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Coastal modelling of sea level rise for the Christchurch coastal environment

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ABSTRACT

Predictive modelling provides an efficient means to analyse the coastal environment and generate knowledge for long term urban planning. In this study, the numerical models SWAN and XBeach were incorporated into the ESRI ArcGIS interface by means of the BeachMMtool. This was applied to the Greater Christchurch coastal environment to simulate geomorphological evolution through hydrodynamic forcing. Simulations were performed using the recent sea level rise predictions by the Intergovernmental Panel on Climate Change (2013) to determine whether the statutory requirements outlined in the New Zealand Coastal Policy Statement 2010 are consistent with central, regional and district designations. Our results indicate that current land use zoning in Greater Christchurch is not consistent with these predictions. This is because coastal hazard risk has not been thoroughly quantified during the process of installing the Canterbury Earthquake Recovery Authority residential red zone. However, the Christchurch City Council's flood management area does provide an extent to which managed coastal retreat is a real option. The results of this research suggest that progradation will continue to occur along the Christchurch foreshore due to the net sediment flux retaining an onshore direction and the current hydrodynamic activity not being strong enough to move sediment offshore. However, inundation during periods of storm surge poses a risk to human habitation on low lying areas around the Avon-Heathcote Estuary and the Brooklands lagoon.

Keywords: Coastal modelling, sea level rise, Coastal hazard planning, ArcGIS, BeachMM tool, NZCPS 2010.

1. INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) has proposed that the rate of global sea level rise (SLR) that has occurred since the mid-19th century was larger than the mean rate of the previous two millennia (IPCC, 2013). During the period from 1901-2010 the global mean sea level has risen by 0.19 m (IPCC, 2013), or an estimated mean global rate of 1.7–1.8 mm a^{-1} during the last century (Gehrels, Hayward, Newnham & Southall, 2008). Over the past 7000 years the sea level around New Zealand has remained relatively stable, although evidence suggests that a rapid rise has recently occurred (Gehrels et al., 2008).

New Zealand's dynamic coastal zone is governed by The New Zealand Coastal Policy Statement 2010 (NZCPS 2010) which covers the coastal marine area from the line of Mean High Water Springs (MHWS) to 12 nautical miles offshore (New Zealand Government, 2010). It is a requirement of the Resource Management Act 1991 to be reflected in regional policy statements, regional plans and district plans (New Zealand Government, 2010) to provide planners with robust objectives and policies.

The Christchurch coastal environment has undergone major geomorphic change due to a series of major earthquakes in 2010 – 2011. This created localised uplift and subsidence within the urban environment, altering vulnerability to flood or storm surge inundation for many residents (A. Eaves, observation, 22nd February 2011). A state of emergency gave rise to the creation of the Canterbury Earthquake Recovery Authority (CERA), a new central government department to manage Canterbury's disaster recovery. CERA identified and re-zoned residential areas that suffered significant land damage, and provided public compensation to those residents displaced by the re-zoning. During this period of disaster management, it would be prudent to evaluate the NZCPS 2010 in order to provide a more realistic outcome given the major change in topography.

Predictive models can potentially be used to understand the future consequences of SLR on coastal environments. These models create the opportunity to simulate and understand the physical processes affecting the coastal environment over varying timescales; providing decision makers with valuable quantitative information about a range of conditions (Silva & Taborda, 2013). Geographic Information Systems (GIS) provide spatial analysis and data integration techniques for the accurate mapping and analysis of coastal features (Allen, Oertel & Gares, 2012). When GIS is used in combination with the statutory guidance and legislative tools of the NZCPS 2010 it enables local and territorial authorities to deliver prudent and effective outcomes for coastal management.

The aim of this study is to use predictive modelling to determine whether CERA's land use zoning meets the obligations outlined in the NZCPS 2010 for future SLR. The modelling allows for an estimation of the extent of the Greater Christchurch shoreline in 100 years, the effects of storm surge, and progradation or erosion outcomes for the foreshore given SLR estimates made by the IPCC. Thus providing robust synthesised scenarios for planners to draw conclusions on the possible outcomes for the future of greater Christchurch's coastal zone.

2. BACKGROUND

2.1 Sea level rise

The constituent drivers to a change in sea level are: isostatic changes in the earth's crust through plate tectonics or post-glacial rebound; eustatic changes through thermal expansion or contraction of the oceans via changes in density, salinity or a redistribution of freshwater storage; and departures from the global mean ocean circulation resulting in regional storm surge, changes to the significant wave height, and non-uniform atmospheric oscillations from temperature and salinity changes (Nicholls & Lowe, 2004). Non-uniform atmospheric oscillations are also known as the climate related Mean Sea Level Anomaly (MSLA), which includes the Interdecadal Pacific Oscillation (IPO) and the El Nino Southern Oscillation (ENSO) (Stephens, Bell, Ramsay & Goodhue, 2013). Stephens et al. (2013) have quantified the sea level components as: long term SLR, MSLA, tide, storm surge, and wave setup and run up. A range of ocean processes have been affected by both the long term progressive changes and the decadal variations in the climate; including global SLR and the enhanced intensities of storms which generate more extreme waves and elevate storm surges (Komar, Allen, Ruggerio & Harris, 2013). SLR observations also contain inherent errors and uncertainties that need to be reported as well as any other diagnostic indicators (Allen et al., 2012).

The IPCC provides science and guidance to nation states on potential outcomes of climate change. Their SLR predictions are driven by greenhouse gas concentration trajectories determined by estimates of future emissions. The IPCC has proposed that the rate of global SLR that has occurred since the mid-19th century was larger than the mean rate of the previous two millennia (IPCC, 2013). During the period from 1901-2010 the global mean sea level has risen by 0.19 m (IPCC, 2013), or an estimated mean global rate of 1.7–1.8 mm a^{-1} during the last century (Gehrels, Hayward, Newnham & Southall, 2008). Over the past 7000 years the sea level around New Zealand has remained relatively stable; however, evidence from saltmarsh cores from southern New Zealand suggests that a rapid rise has recently occurred (Gehrels et al., 2008). Hannah (2004) estimated a rate of SLR for New Zealand of 2.8 ± 0.5 mm yr^{-1} for the 20th century which was a considerably higher rate than that for preceding centuries. This was comparable with the nearest reliable tide-gauge at Lyttelton, where a rise of 2.1 ± 0.1 mm yr^{-1} between 1924 and 2001 was recorded (Gehrels et al., 2008; Hannah, 2004). This rate is higher than the global average of 1.7–1.8 mm yr^{-1}, which can be attributed to regional thermal expansion (Gehrels et al., 2008). Ocean warming will be greater at depth in the Southern Ocean, with best estimates of ocean warming at a depth of about 1000 m by 0.3°C to 0.6°C by the end of the 21st century (IPCC, 2013).

2.2 Planning for sea level rise: the New Zealand context

The effects of SLR require the implementation of effective coastal planning and forecasting for low-lying coastal areas. In New Zealand, the primary statutory document for long term coastal planning is the NZCPS 2010. The NZCPS 2010 outlines statutory directives that regional and territorial authorities must comply with through their planning documents, policy statements and resource consenting processes (New Zealand Government, 2010). These objectives and policies are:

> Objective 5: *To ensure that coastal hazard risks take account of climate change, are managed by: locating new development away from areas prone to risks; consider responses, including managed*

retreat, for existing development in this situation; and protecting or restoring natural defences to coastal hazards (NZCPS 2010, p. 10).

Policy 6: *(1) (i) set back development from the coastal marine area and other water bodies, where practicable and reasonable, to protect the natural character, open space, public access and amenity values of the coastal environment* (NZCPS 2010, p. 13).

Policy 24: *Identification of coastal hazards (1) Identify areas in the coastal environment that are potentially affected by coastal hazards, giving priority to the identification of areas at high risk of being affected. Hazard risks, over at least 100 years are to be assessed having regard to: (a) physical drivers and processes that cause coastal change including sea level rise; (b) short-term and long-term natural dynamic fluctuations of erosion and accretion; (c) geomorphological character; (d) the potential for inundation of the coastal environment, taking into account potential sources, inundation pathways and overland extent; (e) cumulative effects of sea level rise, storm surge and wave height under storm conditions; (f) influences that humans have had or are having on the coast; (g) the extent and permanence of built development; and (h) the effects of climate change on: (i) matters (a) to (g) above; (ii) storm frequency, intensity and surges; and (iii) coastal sediment dynamics; taking into account national guidance and the best available information on the likely effects of climate change on the region or district* (NZCPS 2010, p. 23).

Under the Resource Management Act 1991 (RMA), the regional regulatory authority, Environment Canterbury (ECan), must give effect to the policies and objectives in the NZCPS 2010. Similarly, the Christchurch City Council (CCC), as the local territorial authority, must also give effect to the objectives and policies outlined in the NZCPS 2010. ECan has produced a series of maps outlining the landward boundary of hazard zones and a sea water inundation zone boundary (ECan, 2011). The landward boundary of hazard zone 1 is approximately

Site	ECan Profile	Dune height (m)	Slope	Sea level rise (m)	Shoreline Retreat (m)	Shoreline Retreat range (m)
Spencer Park	C1755	5.0	0.01	1.0	70	30-100
Bottle Lake	C1400	9.0	0.01	1.0	70	30-100
North New Brighton	C1065	5.1	0.01	1.0	70	30-100
New Brighton	C0952	8.3	0.01	1.0	60	30-80
New Brighton	C0815	8.6	0.01	1.0	60	30-80
South New Brighton	C0600	8.7	0.01	1.0	60	30-80
Southshore	C0471	6.9	0.01	1.0	60	30-90
Scarborough	-	3.9	0.016	1.0	60	30-90
Taylor's Mistake	-	4.6	0.025	1.0	40	20-60

Table 1: Summary of estimated shoreline retreat due to sea level rise (information sourced from Tonkin and Taylor Ltd, 2013).

	Avon River	Heathcote River
Area of land inundated by 3.3m level (1% AEP event)[1]	1,226 ha	1,171 ha
Suburbs affected by a 1% AEP event inundation level	Travis Wetland Avondale Wainoni Dallington Horseshoe Lake Bexley	Ferrymead Woolston Linwood Hillsborough

Table 2: Summary of inundation impacts for the Lower Avon and Heathcote Rivers (information sourced from Tonkin and Taylor Ltd, 2013).

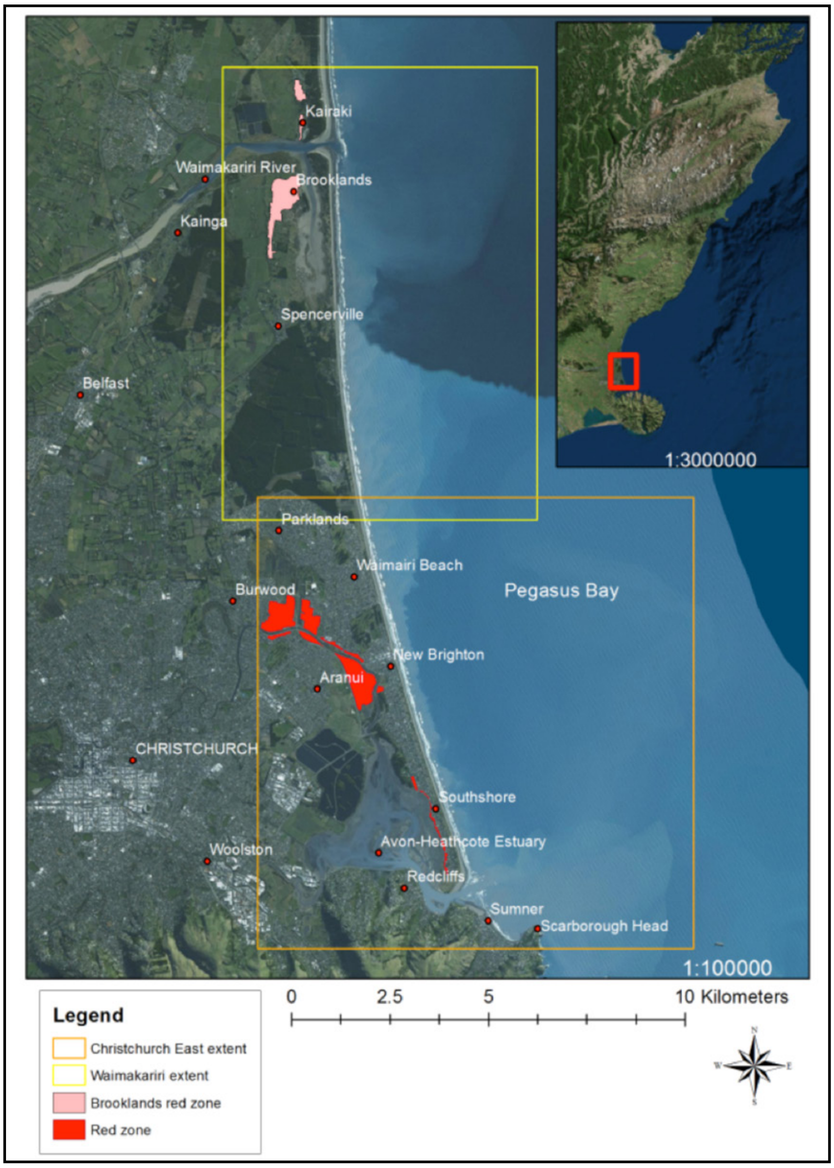

Figure 1: The modelled extent of Eastern Christchurch (main image) and setting within the South Island of NewZealand (upper right image).

aligned with the landward extent of the secondary dune system. The sea water inundation zone boundary has not been mapped by ECan for Eastern Christchurch. These zones do not currently comply with the NZCPS 2010 as coastal processes and the effects of climate change require quantified risk assessment for a 100 year period.

Local government and Crown entities have created zones of increased hazard risk in post-earthquake Christchurch to facilitate the rebuild of the city. CERA was established by central government to facilitate the region's recovery after the earthquake events. Their direction saw the implementation of residential red zones, where residents were financially compensated for their voluntary relocation from areas of significant land damage and likely high risk from hydraulic inundation. This residential red zone comprised areas adjacent to the Avon River, the Avon – Heathcote Estuary and the Brooklands lagoon (CERA, 2014). Similarly, the CCC has created a non-statutory Flood Management Area (FMA) that identifies areas at risk of hydraulic inundation, where it is advised not to build.

2.3 Mechanisms for assessment

Planning and engineering design has historically focused on extremes in climate variability due to the slow rate of SLR and therefore the parameters were considered to be stationary (Ministry for the Environment [MfE], 2008). Now, planning timeframes have had to adapt to increasing sea levels using practical high tide levels such as Mean High Water Spring (MHWS) tide being exceeded 10% of the time, and estimates of extreme high storm tides (MfE, 2008). However, while global climate change is well documented, regional impacts and changes can be less well quantified and may differ between regions, leading to subjective interpretations of the future risk

(Reisinger, 2009).

Current best-practice utilises two theories. The Bruun Rule (Bruun, 1962) is a simple two-dimensional model that assumes a closure depth of offshore sediment exchange, no onshore or offshore gains or losses, no long term seasonal anomaly, instantaneous response to sea level change, and no account of sediment characteristics (Tonkin and Taylor Ltd, 2013). This model was deemed suitable by Judge Bollard in the Environment Court in Skinner v Tauranga District Council A 163/02 as a precautionary approach to coastal hazard planning for open coast beaches (MfE, 2008). Passive inundation, or the "bathtub" approach, is where a certain SLR will intersect the terrestrial contour height; for example, where the MHWS in 2115 will intersect the existing cross-shore profile (EShorance, 2010).

A recent report by Tonkin and Taylor Ltd (2013) considers the implications of a projected SLR of 1.0 m by 2115 in line with MfE (2008) guidelines. The report utilises the Bruun Rule and passive inundation to estimate the extent of inundation. They conclude that storm inundation, greater frequency of extreme tidal levels and the progressive retreat of the shoreline in low lying areas will be the main impacts. Table 1 presents Tonkin and Taylor's (2013) estimates of shoreline retreat due to a SLR of 1.0 m. Uncertainty around sediment supply from the Waimakariri River has led to the assumption that the system is in dynamic equilibrium and that in future there will be no long term trend of progradation (Tonkin and Taylor Ltd, 2013). The risk of inundation along the New Brighton dune system is not expected to have any effect as the elevations are above storm surge levels (Tonkin and Taylor Ltd, 2013). Along the Sumner and Clifton revetments a general lowering of the beach profile will occur due to scouring at the base with inundation likely due to low points in the road and structure in the future, with Clifton beach facing coastal squeeze (Tonkin and Taylor Ltd, 2013). The inundation impacts on the lower Avon and Heathcote rivers reported by Tonkin and Taylor (2013) are given in table 2, which utilises a passive inundation level of 2.15 m (Tonkin and Taylor Ltd, 2013).

2.4 Study area

This study focuses on the Greater Christchurch coastal environment and surrounding coastal marine area in the southern extent of Pegasus Bay. Figure 1 shows the extent of the study area. The Christchurch shoreline had a previous position west of the CBD during the last Holocene high stand, though its current position is now 11 km seaward (Hart, Marsden & Francis, 2008). This progradation of Pegasus Bay is due to the inability of the marine environment to remove wave-eroded sediment from the floor of the bay, leading to gradual nearshore aggradation which is then transported landward to form new berms (Schulmeister & Kirk, 1997). However, this wave dominated environment is strong enough to disperse river derived sediment from the Waimakariri, Ashley and Waipara rivers across the nearshore (Schulmeister & Kirk, 1997)

Pegasus Bay is sheltered from the predominant hydrodynamic forcing by Banks Peninsula leading to nourishment of the bay via a counter-clockwise eddy in the Southland Current; sediment is dragged north from the Canterbury Bight where it settles under calmer conditions (Brown, 1976; Hart et al., 2008; Schulmeister & Kirk, 1997). The Southland Current drives sediment south along the shore in the southern extent of Pegasus Bay (the study area for this paper) and north in the northern extent of the bay (Hart et al., 2008). However, long-shore sediment transport occurs in both north and south directions, with the absence of a dominant drift direction due to the planform equilibrium of the bay (Brown, 1976). Thus, sediment transport is determined by incident wave angle and ocean current. The dominant wave directions in Pegasus Bay are from the east and south-east, with southerly waves refracting around Banks Peninsula which rarely exceed a wave height of 2.5 m (Schulmeister & Kirk, 1997).

3. METHODS AND MATERIALS

3.1 The predictive models

The predictive computer modelling used derives assumptions from general theory through the numerical hydrological equations used in SWAN and XBeach to create idealised representations that were interpreted in ArcGIS via the BeachMM tool (Silva & Taborda, 2012). The third-generation SWAN wave model provides realistic estimates of wave parameters in coastal areas utilising wind, bottom and current conditions (Booij, 2012). XBeach is a recent and open source model for nearshore processes, which allows for the computation of natural coastal response to temporally varying storm conditions that include dune erosion, over-washes and breaching (Roelvink, Reniers, Van Dongeren, De Vries, Lescinski & McCall, 2010). The BeachMM tool is a geoprocessing tool that integrates these two numerical models into the

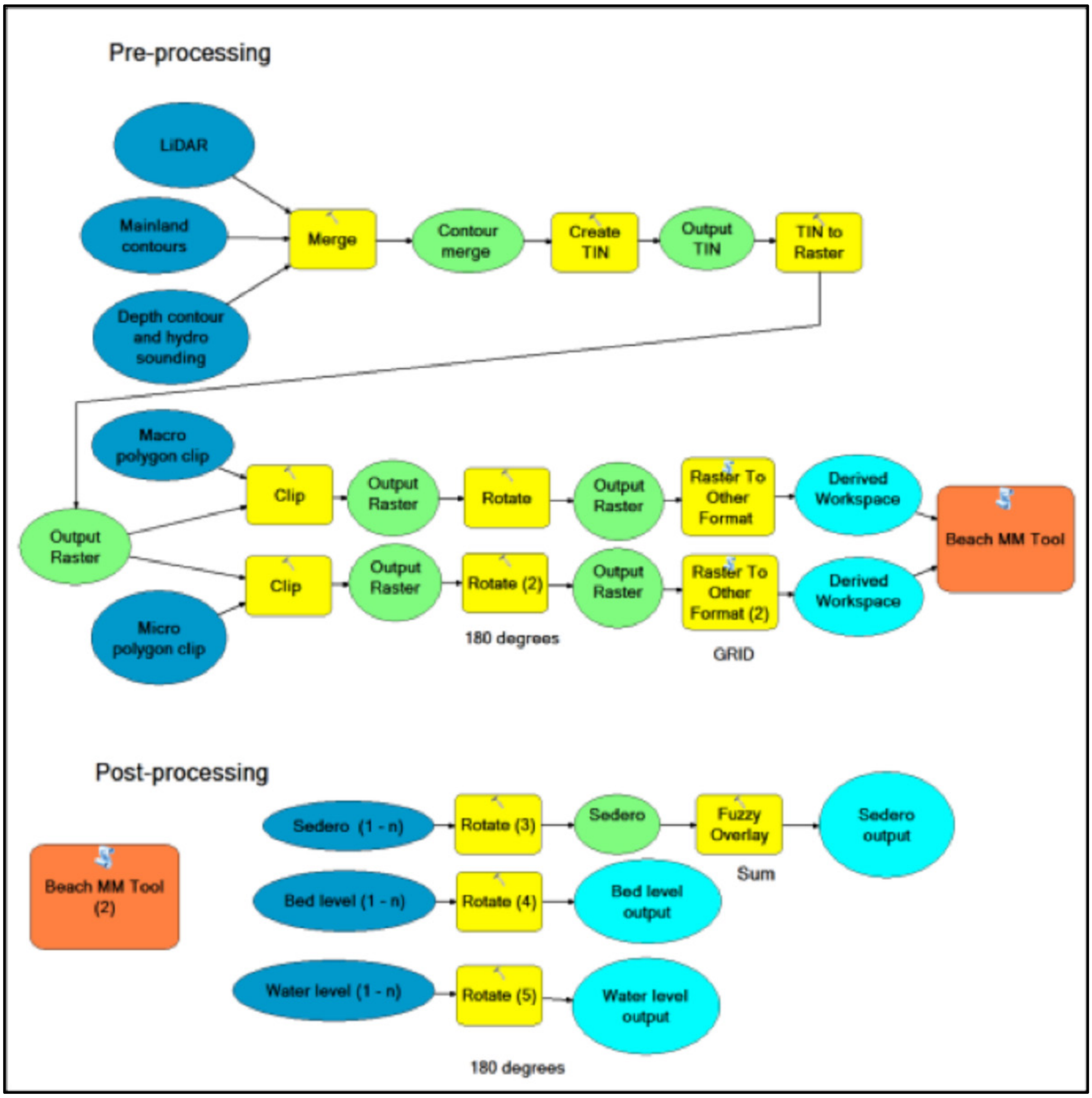

Figure 2: Flow diagram of the ArcGIS tools used for analysis.

ArcGIS platform, streamlining the process for modelling beach morphodynamics (Silva & Taborda, 2012). The application of this tool simplifies dataflow, permits tight coupling, minimises human error, and allows for enhanced visualisation of results (Silva & Taborda, 2012). SWAN provides a very stable environment on which to gather the hydrodynamic forcing information as it has been in development for many years and is therefore well refined. Conversely, XBeach has been developed recently, with little support for those choosing to operate over a GIS platform.

The methods used follow those of Silva and Taborda (2013) to link numerical models with the GIS environment. The models were run utilising local parameters for the present to validate the model output, and again for an estimated sea level projection 100 years from now as directed by the NZCPS 2010 and the minimum and maximum IPCC 2013 projections. To give an overall view, the 100 year minimum and maximum values of 0.26 m and 0.98 m were modelled (IPCC, 2013), as these were the most current predictions at the time of this investigation.

Mean conditions and conditions during storm events were simulated within each scenario. The study area was divided into two grid extents, one focusing on East Christchurch, and the other on the Waimakariri River mouth. The Waimakariri River extent was only examined under the maximum projection. The CERA red zone (CERA, 2014) ECan's coastal hazard boundary (ECan, 2011) and the FMA (CCC, 2012) were mapped alongside the results to consider which extent meets Policy 24 of the NZCPS2010. Data was provided by AAM PTY Ltd (AAM Pty Ltd, 2011), Land Information New Zealand (LINZ, 2013a, 2013b), NIWA (NIWA, 2013), ECan (ECan, 2014a, 2014b), and the IPCC (IPCC, 2013). Figure 2 shows a flow diagram of the procedure.

Simulation	Water level (m)	H sig (m)	T (s)	Sea θ (°)	Wind v (m s^{-1})	Wind θ (°)
Mean	0	1.95	8.8	194.2	5.11	75
Storm	1.96	7.49	13.3	140	9.2	230

Table 3: Parameters used in the simulations.

	Present mean (m)	Present storm (m)	100 year min (m)	100 year max (m)
MHWS	0	1.19	1.19	1.19
Storm surge	0	0.77	0.77	0.77
SLR	0	0	0.27	0.98
TOTAL	0	1.96	2.23	2.94

Table 4: Water level calculations given different scenarios.

3.2 Simulations

To attempt to simulate a realistic scenario, SWAN and XBeach were run for a 10-year period, followed by a 2-day storm and repeated with increasing water levels until 100 years had passed. This created two grouped simulations consisting of twenty cumulative iterations.

These were:

1. Future maximum scenario; with the SLR prediction of 0.98 m.

2. Future minimum scenario; with the SLR prediction of 0.27 m.

The parameters used were: significant wave height (H sig); wave period (T); wave direction (Sea θ); wind velocity (Wind v); and wind direction (Wind θ). Storm conditions were created from peak values of a storm on the 28th of June 2012. This storm is considered an extreme event as H sig falls within the top 1 % of all significant wave heights (Komar et al., 2013). Table 3 outlines the various parameter settings used in the simulations. Water levels have been calculated according to table 4. A storm surge of 0.77 m was calculated by subtracting the predicted tide level provided by LINZ (2013a) from the observed tide level recorded by the offshore wave buoy at the time of the storm. The output variables were net sedimentation or erosion (sedero), bed level and water level.

3.3 Calibration, assumptions and related limitations

Calibration was undertaken through running the model for a short period, then comparing results with field observations. The SWAN graphic user interface was utilised to test the hydrodynamic forcing, bathymetric grid and changing water level. Wave height, wave period, wind direction, and wind velocity were then compared with those forecasted by Meteo365 (2013) and observations from the foreshore and the surf zone.

The modelled scenarios operate as a closed system for sediment flux. River sediment discharge was not included into the models due to a lack of data. Mean measurements were used for climate and hydrodynamic parameters to reduce the workload.

Limitations of the SWAN model were:

1. SWAN does not compute wave-induced currents (Booij, 2012);
2. Unexpected interpolation patterns on the computational grid may arise from the differing resolution of the input grid (Booij, 2012);
3. SWAN can have convergence problems due to the iteration process (Booij, 2012).

Limitations of the XBeach model were:

1. XBeach does not perform well in very shallow water (Roelvink, Reniers, Van Dongeren, De Vries, Lescinski & McCall, 2010);

2. The computational x-axis must be orientated toward the coast and rectilinear (Roelvink et al., 2010).

4. MODELLING OUTCOMES

4.1 Sedimentation and Erosion

The net result of all simulations for sedero over the period for both the minimum and maximum scenarios illustrates a slight progradation of the foreshore with

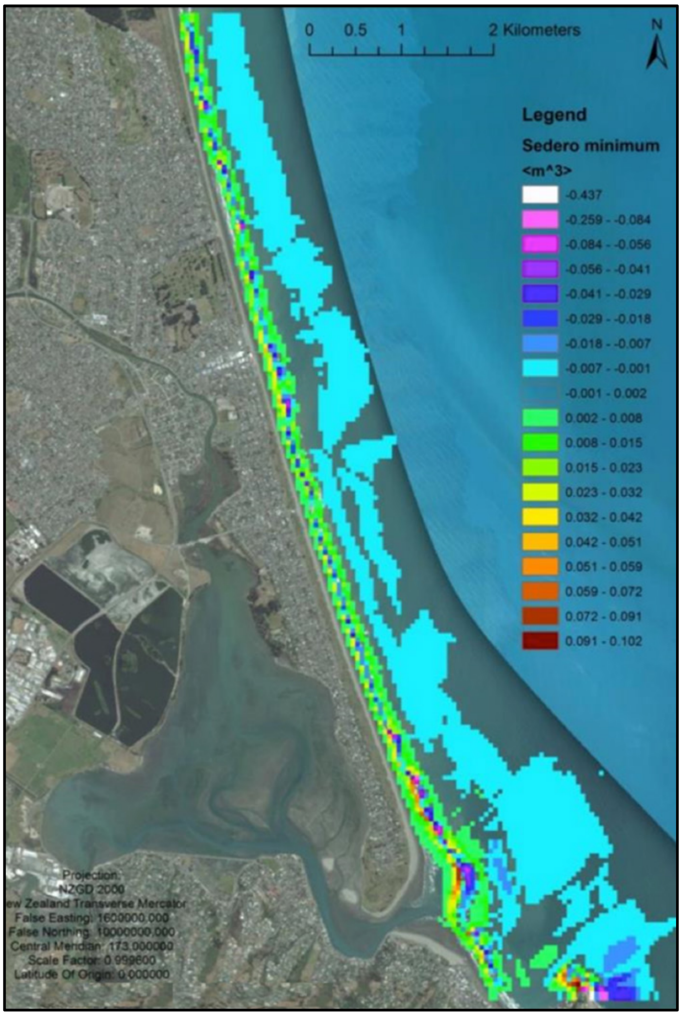

Figure 3: Minimum predicted net sedimentation and erosion for East Christchurch over 100 years. Complex changes in sediment occur at the Avon-Heathcote ebb tidal delta and Scarborough Head.

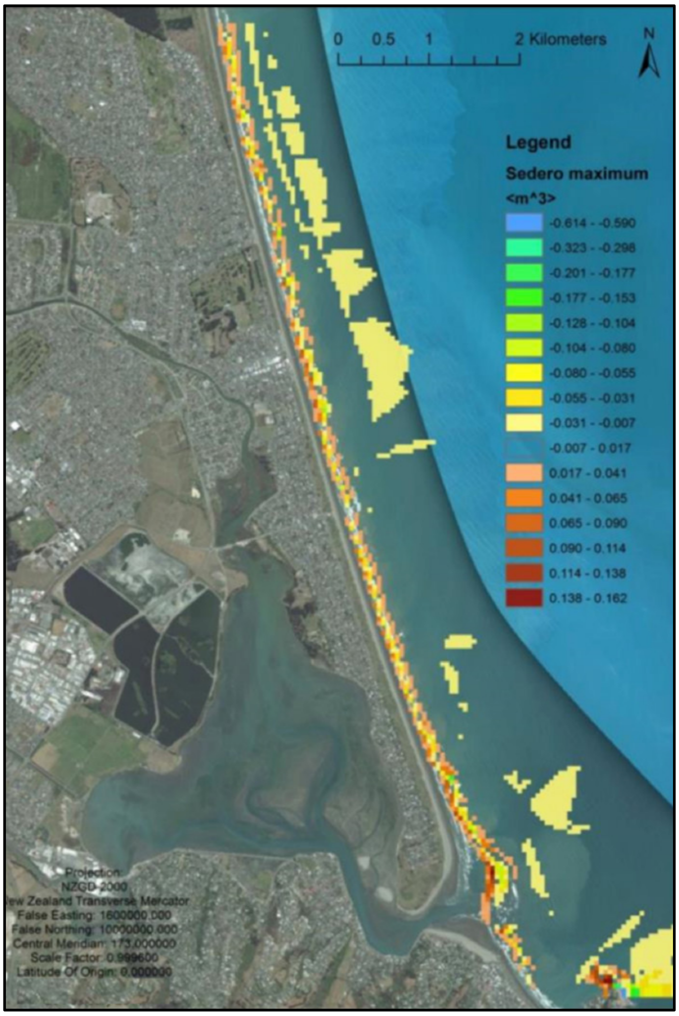

Figure 4: Maximum predicted net sedimentation and erosion for East Christchurch over 100 years. Complex changes in sediment occur at the Avon-Heathcote ebb tidal delta and Scarborough Head.

the majority of the sediment being received from the nearshore. The most dynamic areas were the Avon-Heathcote Estuary ebb tidal delta, the Waimakariri River mouth, and Scarborough Heads.

These results suggest that the future foreshore of East Christchurch may prograde over the 100 year period by 0.008 to 0.041 m^3 per m^2. Conversely, the nearshore seabed will erode by 0.004 m^3 to 0.031 m^3 per m^2 over this closed system under the maximum scenario. Under the minimum scenario, a similar effect will occur to a smaller magnitude. Similarly, the Waimakariri coastal zone foreshore will prograde over the period by 0.095 to 0.158 m^3 per m^2 where the nearshore will be slightly lower by 0.095 to 0.032 m^3 per m^2. The Avon-Heathcote ebb tidal delta appears to aggrade on its inner extent and erode on its outer extent due to wave domination across its surface. At Scarborough Head erosion will occur in areas of high wave climate exposure on the eastern flank and accumulate in the nearby north facing flank. There are complex interactions at the Waimakariri River delta with very high rates of accretion and erosion within a small area due to fluvial discharge. Accretion occurs on the inner extent and a channel is carved on the northern extent of the delta. These results can be seen in figures 3, 4 and 5.

4.2 Future water level

The future minimum and maximum water levels under storm conditions will lead to inundation of coastal areas of Greater Christchurch. The areas affected will be around the fringes of the Avon-Heathcote Estuary, Brooklands and Kairiki due to their low topography. Sumner, the lower reaches of the Avon and Heathcote rivers, and farmland adjacent to the Brooklands lagoon will also be inundated to varying extents.

The level of inundation for both the minimum of 2.23 m above MSL and maximum of 2.94 m above MSL are shown in figure 6 under storm conditions. This extent is similar to that of the CCC's FMA.

The future minimum and maximum under mean conditions or MSL are shown in figure 7. This extent is

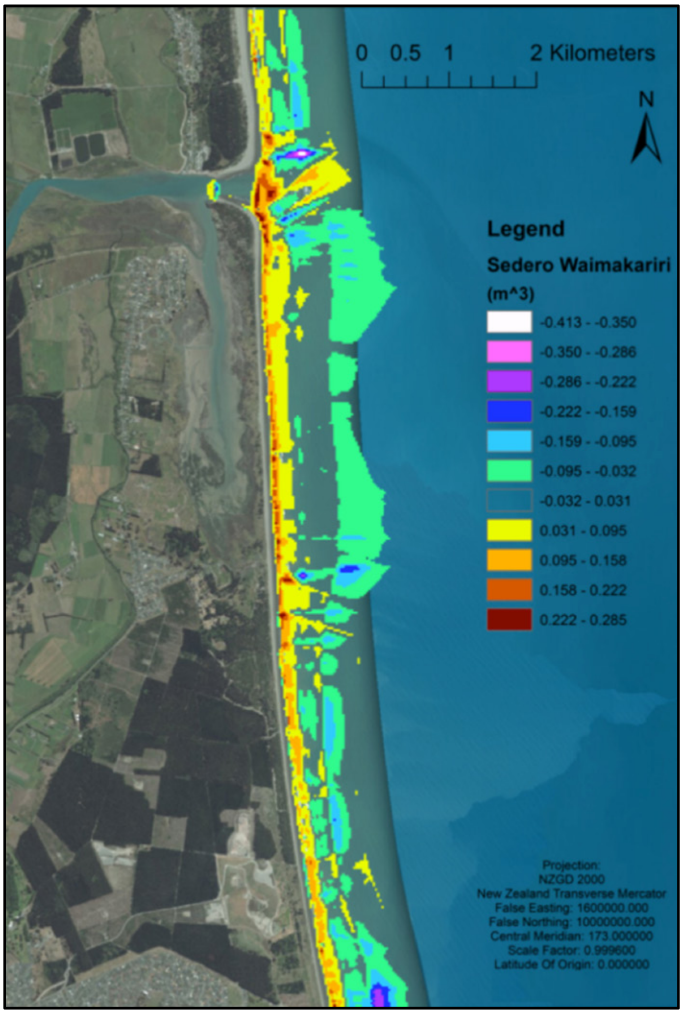

Figure 5: Maximum predicted net sedimentation and erosion for the Waimakariri coastal zone over 100 years. Complex changes in sediment occur at the river mouth with sediment plumes in the nearshore eroded and deposited on the beach face.

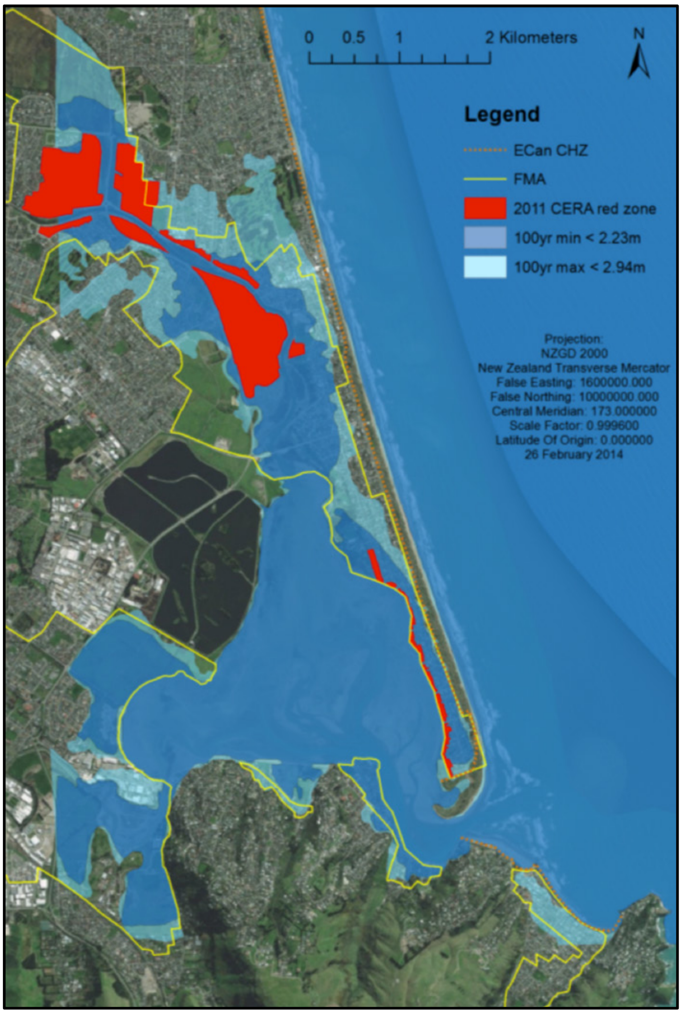

Figure 6: Inundation scenarios modelled under storm conditions for East Christchurch given a sea level rise for 100 years of 0.23 m (min) and 0.98 m (max), a storm surge of 0.77 m, during a MHWS of 1.19 m. Inundation propagates inland beyond the study area.

similar to that of the current MHWS of 2015.

The flooded extent for the Waimakariri coastal environment under the maximum scenario with storm conditions is shown in figure 8. This extent is larger than that of the CCC's FMA.

5. DISCUSSION

The aim of this research was to determine if the current CERA zoning for Greater Christchurch meets the obligations outlined in the NZCPS 2010 for future SLR. The modelling outcomes suggest that it does not. This is because coastal hazard risk has not been comprehensively quantified and the residential red zone requires expansion. However, the CCC's FMA provides an extent to which managed retreat away from this area would reduce the risk of hydraulic inundation of property. Currently, development can still be undertaken on areas that are at risk from predicted levels of inundation. The present MHWS level will frequently be exceeded in the future, particularly in areas with a low tidal range such as those occurring through the central parts of the east coast, leading to storm inundation having a greater influence and driving enhanced coastal erosion (MfE, 2008). Under the RMA 1991, local government is required to effectively identify, account, avoid and mitigate any coastal hazards, vulnerabilities, or consequences over at least a 100 year period to preserve coastal environments from inappropriate development while enhancing public access. Simulating coastal change at timescales relevant to planning and development requires new types of modelling approaches over large temporal and spatial scales. These approaches should incorporate high quality datasets to enable the refinement, calibration and validation of such models (MfE, 2008).

5.1 The future shoreline of Greater Christchurch

The extent of the Greater Christchurch shoreline

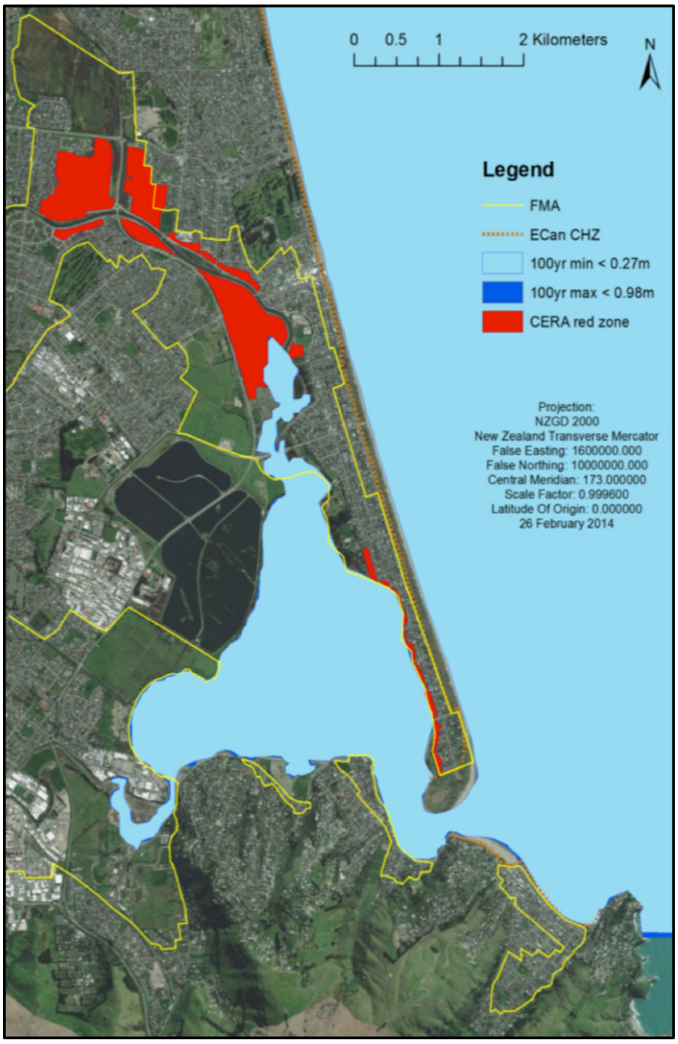

Figure 7: Inundation scenarios modelled under mean conditions for East Christchurch given a sea level rise for 100 years of 0.23 m (min) 0.98 m (max). Inundation is minimal under mean conditions.

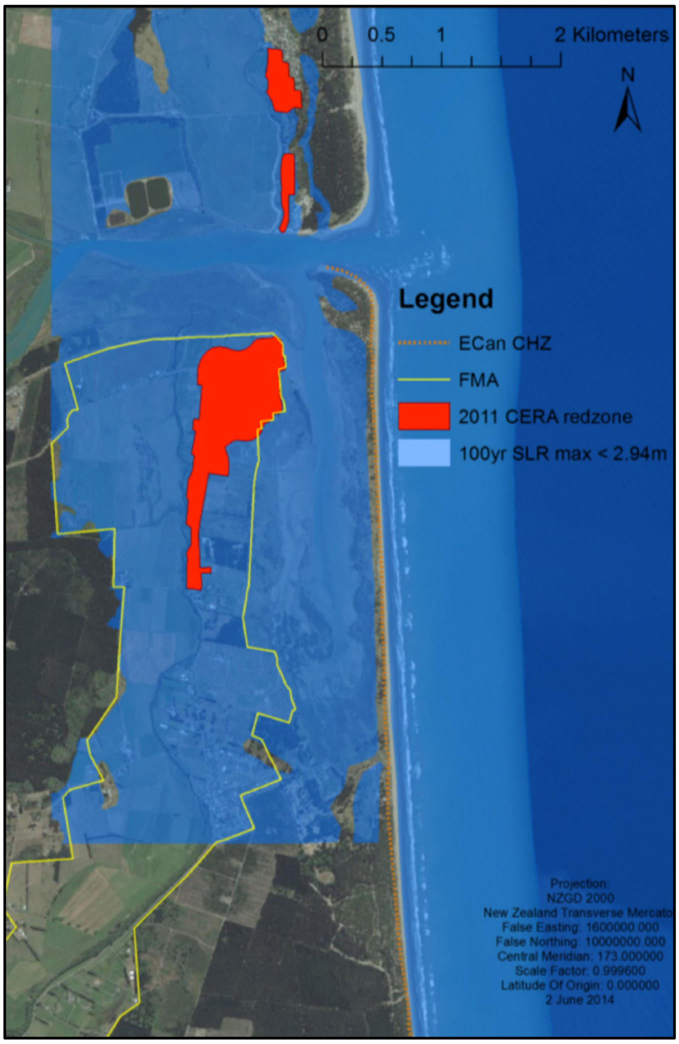

Figure 8: Inundation scenarios for the Waimakariri coastal environment under storm conditions given a sea level rise for 100 years of 0.98 m (max), a storm surge of 0.77 m, during a MHWS of 1.19 m. Inundation propagates inland beyond the study area.

in 100 years will be similar to that exhibited by the maximum inundation scenarios visible in figures 6 and 8 because they quantify storm surge during a MHWS tide. This extent provides a precautionary approach in the absence of scientific certainty. The results indicate that the sandy coastline will continue to prograde under the closed sediment flux, with enhanced progradation likely to occur given continued sediment supply from the Waimakariri River. As Pegasus Bay is marine dominated, where sediment can be dispersed but not removed from the nearshore, what is not lost to deep water during storms will incrementally nourish terrestrial dunes during modal conditions (Schulmeister & Kirk, 1997). Thus, the New Brighton and Southshore dune system will prograde seaward. The accumulation of sediment on the inner fan of the ebb tidal delta of the Avon-Heathcote Estuary may intermittently reduce channel width and depth significantly constricting river and tidal flow. Therefore close sedimentation monitoring of the Avon-Heathcote Estuary will help determine spatial outcomes.

Tonkin and Taylor Ltd's (2013) predictions of Greater Christchurch coastal dune recession with SLR relies on an overly simplified methodology inherent when using the Bruun Rule. The two-dimensional Bruun Rule is considered to be obsolete in predicting the contemporary geomorphology of foredunes in response to SLR (Hilton, 2013). This is because it assumes unconsolidated sediment, no sediment inputs, and no net alongshore flux (Hilton, 2013).

5.2 Zoning for storm anomalies

The current CERA red zone is ineffective at dealing with a flood inundation hazard enhanced by 100 years of SLR. This is because the extent of the area of inundation will be larger than that currently designated. Coastal processes will maintain an adequate buffer against storm surge along the dune system, although storm surge with a MHWS tide will not prevent inundation of low lying areas adjacent to the Avon-Heathcote Estuary and the

Brooklands Lagoon. This paper identifies the minimum inundation hazard zone as the 100 year maximum of 2.94 m above the 2014 MSL outlined in figures 6 and 8, or the setback limit for occupation. Similarly, the FMA provides an acceptable extent to inhibit development. However, given the high risk associated with future inundation, consideration should be given to red-zoning parts of the FMA immediately.

Given the future Waimakariri coast, storm surge will result in extensive flooding of Brooklands, Kairiki and the surrounding low lying area which is predominantly agricultural. The amount of flooding modelled is a modest estimation, as during a period of storm surge precipitation is likely, which would elevate the river discharge and increase the water level in the lagoon at high tide. The CERA red zone at Brooklands was appropriate, although should be extended further landward. An expansion of the Kairiki red zone is advised.

The maximum inundation scenario is not as great as that modelled by Tonkin and Taylor Ltd (2013) as the modelling extent was smaller and coastal processes were accommodated which limited dune overtopping and coastal erosion. The MfE (2008) report claims that the passive inundation approach tends to overestimate the inundation. However, Tonkin and Taylor Ltd (2013) were more accurate in dealing with sections of the coastal environment that were backed by revetments due to grid resolution. Tonkin and Taylor Ltd (2013) employed a similar SLR to this study, although prudently allowed a free board of 0.4 m to accommodate localised wave effects and other uncertainties.

With the advent of accurate predictive computer modelling and the general acceptance of climate change, the use of historical annual exceedance probabilities and return periods becomes increasingly redundant. The use of these static measures prescribed from recent human history for the classification of episodic hazard events becomes very difficult with climate change. The integration of GIS, satellite imagery, sensor technology and numerical modelling provides for a more objective scientific expression.

5.3 Risk mitigation

Coastal hazard zoning is often met with public contestation, as much time and money is invested into the built environment. Predictive geomorphological analysis must therefore be robust to define these zones. In order to mitigate risk, retreat maybe a safe long term option. Compensation payments from government may be an option for those directly affected by land use zoning changes. CERA performed this during the instalment of the residential red zone by offering compensation to those directly affected for their built assets at 2007 valuations. Acceptance of the relocation compensation was voluntary, as the Canterbury Earthquake Authority Act 2011 had no statutory requirement for the compulsory acquisition of land (CERA, 2011). Alternatively, coastal hazard zones could be treated as a physical delineation where local and regional authorities cannot issue future resource consents and occupation becomes a prohibited activity under the RMA 1991. It may be wise for existing residents within a coastal hazard zone to be offered market compensation by government to retreat and failing to accept the authorities' offer would remove all future liability from the authority.

6. CONCLUSION

The statutory requirements outlined in the NZCPS 2010 were assessed against current land re-zoning in greater Christchurch to determine whether the effects of sea level rise were appropriately quantified. This analysis suggests that it does not comply with Policy 24, as coastal hazard risk and coastal processes were not comprehensively quantified by CERA when creating the residential red zone. Silva and Taborda's (2012) BeachMM tool predicted a water level and coastal morphodynamics that aligned more accurately with the Christchurch City Council's Flood Management Area, an extent to which managed retreat is a prudent option to reduce hydraulic inundation risk. At present inundation during periods of storm surge poses a risk to human habitation on low lying areas around the Avon-Heathcote Estuary and Brooklands Lagoon. The results of this research suggest that progradation will continue to occur along the Greater Christchurch exposed foreshore. The BeachMM tool facilitates predictive spatial and temporal analysis effectively and the efficiency of that performance is only limited by computational capacity.

7. REFERENCES

AAM Pty Ltd. (2011). Christchurch LiDAR Survey May 2011 (Vol. A18797A01NOB). Brisbane.

Allen, R., Oertel, G., and Gares, P. (2012). Mapping coastal morphodynamics with geospatial techniques, Cape Henry, Virginia, USA. Geomorphology, 137(1), 138-149.

Backstrom, J., Jackson, D., and Cooper, A. (2009). Contemporary morphodynamics of a high-energy headland-embayment shoreface. Continental Shelf Research, 29(11–12), 1361-1372.

Booij, N. (2012). SWAN: Scientific and technical documentation. In The SWAN Team (Ed.). The Netherlands: Delft University of Technology.

Brown, A. F. (1976). Beach and nearshore dynamics, Pegasus Bay. Unpublished MA thesis, University of Canterbury, Christchurch, New Zealand.

Brown, L., and Weeber, J. (1992). Geology of the Christchurch urban area. Lower Hutt, New Zealand: Institute of Geological and Nuclear Sciences Ltd.

Bruun, P. (1962). Sea level rise as a cause of shore erosion. Journal of Waterways and Harbors Division, ASCE, 88, 117–130.

CCC. (2012). Planning maps: Flood management areas. Retrieved 28 February 2014, from http://resources.ccc.govt.nz/files/OperativeVariation48PlanningMaps.pdf

CERA. (2011). Canterbury Earthquake Recovery Authority draft recovery strategy for Greater Christchurch Retreived 1 July 2013, from http://cera.govt.nz.

CERA. (2014). CERA Basemap. Retrieved 10 April 2014, from http://maps.cera.govt.nz/html5/?viewer=public

ECan. (2011). Regional Coastal Plan. Retrieved 27 September 2015, from http://ecan.govt.nz/publications/Pages/regional-coastal-environment-plan.aspx

ECan. (2014a). About the wave buoy and how it works. Retrieved 5 February 2014, from http://ecan.govt.nz/services/online-services/monitoring/coastal-monitoring/wave-buoy/Pages/about-wave-buoy.aspx

ECan. (2014b). River flow data northern region. Retrieved 15 May 2014, from http://ecan.govt.nz/services/online-services/monitoring/river-flows/Pages/river-flow-chart.aspx?SiteNo=65101

EShorance. (2010). Estuarine shoreline response to sea level rise: Report prepared for Lake Macquarie City Council.

Hannah, J. (2004). An updated analysis of long-term sea level change in New Zealand. Geophysical Research Letters, 31(3), L03307.

Hart, D., Marsden, I., and Francis, M. (2008). Coastal systems. In M. Winterbourn (Ed.), The Natural History of Canterbury (Vol. 3, pp. 653-684). Canterbury University Press.

Hilton, M. (2013). How will foredunes respond to climate change? Some findings from southern New Zealand. Paper presented at the New Zealand Coastal Society Annual Conference, Hokitika, New Zealand.

IPCC. (2013). Climate change 2013: The physical science basis: Summary for policymakers. In Twelfth session of Working Group 1 (Ed.), (Vol. 5).

Komar, P., Allen, J., Ruggerio, P., and Harris. (2013). Earth's changing climate and coastal hazards: The U.S. Pacific North West and Hawke's Bay, New Zealand. Paper presented at the New Zeland Coastal Society Annual Conference, Hokitika, New Zealand.

LINZ. (2013a). Data Service. Retrieved 30 October 2013, from http://data.linz.govt.nz/

LINZ. (2013b). Sea level data. Retrieved 14 November 2013, from http://apps.linz.govt.nz/ftp/sea_level_data/SUMT/

McFadgen, B. G. (1985). Late Holocene stratigraphy of coastal deposits between Auckland and Dunedin, New Zealand. Journal of the Royal Society of New Zealand, 15(1), 27-65. doi: 10.1080/03036758.1985.10421742

Meteo365. (2013). New Brighton Beach surf forecast and surf reports. Retrieved 10 December 2013, from http://www.surf-forecast.com/breaks/New-Brighton-Beach

Ministry for the Environment. (2008). Coastal hazards and climate change: A guidance manual for local government in New Zealand. In D. Ramsay, and Bell, R. (Ed.), (2 ed., pp. viii+127).

The Resource Management Act (1991).

New Zealand Government. (2010). New Zealand Coastal Policy Statement 2010. Wellington: Department of Conservation.

Nichol, S. L., Lian, O. B., Horrocks, M., and Goff, J. R. (2007). Holocene record of gradual, catastrophic, and human-influenced sedimentation from a backbarrier wetland, northern New Zealand. Journal of Coastal Research, 23(3), 605-617. doi: 10.2307/4494232

Nicholls, R. J., and Lowe, J. A. (2004). Benefits of mitigation of climate change for coastal areas. Global Environmental Change, 14(3), 229-244. doi: http://dx.doi.org/10.1016/j.gloenvcha.2004.04.005

NIWA. (2013). The National Climate Database. Retrieved 13 November 2013, from http://cliflo.niwa.co.nz/pls/niwp/wgenf.genform1

Pahnke, K., and Sachs, J. P. (2006). Sea surface temperatures of southern midlatitudes 0–160 kyr B.P. Paleoceanography, 21(2), PA2003. doi: 10.1029/2005pa001191

Reisinger, A. (2009). Putting it together, climate change as a risk management problem. Climate Change 101 An Educational Resource Science – Impacts – Adaptation – Mitigation – Decision-making. (pp. 227-252). Wellington: Institute of Policy Studies and New Zealand Climate Change Research Institute.

Roelvink, D., Reniers, A., Van Dongeren, A., De Vries, T., Lescinski, J., and McCall, R. (2010). XBeach Model description and Manual (Vol. 6): UNESCO-IHE Institute for Water Education, Deltares and Delft University of Technology.

Schulmeister, J., and Kirk, R. (1997). Holocene fluvial-coastal interactions on a mixed sand and sand and gravel beach system, North Canterbury, New Zealand. Catena, 30(4), 337-355.

Silva, A., and Taborda, R. (2012). Beach Morpho-Modelling Tool V1.1: Installation instructions and user guide: Geology Department, Science Faculty of Lisbon University.

Silva, A., and Taborda, R. (2013). Integration of beach hydrodynamic and morphodynamic modelling in a GIS environment. Journal of Coastal Conservation, 17(2), 201-210. doi: 10.1007/s11852-012-0212-5

Stephens, S., Bell, R., Ramsay, D., and Goodhue, N. (2013). The "red-alert" tide calendar; enhanced. Paper presented at the New Zealand Coastal Society Annual Conference, Hokitika, New Zealand.

Stephenson, W., and Shulmeister, J. (1999). A Holocene progradation record from Okains Bay, Banks Peninsula, Canterbury, New Zealand. New Zealand Journal of Geology and Geophysics, 42(1), 11-19.

Storms, J. E. A., and Salomon, B. K. (2007). The impact of rapid sea level changes on recent Azerbaijan beach ridges. Journal of Coastal Research, 23(2), 521-527. doi: 10.2307/4494220

Tonkin and Taylor Ltd. (2013). Effects of sea level rise for Christchurch City: Report prepared for Christchurch City Council.

White, S. A., and Wang, Y. (2003). Utilizing DEMs derived from LIDAR data to analyze morphologic change in the North Carolina coastline. Remote Sensing of Environment, 85(1), 39-47.