures	Total length Condition A	Total length Condition B	Total length Condition C	Total length Condition D	Total length Condition E
42	1115m	1078m (97%)	98m (9%)	491m (44%)	189m (17%)	32m (3%)	268m (25%)
Note: Analysis excludes SB3 around the east side of Jellicoe Marsh, which is graded condition 'B'. percentages are of total shoreline length							

Structures which were graded an 'A' – no evidence of structural failure, are all located in the northern part of park (**Appendix B3a**), having all been replaced/repaired since the CES. Some of the repaired sections in this northern park area (e.g RM5, GBRM1) along with the replaced reno at the north end of Jellicoe Marsh (RM1, **Appendix B3c**) are graded condition 'B' due to some minor deterioration in the original reno baskets. However, the majority of length of structures in the condition 'B' category are shown on **Appendix B3c** map as the stopbank (SB3- 295 m) around the eastern side of Jellicoe Marsh (current repairs will likely to move it to a 'A' condition), the detached rock breakwaters on the estuary bed protecting the boardwalk on the eastern side of the marsh (IS46 - IS42 – 170 m). There is also 140 m of unrepaired of reno that has also be graded condition 'B' located at the northern (RM4-D, **Appendix B3a**) and southern ends (RM2-A to RM2F, **Appendix B3c**) of the assumed to original 1993/94 structure.

Structures ranked condition 'D' (20-50% damage) and condition 'E' (greater than 50% damage resulting in significant loss of functionality), make up 28% of the shoreline in Area 3 (300m). These are the majority of the unrepaired reno mattress assumed to be originally constructed in 1993/4 (RM4B, RM3-A&B, RM2-I&H). An example of condition 'E' reno mattress (RM2-I), damaged and disturbed by lateral spread of the estuary edge is presented in **Figure 18.**

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Figure 18: a) Condition 'E' reno mattress in Area 3 (RM2-I) (Jacobs, 2019 image); b) Land Condition behind the structure also graded 'E' due to significant erosion (ECan drone image, 2019).

5.1.4 Current Land Condition

Although there were 300m of structures in Area 3 were ranked as being condition 'D' and 'E', as presented in **Table 13**, there length of land behind the structures having similar gradings (e.g. erosion scarp greater than 1m landward from the structure or scarp elevations greater than 0.2m) was 1.5 longer at 465 m.

Table 13: Summary of land condition behind the estuary edge for Area 3

Total number of shoreline sections	Total shoreline length	Total length N/A due to Infrastructure	Total length Condition A	Total length Condition B	Total length Condition C	Total length Condition D	Total length Condition E
45	1115m	346m	96m	147m	59m	83m	384m
Note: The analysis only includes sections on the estuary edge, so does not include section SB3 around the east side of Jellicoe Marsh							

As expected there is a strong correlation between structure condition and land condition, with all structures graded 'D' and 'E' also having 'D' and 'E' land conditions. Additional land condition 'E' was present behind RM4-C, RM4-A, and RM2-G all of which had a structure condition grading of 'C'. In these instances, as shown in **Figure 19**, despite being in reasonable condition. It is not providing effectiveness protection against erosion due to being at too low elevations to prevent overtopping and back scour.

Only at reno section RM3-A is the land condition ('B') assessed as being better than structure condition ('E'). This appeared to be due to the elevation that the reno was built to being much higher up the bank compared to the adjoining sections, so that although the reno baskets are badly damaged, the land behind is not eroded. Cobbles which had fallen out of the broken reno baskets were still providing protect for the toe of the bank.

No land condition was assessed for the detached breakwaters and reno mattress structures on the east side of Jellicoe Marsh, as they are protecting the board walk rather than land. For this area the land assessment is around the east side of the Marsh behind (SB3) has been graded condition 'A' – extensive vegetation cover with no evidence of erosion.

Figure 19: RM2-G Example of Condition 'C' reno mattress with a Condition 'E' coastline (Jacobs, 2019).

5.2 Change in Elevation 2003-2019

The Area 3 maps showing 2003 LiDAR 'high ground' elevations along the estuary edge compared to 2019 surveyed 'high ground' and structure elevations along with comparisons to design estuary flood levels are presented in **Appendix C3a** (mainly structures repaired/replaced since 2015)**, C3b** (the majority of the unrepaired original reno structure)**, and C3c** (Jellicoe Marsh). Each of these sub areas are discussed separately below. However, over the total 1.1 km length for the whole area, for around half the 'high ground' feature is higher in 2019 due to new structures, and half is lower.

5.2.1 Structures Repaired/Replaced Since 2015

The structure elevation mapping in **Appendix C3a** shows that the repaired/replaced structures at the northern end of the park (chainage 2875 to 3100m, structures RV2-A to GBRM1-A) have elevations above the current (2018) 10-year return period flood level (10.89m) except for RM5, where the added layer of reno mattress has a minimum elevation of 10.77m and average of 10.85m (See **Figure 20**). It is noted that some structure sections (e.g. RM5) are up to 0.2m below their design elevation of the 2010 100-yr flood level + 100mm freeboard (11.04m), which is now approximately the current (2018) 50-year return period design level. This design elevation was exceeded on 2/2/2018 (extreme water level of 11.08m).

However, in all locations across this area there is a higher bank, shown as the 2019 'high ground' elevation on the mapping, above the structures, which increases the protection against inundation in extreme water levels. This 2019 'high ground' has elevations above the current (2018) 100 year-return period flood level (11.14m) except around the jetty, which have elevations around the current (2018) 50-year return period flood level (11.06m). As shown in **Figure 20**, the 'high ground' above RM5 increases the minimum protection against inundation to around 11.2m.

Figure 20: RM5-A upper layer of reno mattress added in 2017 to 10.8m elevation, with high ground up to 11.2m behind structure (Jacobs, 2019).

Over the majority of the repaired area the 2019 'high ground' elevation is shown in **Appendix C3a** to be in the order of 0.1 to 0.2m above the corresponding 2003 'high ground' elevation. This is contrary to the reported subsidence by up to -0.5m in this area due to CES (EQC mapping). However, for a number of locations the higher current ground levels are considered most likely to be as a result of landscaping as part of the repair works.

5.2.2 Unrepaired Original Reno Structure

The mapping of the current elevations of these structures in **Appendix C3a** and **3Cb** shows that all sections of the reno except for RM3, are below the current (2018) 10-year return period flood level (10.89m), with the majority except for RM2-A at the southern end also being below the current 2-year return period flood level (10.68m), which has been exceeded 15 times since the CES. For 160m of structure RM2-I (chainage 3350 – 3510), the elevation of the reno is below MHWS[9] (10.26m) therefore is overtopped on greater than a monthly basis and not providing any effective erosion protection for the edge. Consequently, shoreline erosion has been the greatest at this structure, with maximum distance from the reno being measured by the DSAS analysis as 13.4m (**Appendix D3b).** The location of the erosion scarp in relate the reno mattress at this structure is shown in **Figure 18.**

Over most of the length of the reno mattress structures, except for 125 m at RM3 and RM2- A to RM2-E, the 2019 'high ground' is the erosion scarp located behind the structure due to frequent overtopping of the reno. The top of this scarp has a general elevation of 10.9-11.1m, with evidence of debris lines behind the scarp indicating that it has been overtopped by wave run-up in the recent past although water levels were at least 0.2 m lower that the height of the scarp. The frequency and impacts of this overtopping could be examined further in a risk assessment in Stage 2.

The comparison of 'high ground' elevations between 2003 and 2019 suggest that the combination of subsidence and lateral spread has resulted in the current elevations being on average 0.25m lower than in 2003, with the maximum change in the order of -0.5m. This is consistent to the subsidence reported by EQC in this area.

[9] [9] MHWS elevation as defined by ECan and exceeded by 13.34% of high tides: Is M_2+N_2 tidal constituents.

Due to difficultly in accurately determining the spatial location of the reno structures in the 2003 LiDAR survey, it is not possible to accurately define the structure elevations prior to the CES. However, applying the mapped 'high ground' elevation changes at the structures to each of the reno section elevations, would give a pre-CES reno elevation estimate in the order of 10.7 - 10.8m, except for sections RM4-B and RM2-I & G, which return much lower elevations in range the 10.2 to 10.65 m. While these higher levels seem reasonable estimates of the likely pre-CES structure elevations (although slightly low), it is considered the lower elevations are not – being much too low. It is therefore considered that the current extreme low elevations at these sections of the reno mattress (e.g. RM4-B and RM2-I & G) is due to the structures suffering more slippage downward into the estuary as a result of lateral spread of the estuary edge.

5.2.3 Jellicoe Marsh

The elevation mapping in **Appendix C3c** is difficult to interpret due to the 'high ground' line passing around the north and east sides of the marsh, while the structures are both the stopbank (SB3) on the east and the reno mattress (RM1), detached breakwaters (IS46 – IS42) and stopbank (SB2) on the west side of the marsh.

For the back of the marsh (e.g. eastern side) the results shown that there is high ground around the north edge of the marsh, which appears to have changed little because of the CES. The repairs to the eastern stopbank (SB3), raising the elevation to 11.2m, appears to have improved the protection from flooding for properties further east.

For the structures on the west (e.g. estuary) side of the marsh, the mapping does not allow comparison with pre-CES elevations. However, results indicate that the northern bund with the reno mattress drops below the current (2018) 10-year flood level (10.89m) at structure RMRV1-A, which is where overtopping of the track has occurred, while the weak point at the southern end is the informal rock and rubble revetment (IS41) which has an maximum elevation of only 9.87m, hence is overtopped in most high tides. In comparison the southern end stopbank (SB2) has elevations (minimum 11.16m) above the current (2018) 100-year flood level. The elevation of the detached breakwaters (Structures IS42 to IS46) are shown to be in the range of 10.0m to 10.4m, which is appropriate for their function of a wave trip wall.

5.3 Change in Edge Position February 2011-2019

Maps for the shoreline position change between February 2011 and May 2019 from the DSAS analysis for Area 3 are presented in **Appendix D3a** and **D3b,** with the summary of results being presented in **Table 14.** As outlined in Section 2.3.2, since the 2011 aerial imagery is from after the 22nd February earthquake, it does not include any consideration of the effects of lateral spread in this and the 4th September 2010 earthquake on the change in shoreline position. As indicated above, for some parts of the unrepaired reno mattresses, this may have had a considerable bearing on the position of the mapped February 2011 shoreline used in this analysis. For this area the results from shoreline mapping of the January 2016 shoreline by Jacobs (2019)[10] were also used to investigate any temporal changes in erosion rates since 2011. Note that this analysis was only possible at a smaller number of transects. Full results for individual transects within the area are available in digital form supplied to council with this report. Note DSAS analysis was not undertaken for Jellicoe Marsh.

5.3.1 Structures Repaired/Replaced Since 2015

For this area, the erosion changes in the shoreline position are associated with the structure repairs/replacement. For example, for the jetty carpark (transect 289-293, Structure NS14), the current shoreline has been established up to 9m east of the 2011 shoreline due to the effects of lateral spread and subsidence of the former carpark edge. Similarly, structure GBRM3 immediately north of the public boat ramp (transects 302-303) has been established up to 7m east of the former 2011 shoreline. For the majority of repaired/replanted structures the shoreline shift has been smaller, in the range of -1m to -4m.

[10] Jacobs (2019): South New Brighton Park Erosion: strategy and options report. Prepared for Christchurch City Council

Table 14: Summary of DSAS Analysis results for Area 3 shoreline change 2011-2019

Location	Time period	Total shoreline analysed	+1m to +4m advance	±-1m change	-1 to -4m erosion	-4 to -8m erosion	-8 to -12m erosion	>-12m erosion
Northern repaired/ replaced structures	**2011-2019**	**210m**	**0m**	**50m**	**90m**	**60m**	**10m**	**0m**
Unrepaired original reno structures	2011-2016	190m	0m	70m	110m	20m	0m	0m
	2016-2019	190m	20m	80m	70m	20m	0m	0m
	2011-2019	**550m**	**0m**	**140m**	**280m**	**70m**	**50m**	**10m**

Note: change of ±1 m is within the margin of error for determining change, hence is interpreted as 'no change'.

Distances are from the sum of DSAS transects spaced every 10m alongshore, so may not match shoreline distances in previous tables.

5.3.2 Unrepaired Original Reno Structure

This area has suffered the greatest post CES erosion, with an average shoreline retreat of -3.5m over the 550 m length (DSAS Transects 317 to 374) since February 2011. For only 140 m of the reno length has there been no change in the edge position or development of erosion scarps behind the structures, predominantly at the high ground at RM3-B (40 m, transects 328-331)) and at the southern end (RM2-E to RM2-A, 70 m, transects 368-374).

As shown in **Appendix D3b**, the greatest erosion has occurred in association with the lowest elevation reno section, RM2-I (transects 339-352) **(Figure 18)** with average erosion along this section being -8.5m and a maximum of -13.4m (transect 344) corresponding to the location of the lowest elevation of the reno (9.89m).

From **Table 14**, the breakdown of erosion into pre and post 2016 indicates a similar distribution of erosion distances has occurred across both time periods. The conversion of these recession distances in rates resulted in no clear trend with 40% of the available transects (7) showing decrease in rate, 40% showing an increase (7), and the remaining 20% having similar rates. Further investigation of the relationship between these rates, structure elevation and land elevation could be included in stage 2 assessment.

The relationship between erosion distance and reno elevation in terms of design flood levels is presented **Table 15,** which shows that reno's with lower elevations have been less effective at reducing erosion, with those with elevations below MHWS the least effective. However, the Table also shows that erosion of up to 0.5 m/yr has still occurred over most of the length of reno's with elevations above a 20-year design flood level (e.g. above 10.96m). This erosion is likely to occurred in not only the two extreme storm tide levels that exceeded this elevation (July 2017 and February 2018) , and also due to wave effects overtopping the structures in other high storm tide events (e.g. March 2014, June 2017, and January 2018 that exceeded the 5-year return period water level).

Table 15: Relationship of shoreline change to elevation for unrepaired reno mattress in Area 3

			Average shoreline change across structures 2011-2019			
Average Structure Elevations	**Total length**	**Total structure sections**	**± 1m**	**-1 to -4m**	**-4 to -8m**	**-8 to -12m**
< MHWS (10.257m)	186.8m	1	0m	0m	0m	186.8m
Up to 10.68m (2-yr ARI)	293.5m	9	43.4m	250.1m	0m	0m
Up to 10.88m (10-yr ARI)	22.3m	2	22.3m	0m	0m	0m
Up to 10.96m (20-yr ARI)	0m	0	0m	0m	0m	0m
Up to 11.06m 50-yr ARI)	81.1m	2	19.7m	61.4m	0m	0m
Total	**583.7m**	**14**	**85.4m**	**311.5m**	**0m**	**186.8m**

6. Area 4: Ebbtide Street to Godwit Street

6.1 2019 Condition

6.1.1 Area Description

Area 4 is defined as being the 480 m of estuary edge from the intersection of Estuary Road and Ebbtide Street, south to Godwit street as shown in **Figure 21**, which historically and currently comprises of a stopbank with rock revetment on the estuary side along most of its length (470m). The base maps for structure type, footprint, and condition are presented in **Appendix B4**.

Figure 21: Area 4 Overview map – Estuary Rd to Godwit St

The estuary edge within this section of coast is primarily orientated to the south west and exposed to winds from this direction blowing over a maximum fetch of 3.5 km. However, only the northern part of section around Estuary Rd is directly exposed to southerly winds. The map estuary channel is over 500m from the edge along Area 4, resulting in a wide inter-tidal area in front of the stopbank. No salt marsh is present along the edge in this area.

The hinterland behind the estuary edge in Area 4 is primarily residential road zone, with a residential area set back 35-65m behind the cleared land.

6.1.2 Structure History

1950 aerial photographs show a structure being present as a straight edge along Ebbtide Street. It is assumed that is the low concrete wall present at the toe of the existing revetment, which was recorded in 2002 as having a height of 0.9m **(Figure 22a)**. From the line of this bank in 1950 aerial photographs, it appears that reclamation has occurred behind the southern end of the bank adjacent to Godwit Street (SBW1-A). Plans were proposed in 1992 for the stopbank to be constructed above the wall to 10.9m, with construction occurring some time prior to 1995. The opening in 1995 of a walkway on top of the stopbank began to deteriorate the bank to lower levels due to the increased foot traffic, resulting in the council topping the wall back up to 10.9m. Images prior to the CES, show the estuary side of the stopbank contained less rock than at present. Images taken in the days following the 4th September 2010 show there was some damage to the stopbank in this event in the form of cracks and slumping (**Figure 22b**).

Following the CES, Citycare drafted plans for rock revetment to be put on the estuary edge of the Ebbtide Street stopbank. The original design changed due to damage in king tide experienced in the weeks before installing the revetment (assumed to be high estuary levels in March 2014), with the of the wall following this event being shown in **Figure 22c**. By the end of July 2014 the installation of the revetment on the stopbank had been completed, with the stopbank being in a similar condition as in the 2019 survey (**Figure 22d**).

Figure 22: Ebbtide Street stopbank (SBW1-B): a) 2002 low concrete wall only (Ecan, 2002); b) Following the 4th September 2010 earthquake (CCC, 2010); c) Prior to placement of revetment July 2014 (CCRU image) d) Current stopbank and revetment above original concrete wall (Jacobs, 2019)

The informal rock revetment, IS40-A, at the southern end of the stopbank is recorded in the ECan 2002 inventory as being present since 1967 and as closing -off the reclamation behind the concrete wall to the north. (**Figure 23**).

At Godwit Street (NS11) the remnants of a former pebble beach renourishment are evident (**Figure 24)**. The concept of renourishment at this location was proposed in Walter (1995), with consent granted in 2000 for the placement of 1,700 m^3 of sand and gravel. It is uncertain the actual volumes and locations of the placements. The consent expired in 2005.

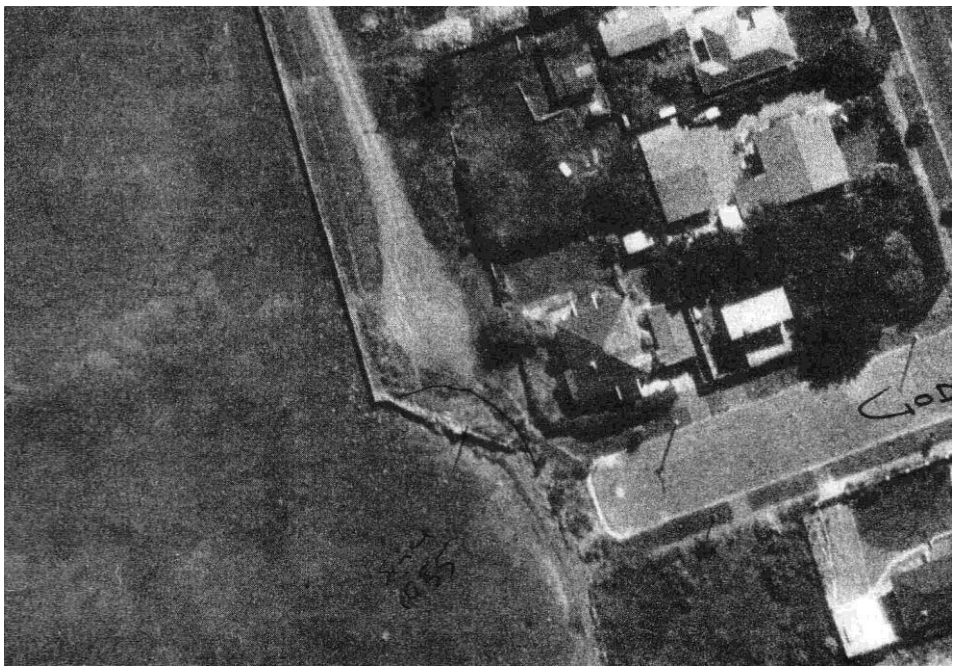

Figure 23: Stopbank (SBW1-A) and informal revetment (IS40-A) forming reclamation at the north side of Godwit Street 2002 (ECan 2002)

Figure 24: Remnants of former pebble beach renourishment at Godwit Street (NS11-A) (Jacobs, 2019).

6.1.3 Current Structure Condition

The 2019 survey showed that this area had 4 structure sections which cover the entire 460m of estuary edge, three being the Ebbtide Street stopbank, and the fourth a 20m rock revetment (IS40) aligned east - west at the southern end of the stopbank. The splitting of the Ebbtide Street stopbank into three separate structure sections was as a result of a 17m section at the northern end (SB1) where the toe concrete wall has been removed or buried, and the southern 20m being backed by grass rather than Ebbtide Street (SBW1-A) – therefore has a land condition assessment. A summary of the length of condition on the structures is presented in **Table 16**, and further survey information can be found in **Appendix B4**.

For structure condition the entire length of the Ebbtide Street stopbank graded as 'B', with the absence of the toe wall in section SB1-A not appearing to affect the functionality of the stopbank, and the rubble revetment (IS40-A is graded as condition 'C'. Although the stopbank has been repaired since the CES with rock being added to the revetment, the low concrete wall along the toe of the revetment dating from at least the 1950's has many cracks along the entirety of its occurrence (**Figure 24)**, hence the condition grading of 'B'.

Table 16: Summary of structure condition and lengths in Area 4

Total number of structures	Total shoreline length	Total length of structures	Total length Condition A	Total length Condition B	Total length Condition C	Total length Condition D	Total length Condition E
5	483m	468m (97%)	0m (0%)	445m (94%)	23m (3%)	0m (0%)	0m (0%)
Note: Percentages are of total shoreline length							

6.1.4 Current Land Condition

Due to the presence of Ebbtide Street behind the majority of the stopbank length, only the southern 23 m of the bank (SBW1-A) has a land condition grading, along with the 38m further south at Godwit Street (IS40-A and NS11-A). For the small southern stopbank section, the condition is 'A' – no evidence of erosion of vegetation die back, and condition 'C' at Godwit Street due to the presence of a small (< 0.2m) erosion scarp.

Figure 25: Ebbtide Street stopbank (SBW1, SB1, SBW2) recorded damage in 2019 survey (Jacobs, 2019)

6.2 Change in Elevation 2003-2019

The Area 4 maps showing 2003 LiDAR 'high ground' elevations along the estuary edge compared to 2019 surveyed 'high ground' and structure elevations along with comparisons to design estuary flood levels are presented in **Appendix C4.** This map shows that the stopbank north of Caspian Street has elevations in the order of 11.5m, meeting current design standards for 50-year return period protection plus freeboard. However, the section south of Caspian Street has progressively lowering elevations with a 200m length of SBW1-B having an average elevation 11 m, and the 23 m long southern most section (SBW1-A) being even lower, with an average of 10.75m and a minimum of 10.62m. Applying current (2018) water level statistics, this southern section would be overtopped in 5-year-return period events (10.80m). It is uncertain whether this occurred in the extreme storm tide events of June & July 2017, and January & February 2018 which exceeded this level. At the end of Godwit Street, where there are no structures (NS11-A), the elevation of the natural beach is in the order of 11.1m, with evidence of small erosion scarping behind the beach (Condition 'C' grading) inferring limited low energy overtopping.

In relation to the 2003 LiDAR 'high ground' levels, the whole length of the stopbank except for the southern section (SBW1-A) is generally the same or slightly higher elevations that pre-CES levels. However, at Godwit Street the current 'high ground' levels are up to 0.5m lower that inferred from the 2003 LiDAR, but as stated above with limited impact on the land condition.

6.3 Change in Edge Position February 2011-2019

Maps for the shoreline position change between February 2011 and May 2019 from the DSAS analysis for Area 4 are presented in **Appendix D4** with the summary of results being presented in **Table 17.**

Table 17: Summary of DSAS results for Area 4 shoreline change 2011-2019

	Total shoreline analysed	+4m to +1m advance	± 1m Change	-1 to -4m erosion	-8 to -4m erosion	-12 to -8m erosion	>-12m erosion
Area 4	**490m**	**10m**	**470m**	**10m**	**0m**	**0m**	**0m**
Note: change of ±1 m is within the margin of error for determining change, hence is interpreted as 'no change'. Distances are from the sum of DSAS transects spaced every 10m alongshore, so may not match shoreline distances in previous tables.							

The results show that as expected the magnitude of change in position over most of the area is less than the margin of error of the analysis (e.g. <1m) due to the edge of the estuary being defined by the low concrete wall and stopbank. The except to this is small area at the northern end connection to the Jellicoe Marsh where the accretion was measured most likely due to rock placement, and at the informal rubble revetment (IS40-A) at southern end where retreat of 1.4m was measured.

Unfortunately, due to the presence of vegetation no measurement were possible where there are no structures at Godwit street. However, the land condition grading ('C') only indicates low level scarping and vegetation die-back indicates little erosion. It is noted that the continued presence of renourishment pebbles placed in 2000 also indicates a degree of stability of this section of shoreline.

7. Area 5: Southshore - Godwit Street to south of Tern Street

7.1 2019 Condition

7.1.1 Area Description

Area 5 is defined as 1.7km in length of the Southshore Residential Red Zone (RRZ) south of Godwit Street to approximately 300m South of Tern Street, as shown in **Figure 26.** Due to the complexity of the structures along this shoreline, the area is divided into 5 sub-areas broadly representing the areas between road ends as also shown in Figure 26.

Figure 26: Area 5 Overview map – Southshore.

The estuary edge along Area 5 is generally orientated to the south west, hence is exposed to winds from the south west through to north-west. Within this general orientation there are local variations, particularly between Heron and Penguin Street where there is small convex section centred on Kingfisher Lane (Area 5a & 5b). Maximum fetch across the estuary to the pre-dominant high south-west winds direction is around 2.5 km to Heron Street and reducing fetch to the south to around less than 1km at Tern Street. Waves generated from southerly winds trend to blow along shore with Area 5, hence have a reduced effect on water levels. The southern sections from Penguin Street to Tern street (Area 5c, 5d, 5e) have westerly fetch of more than 3km, however, winds from this direction are less extreme that from the south west.

There are isolated areas of saltmarsh on the estuary bed fringe of the edge throughout the area, particularly between Heron and Penguin Streets (Area 5b) but are not as extensive as in Areas 1 and 2.

The estuary edge along Area 5 is primarily made up of a collection of 50 former private structures, mainly vertical walls of various design, covering former individual property widths. Most of for these former structures are now classed as informal revetment structures. A number of these properties also included private boat ramps, resulting in gaps in the wall structures.

The hinterland is primarily RRZ cleared following the CES such that the current residential properties are now setback from the estuary edge by 40-60m. It is understood that in clearing the RRZ, some sections along the edge have further lowered below CES subsidence effects due to the action of contractors, and some of former private seawalls along the edge were also knocked over (Pers Comms. Tim Sintes, Resident, 2019). It is also understood that vandalism over the past 8 years has further damaged some of the structures. Examples of changes in structure condition from the ECan 2002 inventory to the 2019 condition survey are presented in **Figures 27** and **28**. Photographs of changes at other structures are referenced in the digital database and can be found in the photographic database.

On either side of Penguin Street are small areas of pebble beach (Areas 5b and 5c), which are assumed to the remnants of previous beach renourishment exercises. The age of these renourishments is unknown, as no consents for this activity at this location has been sourced.

Figure 27: Structure IS7 -156B Rockinghorse Rd (Area 5e) a) in 2002 showing a seawall with 'Satisfactory' and b) in 2019 with structure condition grading 'E' (Jacobs, 2019 image).

Figure 28: Structure IS32 – 9 Kingfisher Lane (Area 5b) a) in 2002 showing a "satisfactory" seawall (ECan, 2002), and b) in 2019 with structure condition grading 'D' (Jacobs, 2019 image).

7.1.2 Structure History

Historical aerial photographs indicate that the first private structures were constructed between Plover and Tern Streets in the period between 1961 and 1973, with evidence of many involving reclamation of the estuary edge (**Figure 29**).

Figure 29: 1973 aerial photograph showing reclamation and informal structures along estuary edge between Plover and Tern Streets (photo from CH2M Beca, 2019).

By 1995 (from Walter 1995), the presence of these private structures, mainly vertical walls and informal rubble revetments, extended along the whole of Area 5 expect for approximately 120m in isolated areas either side of Penguin Street. Where possible, the age of the individual structures is given in the Appendix A inventory. The 2002 ECan inventory records that most of these structures were in an excellent to satisfactory condition at that time. This inventory also recorded that an overwhelming number of these structures were un-authorised under the RMA 1991, have not been retrospectively consented by the land owners as was the requirement under the Coastal Environment Plan.

Within cleared RRZ, LINZ as the post CES land owner, constructed a temporary bund (O1-A) to a general elevation of 11.2m following the March 2014 extreme storm tide event (10.90m) to provide protection from estuary flooding. At the time of construction, the bund was not continuous; as did not include the road ends which were council land. However, following flooding in these locations in extreme storm tides in July 2017 (10.96m), these gaps were filled by council as emergency works, such that the bund now provides continuous protection over a 1.6km length from Godwit Street to south of Tern Street. As reported by Ch2M Beca (2019) the bund comprises of grassed soil sections (constructed by LINZ) and aggregate or quarry run sections (constructed by council). Over most of its length the bund is offset in the range of 10m to 20m from the estuary edge and provides no erosion protection function. The exceptions to this are at 44a Rockinghorse Road, Heron Street, and Penguin Street; the first two of which the bund is located on the estuary edge with works being undertaken by council in July 2019 to place a rock revetment on the estuary side to protect the bund.

7.1.3 Current Structure Condition

The 2019 condition survey determined that within Area 5 there were 50 structures broken into 56 condition sections covering a total length of 1400m (80% of the shoreline of the area). Mapping of the structure footprint conditions is presented in **Appendix B5a** to **B5e**, and a summary of structure condition by shoreline length is presented in **Table 18**. As can be seen by the footprint mapping the width of the structures is variable, ranging from approximately 6m for informal fill and rubble revetments, to less than 30cm for still standing concrete block seawalls and some former foundations.

Table 18: Summary of structure condition and shoreline length in Area 5

Area	Total number of structures sections	Total shoreline length	Total length of structures	Total length Condition A	Total length Condition B	Total length Condition C	Total length Condition D	Total length Condition E
5a	10	363.8m	363.8m	0m	40.9m	135.4m	187.5m	0m
5b	8	299.3m	197.0m	0m	37.3m	14.2m	72.9m	72.5m
5c	12	411.2m	338.7m	0m	0m	0m	120.8m	218.0m
5d	15	295.9m	295.9m	0m	3.9m	135.5m	111.5m	45.0m
5e	12	394.0m	211.7m	0m	0m	24.4m	98.7m	88.5m
Total (m)	**57**	**1764m**	**1407m**	**0m**	**82m**	**310m**	**591m**	**424m**
Total % of all structures				0%	6%	22%	42%	30%
Total % of shoreline				0%	5%	18%	34%	24%
Note: Does not include LINZ Bund, which has condition grading ‘A’								

As can be seem from the table, the majority of structures (over 1 km) are assessed as being severely damaged - condition ‘D’ or ‘E’ status. The difference between these gradings is that condition ‘D’ structures are still

providing a degree of erosion protection function, normally via remaining foundations, compared to condition 'E' structures where the failure/removal of the foundations and remaining collections of loose rubble is providing less erosion protection. As well Figures 27 & 28, further example of Condition 'D' and Condition 'E' structures are presented in **Figure 30** and **Figure 31** respectively.

Figure 30: Examples of structure condition grading 'D': a) Structure ISIS1 – 126A Rockinghorse Rd (Area 5c); b) Structure IS14 -136B Rockinghorse Rd (Area 5d). (Jacobs 2019 images)

Figure 31: Examples of structure condition grading 'E': a) Structure IS23 – 104A Rockinghorse Rd (Area 5d); b) Structure IS20 - 4 Plover Street (Area 5d). (Jacobs 2019 images)

The Southshore LINZ Temporary Bund (also including the council temporary works across the road ends) was ranked as 'A' for both structure and land behind structure.

7.1.4 Current Land Condition

Although there is over 1000m of structures ranked condition 'D' and 'E' as shown in **Table 19** there is only 690 m of land behind the structures ranked in similar poor condition, of which only around 100m is ranked as Condition 'E' (recession greater than 5m, scarping greater than 0.3m and loss of vegetation). This clearly demonstrates the ability of failed erosion edge structures to still provide some degree of protection against erosion. The majority of Condition 'E' land with the large erosion scarps behind failed structures are between Penguin and Plover Streets (Area 5c- structures IS23, AS22), with smaller areas between Plover and Tern streets (Area 5d). More details on the elevation and erosion at these structures in included sections 7.2 and 7.3.

Table 19: Summary of land condition behind the estuary edge for Area 5

Total number of shoreline sections	Total shoreline length	Total length N/A due to Infrastructure	Total length Condition A	Total length Condition B	Total length Condition C	Total length Condition D	Total length Condition E
67	1764m	24m	72m	213m	578m	587m	289m
No structures North of Tern St	140m	0m	34m	0m	0m	88m	18m

As also shown in Table 19, there is only 140m of Area 5 north of Tern street without structures or the remnants of structures along the estuary edge. However, it is noted that around 72m of this length there were former structures that have been totally removed (Area 5c, sections NS6 & NS5), with the land condition now being graded as condition 'D'. Of the remaining length of coast without structures, 34m (Area 5b, sections NS9 &NS10 - **Figure 32**) was graded as land condition 'A' (no evidence of recession or scarping). It is notable that in both of these areas salt marsh was present on the upper estuary bed, providing a buffer to wave energy arriving at the shoreline. Further investigation into the relationship of salt marsh to erosion distances and land condition could be included in stage 2.

Figure 32: Section of no structures (NS10, Area 5b) with land condition grading 'A'.

7.2 Change in Elevation 2003-2019

Maps presenting a 2003 LiDAR comparison to the 2019 survey data and design flood levels for Area 5 are shown in **Appendix C5a to C5e**. As shown in these maps, the results are complex due to the RRZ land clearance, the varying degrees of edge structure removal, the way the 2019 'high ground' has been defined (combination of structure remnants and banks/scarps between structures, and the limitations and uncertainty around the 2003 LiDAR elevations at the structures. What can to be assessed from the mapping is the elevation of the current structure remnants and 'high ground' in comparison to the current (2018) estuary design

flood levels. The results of this assessment are presented in section 7.2.1 below. However, as pointed out in methodology section 2.4.1, to overcome this limitation, a second analysis was undertaken comparing the 2019 average structure and 'high ground' elevations to the 1995 elevations of ground level, floor level, bottom of bank, top of bank, and wall height given in Walter (1995). The results of this analysis are presented in section 7.2.2.

7.2.1 Current Estuary Edge Elevations against Design Flood Levels

7.2.1.1 Godwit to Heron Street (Appendix C5a)

Remnant structures on the estuary edge between Godwit Street and Heron Street have a range of elevations, but are generally below the current (2018) 10-year flood level (10.89m) except for standing concrete walls (IS37 & (IS35) and rubble revetment in front of the LINZ bund at 44a Rockinghorse Rd (IS34-B) and Heron St (northern part of IS33), all of which are above the current (2018) 100-year flood level (11.14m). The lowest remnant structure elevations along this sub-area are 10.46m at section IS34-A (chainage 1770m) with an average elevation over the 58m of concrete rubble revetment **(Figure 33)** being 10.82m. There is some erosion of the land evident behind the structure, resulting in a land condition grading of 'D'. Part of this structure appears to be similar to what was present in 2002.

For the majority of structures, except these listed above as being above the current 100-year flood level, there is 0.2 to 0.5m 'higher ground' present intermediate behind the remnant structures with a range of elevations from a minimum of 10.8 m at IS33-A to the south of Heron Street (chainage 4825-4950) to a maximum level in the order of 11.3-11.4m immediately north of Heron Street (Chainage 4825 to 4850). Despite the low land elevations at IS33, the land condition is graded as 'C' (recession <1m, scarping <0.2m).

Figure 33: Structure IS34-A north of Heron Street, lowest structure elevation of 10.46m and average of 10.82m. Structure condition grading 'C' and land condition grading of 'D'

7.2.1.2 Heron Street to Penguin Street (Appendix C5b)

Remnant structures on the estuary edge between Heron and Penguin Streets are also generally below the current (2018) 10-year flood level (10.89m) apart from the 40 m low concrete wall structure IS30 (chainage 5080 to 5120 -**Figure 34**) with elevations in the order of 11m. This wall appears to be the same structure present at this location in both 1995 and 2002.

Figure 34: Structure IS30-A, Low concrete wall the same as present in 1995 and 2002. Structure elevation 10.9m with land condition 'B'.

Minimum structure elevations along this sub area are in the order of 10.5m for structures IS26 (Concrete wall) and IS28 (single line rock revetment rock revetment) to the north of Penguin Street. For IS28, the rocks fronted a former vertical concrete block wall structure that has been removed (**Figure 35**), while the concrete wall appears to have present back to at least 2002.

Figure 35: Structure IS26. Minimum 2019 structure elevation in Area 5b. a) 2019 condition -single line rock revetment; b) 2002 concrete block wall above rock revetment. Current land condition 'D'.

The lowest section of 'high ground' corresponds to a section of no structures (NS9 chainage 5125 to 5190, **Figure 36)**, which has general elevations in the order of 10.6 -10.7m. Despite these low elevations, this section of shoreline has the highest land condition of 'A' with no evidence of recession, scarping or vegetation die back. This may be due to the presence of salt Marsh on the upper intertidal bed as shown in Figure 36 reducing wave energy along this section of shoreline. This relationship between estuary edge condition and salt marsh occurrence and abundance could form part of the stage 2 investigations.

Figure 36: Structure NS9-A, No structures. General land elevation at estuary edge of 10.6m. Land condition 'A'.

7.2.1.3 Penguin Street to Plover Street (Appendix C5c)

Remnant structures on the estuary edge between Penguin and Plover Streets are generally the lowest in Area 5, being below 10.7m except of isolated sections of IS23-A where concrete walls are still standing (**Figure 37**), and at the concrete wall & revetment structure at Plover Street (IS21-A). **Appendix C5c** also shows a number of locations where remnant structures have elevations less than 10.5m which generally correspond to the locations of greatest erosion behind the remnant structures (e.g. IS23-A at chainage 5450- see Figure 37, IS22-F, and IS22B).

Figure 37: Structure IS23-A, Variable remnant structure elevations- Wall sections above 11.2m, and low foundation sections 10.25m with 3.5m of erosion behind.

As expected the current 'high ground' is generally above the elevation of the structure remnants, however, it is still below elevations of 10.7m over the majority of the length of the sub-area, hence is likely to be overtopped by events greater than the current (2018) 2-year return period flood event, which has been exceeded 15 times since the CES. The exception to this general pattern is to the north of Plover Street (chainage 5575 to 5625), where the high ground is above 11m.

7.2.1.4 Plover Street to Tern Street (Appendix C5d)

As with the other sub areas, **Appendix c5d** shows a range of remnant structure elevations, with some in the range of 10.4 to 10.6m (e.g. IS20, ISIS1 and IS10 – **Figure 38**) so are below the current (2018) 2-year return period design flood level, and others being still standing walls with elevations in the order of 11.4 to above 11.5m (e.g.IS16 – **Figure 39**, and IS14). Former private boat ramps also present gaps in the elevation of edge structures, often resulting in localised scour around the openings.

Figure 38: Structure IS10-A: a) 2019 low elevation foundation remains of former concrete wall (Jacobs 2019); b) Current structure elevation 10.6m, structure condition 'D', land condition 'D' (A. Crossland 2014).

Figure 39: Structure IS16-A, remaining concrete block wall to elevation 11.3-11.9m. (Jacobs 2019)

Where former walls have been removed and remnant foundations are below 10.7m, the surveyed 'high ground' immediately behind the structures generally has elevations in the order of 11m, except at structure IS10-A (Figure 38) north of Tern Street, where land elevation is in the order of 10.8m

7.2.1.5 South of Tern Street (Appendix C5e)

Remnant structure south of Tern street have general elevations of 10.5 to 10.8 m, hence are generally below the current (2018) 5-year return period flood levels. High ground elevations immediately behind the structures have similar elevations.

7.2.1.6 LINZ Bund

The elevation of the LINZ temporary bund (including council temporary bund across road ends) (structure O1) is shown in all **Appendix C5** maps. The average height of the bund along the 1.6km was surveyed in June 2019 to be in the order of 11.2m, with a minimum elevation of 10.97m approximately 50 m south of Godwit (although this may now be higher due to July 2019 repairs), and a maximum elevation of 11.53m immediately north of Penguin Street. In general the highest sections of the bund are at the locations of the council temporary bund across the road ends.

From the 2019 survey, areas where the bund appears to be less that the 11.2m design elevation are for the first 120m south of Godwit Street (although this maybe being addressed in the July 2019 repairs), and around 85m to the south of Tern Street (chainage 5840 to 5925), and for approximately 125m south of Tern Street (chainage 6040 to 6165). In all of these areas the bund has a general elevation of around 11.05m, equivalent to the current (2018) 50-year return period design flood level without freeboard.

Over most of its length the bund elevation is similar or higher than the corresponding 2003 land level along the line of the bund.

7.2.2 2019 Edge Elevation Compared to Walter (1995)

The results of this analysis are plotted in **Figure 40**. The assumptions about the meaning of the descriptors used in Walter (1995) and limitation of the data (limited to only 38 properties) as listed in section 2.4.1 need to be born in mind when interpreting these results.

The comparison of structure elevation show that influence of the failure/removal of the vertical walls either in or post the CES, with the average drop in the elevation of the edge by 0.68m across the 38 properties. At only 4 were the wall elevations similar between 1995 and 2019, or which 3 had elevations below 11m. Hence the effective edge of the estuary inundation protection on a property by property basis has been considerably reduced. However, the level of inundation protection was not continuous along the whole area, with the Walter (1995) data showing up to 10 properties where the walls were below 11m in elevation, a number of properties recorded as not having walls in the ECan (2002) database, and at least private ramps creating gaps in the walls being recorded in the 2019 survey. It is also noted that the LINZ bund provides a continuous level of inundation protection to a higher level that provided pre-CES. However, the scope of this report does not address the inundation risk to properties and buildings should the bund be overtopped.

For the comparison of 1995 ground level to 2019 ‘high ground’ elevation the results show little trend with 15 of the 32 properties where this comparison was possible showing higher current levels by an average of 0.26m, and 17 properties showing lower current levels by an average of -0.22m. For the properties with higher current levels it is unclear how many and to what magnitude these are due to tectonic uplift and how many are due to difference in the position of the 2019 ‘high ground’ position and the 1995 ground level. For the properties with lower current elevations, it is uncertain how many of these were due to RRZ land clearance activities compared to the effect of earthquake subsidence.

A further comparison was undertaken between the elevation of the 2019 structure (where not a free-standing wall) and the top of bank in 1995 as an indication of the degree to which the existing remnant structures may be providing erosion protection by increasing elevation above the natural edge. The results showed 20 properties had an increase by an average of 0.4m, suggesting a likely erosion benefit of the remnant structures over the natural edge by reducing overtopping frequency and magnitude. However, there were also 14 properties which have had a decrease in elevation by an average of -0.15m, therefore likely that the erosion benefit of the remnant structures would be less.

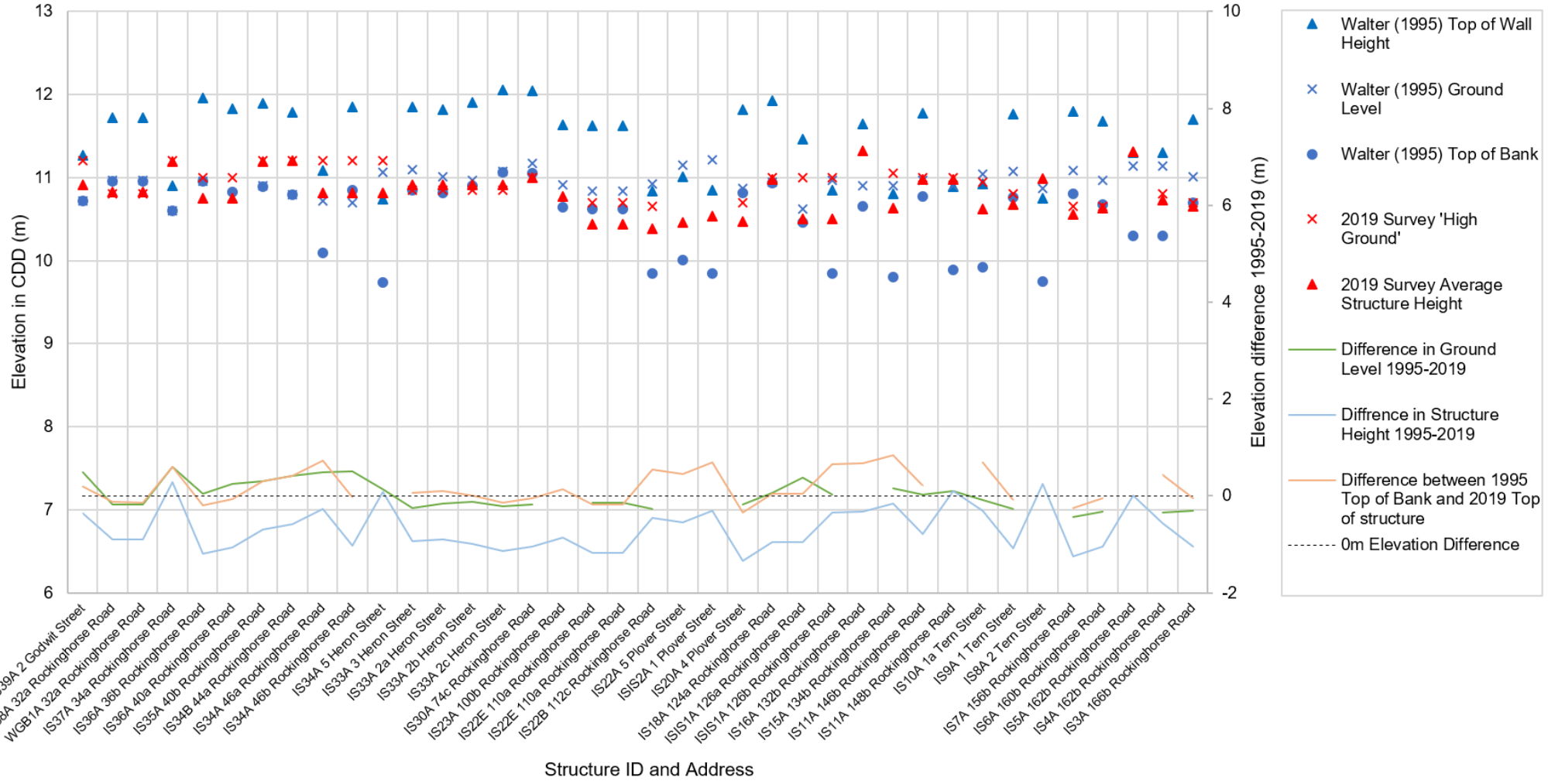

Figure 40: Comparison of structure and estuary edge elevations between 2019 survey and data from Walter (1995)

7.3 Change in Edge Position February 2011 - 2019

Maps for the DSAS analysis shoreline position change between 2011 and 2019 for Area 5 are shown in **Appendix D5a to D5e,** a summary of the results for each sub-area are presented in **Table 20**.

Table 20: Summary of DSAS results for Area 5 shoreline change 2011-2019

Map	Total shoreline analysed	+8 to +4m advance	+4m to +1m advance	± 1m Change	-1 to -4m erosion	-4 to -8m erosion
5a	380m	0m	20m	220m	120m	20m
5b	230m	0m	0m	110m	100m	20m
5c	340m	0m	0m	140m	200m	0m
5d	310m	0m	0m	240m	70m	0m
5e	340m	10m	10m	260m	60m	0m
Total	**1600m**	**10m**	**30m**	**970m**	**550m**	**40m**
Note: change of ±1 m is within the margin of error for determining change, hence is interpreted as 'no change'. Distances are from the sum of DSAS transects spaced every 10m alongshore, so may not match shoreline distances in previous tables.						

As can be seen in the Table, now change in shoreline position could be determined over 60% of the edge in in Area 5. For these locations where erosion was identified, only 40m were identified as having erosion distances of greater than -4m (e.g. rate of > 0.5m/yr). In relation to the post CES erosion distances in Area 3, these distances are low, indicating that the remnant structures are providing a degree of erosion protection along this area of shoreline.

The 2019 field survey indicated that there is a relationship between erosion distance and the elevation of the top of the remnant structures. This relationship is discussed further in the following sections on each sub-area.

7.3.1 Godwit Street to Heron Street (Appendix D5a)

Only 37% of the length of this sub area (140m) shows erosion, with 58% having no change (e.g. ± 1m on DSAS analysis). Shoreline advance of greater than 1m was measured for a 20m length in association with the revetment construction at 44a Rockingshore Rd.

The DSAS analysis only identified two locations with post CES erosion greater that -4m:

- -4.3m erosion immediately south of Godwit Street (transect 426) where the estuary edge is concrete rubble revetment (IS39-A) (**Figure 41a**) that has been in place since pre CES and has a minimum elevation of 10.78m and an average of 10.92m. Some erosion behind the structure was noted in 2019 survey, with land condition graded as 'C' – moderate recession up to 1m. No erosion scarping was recorded.

- -4.1m erosion 90m south of Godwit Street (transect 434) at the boundary of a still standing concrete seawall ((IS37-A) and an area of informal fill (IS36-A) **(Figure 41b)** that present since pre-CES and was recorded as being in poor condition in the ECan (2002) inventory. This structure has a minimum elevation of 10.64m and an average of 10.76m. Some erosion behind the structure was noted in 2019 survey, with land condition graded as 'D' – moderate recession up to 5m. No erosion scarping was recorded.

The setback distance between the LINZ bund (O1) and the estuary edge varies between 0m - 15m. The two areas where the bund is along the edge (44a Rockinghorse Rd and Heron St), it has been protected by council placed rock revetment.

Figure 41: Locations of informal fill between Godwit and Heron streets (Area 5a) with 2011-2019 erosion >4m a) Structure IS39-A, immediately south of Godwit St, and b) Structure IS23-A approximately 90m south of Godwit St. (images Jacobs, 2019).

7.3.2 Heron Street to Penguin Street (Appendix D5b)

The DSAS analysis recorded post CES erosion along 52% of this sub-area, but with only 20m around the stormwater outlet to the south of Kingfisher Lane (transect 467 & 468) being by greater than 4m. As shown in **Figure 42**, the estuary edge at this location is informal fill (IS31-B) that has been present at the site since 1995. Minimum elevation of the structure is 10.77m and an average elevation of 10.90m. The maximum recorded retreat by DSAS was 7m over the 8-year period, with average of -3.95m over the 20m either side of the stormwater outfall. Erosion behind the structure was noted in 2019 survey, with land condition graded as 'D' – moderate recession up to 5m. No erosion scarping was recorded.

Figure 42: Location of informal fill between Heron and Penguin Streets (Area 5b) with 2011-2019 erosion >4m. (image a) from ECan Drone, 2019; image b) Jacobs, 2019).

The setback distance between the LINZ bund and the edge structures varies between 10-20m along this sub area.

7.3.3 Penguin Street to Plover Street (Appendix D5c)

Although the DSAS analysis recorded post CES erosion along 58% of this sub-area, no sections were identified as having erosion of greater than 4m since February 2011. Maximum retreat over the eight year period was recorded as being -3.4m at structure IS23-A (transect 514). This is constant with the location of the most prominent erosion scarp identified in the 2019 survey, which identified the following four substantial erosion scarps were identified in the 2019 survey, resulting in land condition gradings of 'E':

- Structure IS23-A (**Figure 43a**, also shown in **Figure 37**) – Erosion scrap 3.5m landward of structure. Structure is former wall foundation with minimum elevation of 10.25m average of 10.77m, and maximum of 11.35m.
- Structure IS22-F (**Figure 43b**) – Erosion scarp 2.3m landward of structure. Structure is concrete foundation and blocks of former concrete wall with minimum elevation of 10.10m, average of 10.20m and maximum of 10.59m.
- Structure IS22-E **(Figure 43c)**– Erosion scarp 2.7m landward of structure. Structure is concrete foundation and remains of former concrete wall with minimum elevation of 10.31m, average of 10.44m, and maximum of 10.59m.
- Structure IS22-A **(Figure 43d)**– Erosion scarp 2.8m landward of structure. Structure is concrete foundation and remains of former concrete wall with minimum height 10.3m, average of 10.46m, and maximum of 10.59m.

Figure 43: Location of significant erosion scarps behind remnant wall structures between Penguin and Plover Streets (Area 5c) a) IS23-A, erosion 3.5m; b) IS22-F, erosion 2.3m; c) IS22-E, erosion 2.7m; d) IS22-A, erosion 2.8m.

These structures are all low-lying remnants of former walls graded as being structure condition 'E' due to the extent of the damage and the lack functionality due to their low elevations, being below the current (2018) 2-year design flood level. From the water levels given in section 1.3, these remnant structures could have been overtopped at least 15 times in the period since the end of the CES. However, the low erosion distances clearly indicate that these low elevation structures are still providing some form of erosion protection.

The setback distance between the LINZ bund and the estuary edge structures is between 10-15m along this sub area.

7.3.4 Plover Street to Tern Street (Appendix D5d)

The DSAS analysis recorded post CES erosion of only 23% of the shoreline in this sub area, with no areas being measured as having retreated greater than -4m. Maximum retreat over the eight-year period was recorded as -3.8m at structure IS20-A immediately south of Plover Street (transact 535). This is another low elevation informal fill structure of remains of a former wall (shown in **Figure 31b)**, which has a minimum elevation of 10.33m, average of 10.48m and maximum of 10.69m. Erosion behind the structure was noted in the 2019 survey and the land condition was graded 'D' (recession up to 5m). However, the presence of a substantial erosion scarp was not recorded at this location.

The following two substantial erosion scarps were identified behind structures in this sub area in the 2019 survey:

- Structure IS10-A – Erosion scarp 2.5m landward of remainders of former wall foundation and concrete blocks (see **Figure 38a**). Structure elevation of 10.58m - 10.67m.
- Structure IS12-A – Erosion scarp 2.8m behind a former boat ramp infilled with rubble. Structure elevation of 10.64m - 10.69m.

Although these low elevation remnant structures are likely to have been overtopped by up to 15 times since the end of the CES, but again the low rates of erosion indicate that these low elevation structures are still providing some form of erosion protection.

The setback distance between the LINZ bund and the estuary edge structures in this sub-area is in the range of 8-15m.

7.3.5 South of Tern Street (Appendix D5e)

The area south of Tern Street also does not have any areas identified by the DSAS analysis as having post CES erosion greater that 4m, and only 60m (18%) is recorded by the analysis as being erosional, half of which is along the natural coast to south of edge structures. For the structured coast, the greatest erosion recorded over the 8 years was -1.5m at structure IS3-A (transect 584), an informal fill structure from the remnants of a concrete block wall. No substantial erosion scarps or recession greater than 2m were identified in the 2019 survey. For the natural coast, the maximum erosion was -1.4m at transect 600. A 20m section of the natural coast (transects 587 & 588) also recorded shoreline advance in the order of 3.5 -4m since 2011.

The LINZ bund terminates approximately 150m from the southern end of this area, being is setback from the estuary edge around 15m at Tern Street and around 60m at its southern end.

8. Area 6: Natural Coastline South of Tern Street

8.1 2019 Condition

8.1.1 Area Description

Area 6 is defined as the eastern estuary edge from approximately 300m south of Tern Street to the shoreline opposite Shag Rock, as shown in **Figure 44**. This area covers a 1km stretch of without edge structures. The shoreline is largely naturalised vegetated banks, as well as dunes around the southern edge. There are isolated areas of saltmarsh vegetation on the upper estuary bed, however the presence of saltmarsh is not as extensive in this area compared to Areas 1 and 2. The estuary width in this area ranges 600-750m as the estuary channels form a single channel as it approaches the mouth of the estuary. The orientation of the coastline along this area is primarily to the west, however at the south end of the area the coastline curves around until it is orientated to the south, therefore this area of coastline is primarily exposed to westerlies and south westerly winds.

The hinterland in this area is primarily reserve land with walking tracks around the end of the spit. There is a small area of residential land in the northern region of the area, however these houses are set back from the coastline at a minimum of 100m. Historically the spit tip has fluctuated in position by up to 500m, with some historical erosion protection works (concrete filled drums) being placed around the spit tip in the late 1940's or early 1950's .

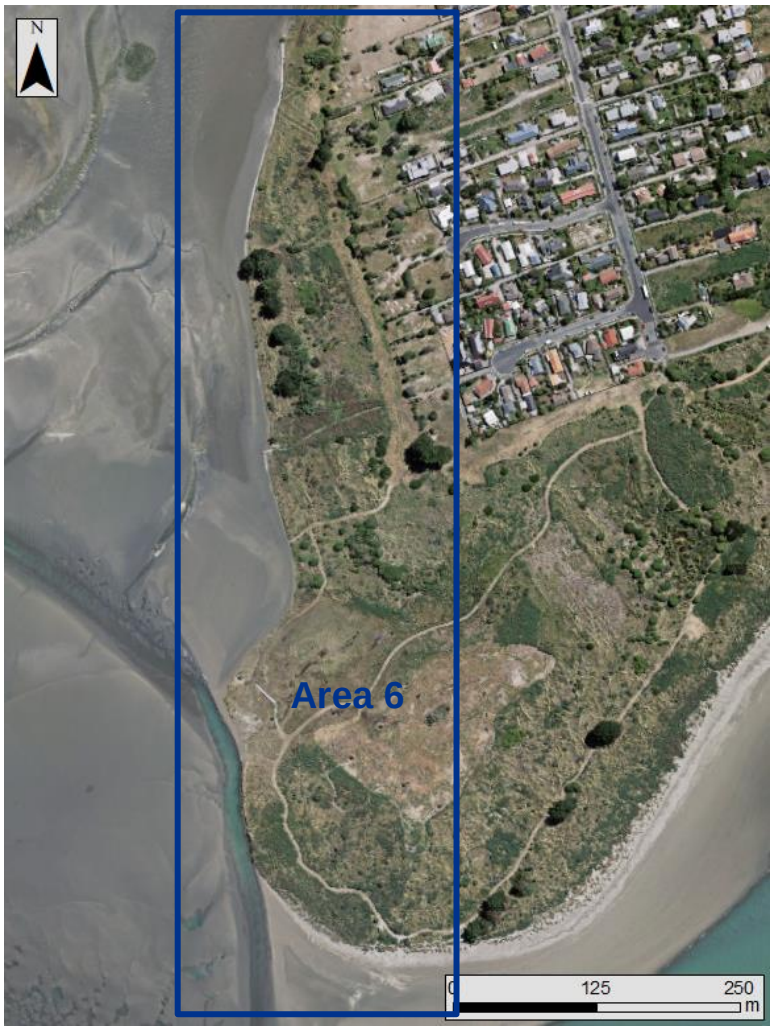

Figure 44: Area 6 Overview map – Spit Reserve

8.1.2 Current Land Condition

An overview of the location of shoreline sections and table of land condition gradings from the 2019 survey is presented in **Appendix B6**. A summary of the resulting land conditions behind the edge is presented in Table 21.

Table 21 Summary of land condition behind the estuary edge for Area 6

Total number of shoreline sections	Total shoreline length	Total length N/A due to Infrastructure	Total length Condition A	Total length Condition B	Total length Condition C	Total length Condition D	Total length Condition E
6	1002m	0m	223m	284m	201m	154m	141m

As shown in the table, the land condition is variable, ranging from grade 'A' to 'E', with nearly 30% being graded in the two poorest categories, (erosion scarps > 2m). The most significant erosion scarps were recorded in section NS1-B, being more than 1m high.

8.2 Change in Elevation 2003 - 2019

LiDAR analysis from 2003 to 2019 is presented in **Appendix C6**. The results of this mapping indicate a variable pattern, with the northern (250m from chainage 6400 to 6650) and central (300m from chainage 6800 to 7100) areas showing the current 'high ground' being around 0.2m lower than the corresponding 2003 elevation and southern area (chainage 7100 to 7400) showing wide fluctuations in the relationship with differences greater than 1m. Some of these patterns are constant with tectonic uplift in the southern estuary and Brighton Spit areas (see **Figure 4**), while others are not.

8.3 Change in Edge Position from 2010/11 to May 2019

The DSAS analysis in Area 6 presented in **Appendix D6** is in two parts: the northern part being the comparison to May 2019 aerial photography from the September 2011 aerial photography (e.g. the same as for areas 1 to 5), and the southern part being the comparison to the shoreline surveyed by ECan in April 2010. For this southern area, the analysis also looked at the differences in erosion patterns from 2010 to 2016, and 2016 to 2019. The summary of these analysis is presented in **Table 22**.

For the northern area, the DSAS results indicate that the majority of the shoreline has been stable, with low magnitude erosion occurring on only 14% of the 200m analysed. The maximum retreat measured was -1.9m at transect 623.

For the southern area, there is more variability in the position change with the most northern transects (transect 659 – 683) displaying erosion over the 9-year period with a maximum retreat of 20m, and the southern transects (transects 684 – 708) displaying shoreline advance with maximum accretion of 25m. In breaking this data into two time periods revealed that both rates of erosion and accretion have increased in the last 3 years compared to the previous 6 years. Due to the complex nature of tidal inlets and the ends of sand spits there are numerous possible reasons for this trend. Any further analysis to determine these reasons is beyond the scope of this project.

Table 22: Summary of DSAS results for Area 6 shoreline position change 2010/11 to 2019

			Net Shoreline Change 2010/11-2019 (m)								
			Shoreline Advance					Shoreline Erosion			
Location	**Time period**	**Total shoreline analysed**	**> +12m**	**+8 to +12m**	**+4 to +8m**	**+1 to +4m**	**± 1m**	**-1 to -4m**	**-4 to -8m**	**-8 to -12m**	**> -12m**
Northern Area 6	**2011-2019**	200m					130m	70m			
Southern Area 6	2010-2016	500m	80m	100m	90m	20m	40m	70m	50m	50m	0m
	2016-2019	500m	30m	40m	20m	30m	80m	50m	140m	100m	10m
	2010-2019	500m	100m	30m	100m	20m	10m	50m	40m	60m	90m

Note: Change of ±1m is within the margin of error for determining change, hence is interpreted as 'no change'. Distances are from the sum of DSAS transects spaced every 10m along shore, so may not match shoreline distances in previous table.

9. Summary of Results

9.1 Estuary Edge Structure Condition

A summary of the structure conditions gradings from each area are presented in **Table 23,** and by structure type in **Table 24.** In total the 7.1km of shoreline surveyed was categorised into 144 sections, of which 117 were structures covering a length of 4.5 km (64% of total shoreline). Note that sections represent lengths of similar condition, hence an individual structure could have multiple sections covering different conditions.

Table 23: Summary of estuary edge structure condition by area

Area	Number of structures sections	Total shoreline length	Total Structure length	Total length Condition A	Total length Condition B	Total length Condition C	Total length Condition D	Total length Condition E
1	13	1699m	1615m (95%)	1117m (66%)	458m (27%)	0m (0%)	38m (2%)	0m (0%)
2	1	1061m	3m (0.3%)	0m (0%)	3m (100%)	0m (0%)	0m (0%)	0m (0%)
3	42	1115m	1078m (97%)	98m (9%)	491m (44%)	189m (17%)	32m (3%)	268m (25%)
4	5	483m	468m (97%)	0m (0%)	445m (94%)	23m (3%)	0m (0%)	0m (0%)
5	56	1764m	1407m (80%)	0m (0%)	82m (5%)	310m (18%)	591m (34%)	424m (23%)
6	0	1002m	0m (0%)	0m (0%)	0m (0%)	0m (0%)	0m (0%)	0m (0%)
Total (m)	**117**	**7124m**	**4571m**	**1215m**	**1479m**	**522m**	**661m**	**692m**
Total % of all structures				27%	32%	11%	14%	15%
Total % of shoreline			64%	17%	21%	7%	9%	10%

Notes: Percentages in the areas are of shoreline length

Area 3 excludes SB3 around the back of Jellicoe Marsh and Area 5 excludes the O1 the LINZ bund as these are not estuary edge structures.

Approximately 2.7km of the edge is made up of structures with a good condition ranking of ‘A’ or ‘B’ (no or limited evidence of damage). These structures are predominantly council stopbanks that have had repairs post-CES north of Bridge Street (Area 1) and at Ebbtide Street (Area 4). These stopbanks were surveyed to have been built to design level (11.4m) for a current (2018) 50-year ARI flood event plus 0.35m freeboard, with the exception of the southern end of Ebbtide Street which was surveyed at an elevation in the order of 11.2m, which 0.15m freeboard on the current 50-year ARI flood level. However, this level is still above the current 100-year ARI flood design level (11.14m).

Approximately 1.35km of the shoreline, making up 29% of length of structures were given a condition ranking of ‘D’ or ‘E’ (severe or extensive damage). These structures were predominantly found in Area 3 (300m) and Area 5 (1km), which make up a significant portion of the shoreline in those areas (Area 3 – 28%; Area 5 – 57%). 40m of the stopbank in Area 1 (fronting Kibblewhite Street) was also given a condition ‘D’ rating due to the

significant erosion occurring on the front face of the stopbank. No structures with 'D' or 'E' rankings were found in Areas 2, 4 or 6.

Table 24: Summary of structure condition by type.

Structure Type	No. of structure sections	Total length of structures	Total length Condition A	Total length Condition B	Total length Condition C	Total length Condition D	Total length Condition E
Boat Ramp	9	32.6m	13.9m (43%)	2.4m (7%)	5.9m (18%)	7.6m (23%)	2.8m (9%)
Bund	1	1589m	1589m (100%)	0m (0%)	0m (0%)	0m (0%)	0m (0%)
Detached breakwater	5	167.4	0m (0%)	167.4m (100%)	0m (0%)	0m (0%)	0m (0%)
Gabion Baskets	8	97.9m	85.8m (88%)	12.1m (12%)	0m (0%)	0m (0%)	0m (0%)
Informal structure - Revetment	11	323.5m	0m (0%)	2.9m (0.8%)	45.7m (14%)	236.9m (73%)	38.0m (12%)
Informal structure – Informal fill	11	342.7m	0m (0%)	24.3m (7%)	119.4m (35%)	38.2m (11%)	160.8m (47%)
Informal structure – Wall	28	690.6m	0m (0%)	55.5m (8%)	141.3m (20%)	271.4m (40%)	222.4m (32%)
Jetty	1	2.2m	2.2m (100%)	0m (0%)	0m (0%)	0m (0%)	0m (0%)
Revetment	3	75.7m	0m (0%)	0m (0%)	25.8m (34%)	49.9m (66%)	0m (0%)
Reno Mattress	21	721m	0m (0%)	270.7m (38%)	163.2m (23%)	20m (2%)	267.9m (37%)
Stopbank	18	2409.8m	1100.3m (46%)	1270.6 (53%)	0m (0%)	38.9m (1%)	0m (100%)
Other	1	17m	17m (100%)	0m (0%)	0m (0%)	0m (0%)	0m (0%)

Gabion baskets and reno mattresses make up majority of the shoreline in South New Brighton Park (Area 3). All of the gabion baskets (approximately 100m) have been repaired post CES and are ranked as condition 'A' or 'B'. Some areas of reno mattress have been repaired or constructed following the earthquake around the Pleasant Point Yacht Club and the Jellicoe Marsh boardwalk total 270m, have been graded condition 'B'. However, there is approximately 600 m of unrepaired reno mattress between the Yacht Club and Jellicoe Marsh, of which half has been ranked Condition 'D' and 'E'. The worst section RM2-I, covering a length of 186m to the north of the South Brighton Holiday Park has slipped down onto the estuary bed, and has suffered the greatest post CES erosion for structures over the whole study area (average -8.5m, maximum -13.4m).

Private structures being a collection of still standing concrete walls, informal revetments (many from collapsed former walls), and informal fill, make up 1.35km of the estuary edge, being 28% of the total structure length and covering 20% of the total study area. Most of these structures are located in Area 5 from Godwit Street to Tern Street, having been constructed by the former individual property owners of the Southshore RRZ. Of these

structures, 70% (970m) have been graded as being condition 'D' or 'E'. Conversely, none of these structures have been graded condition 'A' and only 6% (83m) have been graded condition 'B'.

9.2 Condition of Land Behind Structures

A summary of the land condition grading from each area and across the whole study area is presented in **Table 25**.

Table 25: Summary of land condition behind structures

Area	Total Shoreline Length	No of shoreline sections	Total length Condition A	Total length Condition B	Total length Condition C	Total length Condition D	Total length Condition E	Land condition N/A due to infrastructure
1	**1699m**	15	729m	430m	0m	0m	10m	529m
2	**1061m**	3	1031m	3m	28m	0m	0m	0m
3	**1115m**	45	96m	147m	59m	83m	384m	346m
4	**483m**	6	23m	0m	38m	0m	0m	422m
5	**1764m**	67	72m	213m	578m	587m	289m	24m
6	**1002m**	8	223m	284m	201m	154m	141m	0m
Total	**7125m**	**144**	**2174m (31%)**	**1077m (15%)**	**904m (13%)**	**824m (12%)**	**824m (12%)**	**1321m (19%)**

Note: Number of shoreline sections includes both structure and non-structure sections.

The analysis only includes sections on the edge, so does not include sections SB5 north of Bridge Street, SB3 around the back of Jellicoe Marsh or O1 – the LINZ bund.

The 2019 survey assessed 46% of the 7.1km surveyed as having a land condition behind the edge as being condition 'A' or 'B' (no or mirror evidence of erosion or vegetation die back), while 24% (1.65km) was ranked as condition 'D' or 'E' (significant to extensive erosion, scarping and vegetation dieback). Approximately 1.3km of the land behind the edge was not assessed for condition due to the presence of roads (areas 1 & 4) or marsh (Area 3) being located immediately behind the structures.

Areas 3 and 5 have the greatest lengths of poor condition land behind the edge (e.g. condition 'D' and 'E'), with 467m and 876 m respectively, which is 42% and 50% of the total shoreline length in these areas. However, both areas also include over 200m of condition 'A' and 'B' land behind the edge.

Area 2 has the least evidence of erosion, scarping or vegetation dieback along the edge, with 97% (1031m) of the edge in this area being graded condition 'A'.

9.3 Elevation Changes

The analysis of elevation changes from pre to post CES is complex. However, the following points have been identified for each area:

- For Area 1, the comparison of pre- CES to current stopbank elevations shows that the current stopbank elevations are higher than the pre-earthquake elevations.

- For Area 2, the change in elevation, assumed to be a result of subsidence in the CES, has generally in the order of -0.2m across the whole area, however in some locations it is up to -0.5m.

- For Area 3, for the northern part of the area the 'high ground' feature is higher in 2019 than 2003 by up to 0.2m due to the construction of new structures. However, for the 600m of unrepaired reno, the combination of subsidence and lateral spread has resulted in the current elevations being on average 0.25m lower than in 2003, with the maximum change in the order of -0.5m.

- For Area 4, the whole length of the rebuilt stopbank except for the southern section is generally the same or slightly higher elevations that pre-CES levels.

- For Area 5, a combination of RRZ land clearance, the varying degrees of edge structure removal, the way the 2019 'high ground' has been defined and the limitations and uncertainty around the 2003 LiDAR elevations at the structures made the analysis of pre to post CES level very complex. However, comparison of structure and ground levels against the corresponding information presented by Walter (1995), indicated the following points:

    - Although the removal of seawalls has resulted in an average drop in effective edge elevation in a number of locations, there were gaps where former walls were below 11m and boat ramps, which did not produce a continuous level of inundation protection pre CES.

    - Nearly equal numbers of properties have lower 'high ground' elevations that ground levels in 1995 as have higher levels. It is uncertain how much these levels have been influenced by RRZ land clearance activities and how much is due to earthquake effects.

    - At a number of the properties the remnant wall structures are higher than former natural banks, therefore still produce a greater level of erosion benefit that would occur with the natural banks alone.

- For Area 6, there is a variable pattern, with the northern and central areas showing the current 'high ground' being around 0.2m lower than the corresponding 2003 elevation, and southern area showing wide fluctuations in the relationship with differences greater than 1m.

9.4 Shoreline Position Change

A summary of the range of shoreline position changes from the DSAS analysis are presented in **Table 26**. These results show that the 40% of the shoreline (2.3 km) is stable (changes ± 1m), and 34% (1.9km) has eroded over the 8 year period since 24th February 2011. The majority of this erosion has been by less than 4m (e.g. rate of < 0.5m/yr), with only 330 m having erosion distances for greater than 4m.

The greatest erosion distances (e.g. >12m, >1.5m/yr) have occurred in Area 1 at Bridge Reserve (-32.5m), Area 3 in the centre of the un-repaired reno mattress section (9-13.4m), and on the spit reserve natural shoreline in Area 6 (-20m).

Shoreline advance has been recorded in Area 1 and Area 5 in relation to shoreline repairs and revetment construction respectively, and along the natural shoreline at the tip of the South Brighton Spit in Area 6.

Excluding the natural shoreline in Area 6, the areas with structures that have suffered the greatest spatial extent of erosion are Area 3 (75%), and Area 5 (37%). For Area 3 this erosion includes 400m of the un-repaired reno mattress, with an average retreat of -3.5m and a maximum of -13.4m. This is the worst eroded area of structures in the study area.

In Area 5 the erosion distances are less, predominantly being limited to under 4m, due to the remnant structures still providing some degree of erosion protection along this shoreline. This is an important consideration in any decision to remove or modify the existing remnant structures.

There also appears to be a relationship between the presence of extensive salt marsh on the upper estuary bed and the magnitude of erosion experienced, particularly at locations without edge structures. This relationship should be examined further for evaluating further edge erosion protection options.

Table 26: Summary of shoreline change from DSAS analysis

	Shoreline Advance					Shoreline Erosion				
Area	**>+12m**	**+8 to +12m**	**+8 to +4m**	**+4 to +1m**	**±1m**	**-1 to -4m**	**-8 to -4m**	**-12 to -8m**	**<-12m**	**Total shoreline analysed**
1			300m	570m	320m	160m	30m	20m	80m	1480m
2				20m	200m	60m	30m	10m		320m
3					190m	370m	130m	60m	10m	760m
4				10m	470m	10m				490m
5			10m	30m	970m	550m	40m			1600m
6	**100m**	30m	100m	20m	140m	120m	40m	60m	90m	700m
Total (m)	**100m**	**30m**	**410m**	**650m**	**2290m**	**1270m**	**270m**	**150m**	**180m**	**5350m**
Total (%)	**2%**	**1%**	**8%**	**13%**	**42%**	**24%**	**5%**	**2%**	**3%**	

Note: Change of ±1 m is within the margin of error for determining change, hence is interpreted as 'no change'.

Distances are from the sum of DSAS transects spaced every 10m alongshore, so may not match shoreline distances in previous tables.

Area 6* includes 2011 shoreline from aerial photographs and 2010 shoreline from Environment Canterbury Topographic Survey

9.5 Relationship of Erosion Distance to Structure Elevation

The results from the condition assessment and survey data have indicated a relationship between the elevation of a structure, and the magnitude of erosion behind the structure. This relationship is examined further in **Table 27**. For this analysis, shore change is from the DSAS analysis, therefore some very short structures such as boat ramps, are excluded since they do not intersect with a DSAS transect. Elevations are banded in the current (2018) estuary ARI flood levels. The key points from the results are:

- Of the 7 structure sections which have minimum elevations below the MHWS, approximately 85% had erosion behind their structures
- The occurrence of larger erosion distances was highest for low elevation structures below MHWS elevation, with 187m (42%) of shoreline erosion behind these low elevation structures being by more than 8m.
- Although the occurrence of larger erosion distances decreased with higher structure elevations, erosion was still experienced over all structure elevations.
- The likelihood of any erosion occurring decreased with increasing structure elevation.

Table 27: Summary table of minimum elevation of structures (of the highest elevated edge) compared to the DSAS analysis results of shoreline change behind the structure.

			Net Shoreline Change 2011-2019 (m)					
			Shoreline Advance			Shoreline Erosion		
Elevations	**Total length**	**Total structure sections**	**+4 to +8m**	**+1 to +4m**	**±1m**	**-1 to -4m**	**-4 to -8m**	**-8 to -12m**
< MHWS (10.257m)	446.5m	7	0m (0%)	0m (0%)	63.9m (14%)	195.8m (44%)	0m (0%)	**186.8m (42%)**
Up to 10.68m (2-yr ARI)	993.3m	35	0m (0%)	0m (0%)	723.3m (73%)	270m (27%)	0m (0%)	0m (0%)
Up to 10.88m (10-yr ARI)	321.8m	12	0m (0%)	0m (0%)	141.5m (44%)	170.9m (53%)	0m (0%)	9.4m (3%)
Up to 10.96m (20-yr ARI)	97m	3	0m (0%)	0m (0%)	10.6m (11%)	86.4m (89%)	0m (0%)	0m (0%)
Up to 11.06m 50-yr ARI)	386.8m	5	0m (0%)	0m (0%)	377.5m (98%)	9.3m (2%)	0m (0%)	0m (0%)
< MHWS (10.257m)	1388.6m	20	**247.8m (18%)**	**816.2m (59%)**	223.8m (16%)	100.8m (7%)	0m (0%)	0m (0%)
Total	3616m	82	247.8m (7%)	816.2m (22%)	1540.6m (43%)	833.2m (23%)	0m (0%)	196.2m (5%)