Peer Review of Coastal Hazard Assessment Report

25 July 2016

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Executive Summary

[1] This summary reports initial findings from the peer review panel ('the panel') assessment of the Tonkin & Taylor Ltd (Tonkin & Taylor, 2015) report: *Coastal Hazard Assessment – Stage Two* ('the Report').

[2] We used an iterative process throughout to identify the positive and less positive aspects of the Report. The panel considers the Report is suitable for purpose after selected modifications for the open coast CEHZ, the harbour CEHZ and the Avon-Heathcote and Brooklands Lagoon CIHZ.

[3] The Report gives close attention to the documents that are directly relevant to an exercise of this technical kind, namely MfE (2008b)[1] (shortly to be updated), NZCPS (2010)[2], and Ramsay et al (2012)[3] as well as the IPCC AR5 WGI report in 2013 and WGII report in 2014, especially Reisinger et al (2014) Chapter 25 Australasia (that includes New Zealand)[4] and Church et al (2013) Chapter 13 Sea Level Rise[5].

[4] Tonkin & Taylor consulted with CCC on the use of RCP8.5. We note that the RCP8.5 is referred to as a 'business as usual' scenario in both Ramsay et al (2012) and MfE (2008b) and also that it represents the effects of a very high emission scenario based on exclusion of future additional efforts to constrain emissions and very high population growth, and is commonly used in hazard assessments.

[5] We also note that the IPCC RCP8.5 sea level rise projections for 2065 do not vary greatly (0.27 to 0.47 m). There is greater variability in the 2115 projections (0.62 to 1.27 m). Future changes

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[1] Ministry for the Environment (MfE). (2008b) *Coastal hazards and climate change. A guidance manual for local government in New Zealand*. 2nd Edition. Revised by Ramsay, D and Bell, R (NIWA). Prepared for Ministry for the Environment.

[2]New Zealand Coastal Policy Statement (NZCPS). (2010)

[3] Ramsay, DL, Gibberd, B, Dahm, J, Bell, RG (2012) Defining coastal hazard zones and setback lines. A guide to good practice. National Institute of Water & Atmospheric Research Ltd, Hamilton, New Zealand.

[4] Reisinger, A, Kitching, RL, Chiew, F, Hughes, L, Newton, PCD, Schuster, SS, Tait, A, and Whetton, P (2014) Australasia. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* In: Barros, VR, Field, CB, Dokken, DJ, Mastrandrea, MD, Mach, KJ, Bilir, TE, Chatterjee, M, Ebi, KL, Estrada, YO, Genova, RC, Girma, B, Kissel, ES, Levy, AN, MacCracken, S, Mastrandrea, PR, and White, LL (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA: 1371-1438.

[5] Church, JA, Clark, PU, Cazenave, A, Gregory, JM, Jevrejeva, S, Levermann, A, Merrifield, MA, Milne, GA, Nerem, RS, Nunn, PD, Payne, AJ, Pfeffer, WT, Stammer, D, and Unnikrishnan, AS (2013): Sea Level Change. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, In: Stocker, TF, Qin, D, Plattner, G-K, Tignor, M, Allen, SK, Boschung, J, Nauels, Y. Xia, Y, Bex, V, and Midgley, PM (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA: 1137-1216.

in sea level rise projections for 2115 may be incorporated into an at least 10 year review process of the Coastal Hazard Assessment.

[6] In assessing the Coastal Inundation Hazard Zone (CIHZ) for the Open Coast (New Brighton, Sumner, Taylors Mistake), overall we conclude that the approach used is acceptable. This is a simple 'building block' approach, incorporating the components of storm tide, wave set-up and sea level rise.

[7] Regarding the open coast Coastal Erosion Hazard Zones (CEHZ) (that is, from Waimairi beach to Southshore), the panel applauds that a probabilistic approach was undertaken, but concludes that the analysis needs to be adjusted to address some shortcomings in the component distributions, as detailed in this review report.

[8] For the Open Coast CEHZ probabilistic analysis, the sea level rise figures adopted, based on CCC consultation, were the 'likely' P66% values for 2065 and the 'potential' P5% values for 2115 resulting from adopting the RCP8.5 scenario.

[9] Shoreline erosion at the dune toe was investigated based on the four contributing components of short term dynamics, dune stability, long term trends (including sediment budget considerations) and future sea level rise shoreline adjustment.

[10] The Report considered Waimakariri sediment supply to the open coast beaches. In the first reassessment it would be of value to examine the outcomes for the open coast CEHZ for a wider range of Waimakariri sediment budget scenarios. This can readily be done with the probabilistic modelling approach.

[11] In assessing the CIHZ for harbour environments, we conclude that overall the approach used is acceptable for Lyttelton and Akaroa Harbours, with a simple 'building block' approach, with bathtub inundation incorporating the components of storm tide, wave setup, wind setup and sea level rise. The Lyttelton and Akaroa Harbour CIHZ calculations use the maximum fetch across the embayment to estimate the wave and wind set up and the 1% AEP (Annual Exceedance Probability) storm tide values for the 2115 calculations and 2% AEP storm tide values for the 2065 calculations. This is a conservative approach.

[12] For the Avon-Heathcote Estuary and Brooklands Lagoon CIHZ, TUFLOW hydrodynamic modelling is used instead of the simpler building block bathtub approach applied in the Lyttelton and Akaroa harbour sites. Questions remain for the panel around the accuracy, assumptions and value of this different approach.

[13] The indicated coastal erosion hazard zone CEHZ for all harbour sites, including the Avon-Heathcote Estuary and Brooklands Lagoon, are misleading – in many locations they are not indicative of likely erosion hazard. It is recommended that they be re-assessed with more attention

to detail and on-ground inspections. The 'high tide translation' method values must be discarded and only the 'equilibrium profile' values considered. It is noted that the extent of the indicated CEHZ erosion hazard are contained within the wider extent of the CIHZ coastal inundation hazard zones discussed above.

[14] The Report met with what might be considered truncated time frames for a technical exercise encompassing coastal erosion and inundation over many open coast and harbour sites.

[15] The Report did not consult the community, nor was consultation within its Terms of Reference. Community consultation is not a requirement in Table I of the Ramsay et al (2012) good practice guide.

[16] The Report provided spatial data as requested by CCC on areas susceptible to coastal hazards over a time frame. It included the coastal settlements located on non-consolidated sand and sediment shorelines within CCC's jurisdictional boundaries and classified by their environment type. This was for the technical aspects of mapping.

[17] The Report includes coastal hazard mapping for both the 2065 and 2115 time frames as required to inform the areas above.

[18] The Report acknowledges the occurrence of ground elevation changes with the earthquakes and appropriately uses the 2011 LiDAR survey for baseline ground elevations.

[19] The Report does not assess earthquake-induced changes in groundwater depths and should not do so as this separate exercise is in the area of responsibility of EQC.

[20] There are a number of recommendations from the panel in respect of modelling and these are detailed in the body of this review report and summarised in the recommendations section.

[21] NZCPS Policy 24(1)(a)-(h) is the only NZCPS provision relevant to a technical mapping exercise at the first stage in identifying the coastal environment potentially affected by coastal hazard risk and the likely effects of climate change including sea level rise. It was not identified in the Tonkin & Taylor Terms of Reference for the Report, and should have been.

[22] The Report does not, and should not, stray into what is required under NZCPS Policies, 25 and 27, both of which relate to CCC's management functions in relation to coastal hazard risks once they have been established, including management of those relating to climate change.

[23] While the Report makes inappropriate reference to the NZCPS Policy 3 Precautionary approach, this is not relevant and should be withdrawn as it did not influence the selection of sea level rise values.

[24] NZCPS Objective 5 and other relevant policies – Policy 3 Precautionary approach, Policy 25 Subdivision, use and development in areas of coastal hazard risk, and Policy 27 Strategies for protecting significant existing development from coastal hazard risk, and its consequences, are all relevant to the second and third stages of providing mapping of such areas to a sufficient standard to be included in the CRDP – stages to be defined with the involvement of the community and all stakeholders.

[25] The Report's findings do not close off subsequent use of adaptive planning responses for CCC. The findings will be subject, when reassessed as a result of the panel's responses, to two subsequent stages of stakeholder and community consultation before conclusions can be reached. No conclusive mapping should take place until these consultation stages are complete.

[26] The Report was not required under the Terms of Reference to extend its technical findings in what is a first stage in the identification of areas of potential coastal hazard risk and sea level rise to all the issues alive in NZCPS Objective 5 and Policies 25 and 27. These form a basis for informing issues arising from these technical reports in the identification of coastal hazard areas: See Appendix B.

[27] An evaluation required under s 32 RMA is only undertaken after information provided by CCC and other experts in economics, statistics, planning, traffic etc are brought together to further inform the community, stakeholders and CCC officials on such matters as cost benefit and the other issues identified in Appendix B. This is to inform through a process of adaptive management the evaluation report under s 32 sometime in the future.

Background

[28] This review has been prepared in accordance with the Terms of Reference as prepared by GHD in the commissioning of the Peer Review Panel comprising: retired Environment Court Judge Shonagh Kenderdine (Wellington) (Chair); Associate Professor Ron Cox (UNSW Australia); Dr Willem de Lange (University of Waikato); Dr Deirdre Hart (University of Canterbury); and Dr Murray Smith (the panel).

[29] In June 2015 Tonkin & Taylor Ltd (Tonkin & Taylor) prepared the Report, *Coastal Hazard Assessment – Stage Two* (the Report), for the Christchurch City Council (CCC). The Report (Tonkin & Taylor 2015) was peer reviewed by Dr Terry Hume (Hu*me Consulting Ltd) in May 2015.* The Report provides information on those locations that ar*e considered susceptible to coas*tal hazards over both a 50 year and 100 year planning timeframe for Christchurch and Banks Peninsula, taking into account the potential impact for sea level rise (SLR). The Report was used to inform the development of policy and planning rules within the Proposed Christchurch Replacement District Plan.

[30] Whilst the purpose of the Report was to inform policy decisions for future land use within the Christchurch Replacement District Plan (CRDP), the Local Government Official Information and Meetings Act 2004 has required the report to be notified on Land Information Memoranda for those properties that fall within the areas identified at risk within the report.

[31] In December 2015, following feedback from members of the community on The Report and the recent Parliamentary Commissioner for the Environment's report on sea level rise, the Council passed the following resolution: '*Direct staff to seek a further peer review of the Coastal Hazards Assessment (Tonkin & Taylor, 2015). The peer review be conducted as soon as practicable by a panel of scientific (or other relevant) experts, the details of which will be determined after consultation with affected communities*'.

[32] GHD was commissioned by Christchurch City Council to independently manage this peer review in collaboration with the community potentially impacted. Questions on the Report have been received from the community by email, phone, letters and meetings throughout April 2016.

[33] A Community Reference Group was established to develop the questions and finalise the terms of reference with support from GHD. The group has also advised on the makeup of the Expert Peer Review Panel, selecting a long list of potential panel members for GHD to approach. The Community Reference Group was nominated by the community and consists of members from the different geographic locations identified within the report. This group worked together to develop the terms of reference that was tabled at the council meeting on May 26 2016 (GHD, 2016).

[34] The GHD 2016 Terms of Reference document (GHD, 2016) contains the Tonkin & Taylor (2015) report in Appendix A, the original terms of reference for this work (and the variation) in Appendix B, the terms of reference *f*or the review by Dr Terry Hume in Appendix C, the Peer Review by Dr Terry Hume in Appendix D, a legal reference document to guide the expert panel on the relevant national legislative and policy framework in Appendix E, a full list of questions and material submitted by the local community agreed to be within the scope of the terms of reference in Appendix F, a summary of questions raised by the community that were agreed to be outside the scope of the terms of reference in Appendix G, and a list of potential peer review members in Appendix H.

Scope of the peer review

[35] As outlined by GHD (2016) the purpose of the peer review is to provide the community and the Council with an impartial and expert view on the data, methods and assumptions used within the Report when responding to the brief set by the Council. In doing so, the peer review panel might want to review and critique the terms of reference provided by Council and the peer review brief and report by Hume Consulting Ltd. The panel is asked to review the following key questions:

- Does the report represent good science? The expert peer review panel is asked to assess the methodology and data used and critique any assumptions made.

- Are the findings still relevant in terms of new research?

- Has the report taken account of relevant statutory policy documents in providing technical or expert advice (refer to Appendix E GHD TOR as a guide)?

- Is the report and its findings appropriate for its intended purpose - to inform planning for future land use decisions (refer to Appendix E GHD TOR for full purpose statements)?

[36] The following review by the panel concentrate on the four key questions above. These sections are further supported by a recommendations section, bibliography and glossary. In preparing the responses to the four key questions the Panel noted and have addressed in principle the individual questions raised by members of the community.

Site

[37] The panel visited some of the sites of the proposed hazard zones on 17 June 2016. The day was clear and bright with a chilly easterly wind. Some of the visit to the southern coastline was to Brighton Beach itself and drive by to some other relevant areas around the estuary and the small communities.

[38] Most of the existing development, residential and commercial within the Christchurch dunes area is set back from the current dune toe by a distance of between 500 to 130 metres. The main CCC asset at risk from shoreline retreat due to sea level rise is the northern section of Marine Parade located between Shackelton Road and Beach Road. This section of Marine Parade is approximately 3.2 kilometres long and is located within 60 metres of the current dune toe. The additional existing CCC assets located seaward of this section of Marine Parade are the New Brighton Community Library (Te Kete Wānanga o Karoro) and the North New Brighton Memorial and Community Centre including the associated car parking areas. The dune crest elevation is also lower in these areas which will most likely result in a greater distance of shoreline retreat than adjacent areas.[6]

[39] The three open coast beaches of Clifton, Scarborough and Taylors Mistake are located south of the Avon Heathcote Estuary mouth. Clifton Beach is both a relatively flat estuary harbour and open coast beach which is approximately 900 metres long and has developed an incipient foredune at the eastern end. The western 400 metre long section of Clifton Beach is backed by a rock revetment protecting Main Road and has no high tide beach. The eastern 500 metres of Clifton

[6] Report Vol 1 'Effects of Sea Level Rise For Christchurch City', Site Description 4.3.1, p 43.

Beach is a sandy beach which includes a vegetated dune system. Scarborough is the main sandy beach at Sumner which is approximately 1.2 kilometres long and has no high tide beach or dune system. Scarborough Beach is backed by a rock revetment structure along the entire length. Taylors Mistake is a sandy beach with a dune system that is approximately 500 metres long.

Good science?

Assessment and critique of methodology and data used

[40] In responding, the panel makes the necessary comment that the hazard assessment as undertaken by Tonkin & Taylor (2015) in the Report covered many coastal sites with varying exposures, varying coastal processes and was undertaken in a very tight timeframe with limited budget. In these circumstances, to meet time and budget constraints, simplifying assumptions can be expected. In this case the limiting assumptions that, where made, are clearly stated. Tonkin & Taylor have adopted commonly accepted New Zealand methods as outlined in the Ramsay et al (2012) best practice guide for most of the assessment.

[41] All assumptions are clearly stated in the Report – they are in the main, conservative and lead to varying levels of hazard over-estimation for some sites. The over-estimation is small for 2065 as sea level rise in this timeframe is small. The over-estimation increases in time being reliant on the less certain sea level rise projections – making the hazard lines for 2115 less certain than those for 2065. This is not unusual and is commonly accepted worldwide with continuance of regular monitoring and periodic review/reassessment incorporated in best practice effective climate change adaptation practice. The Report recommends the baselines and both the CEHZ and CIHZ values to be reassessed at least every 10 years or following significant changes in either legislation or best practice and technical guidance.

Open Coast Science

Open Coast Beach Coastal Erosion Hazard Zone (CEHZ)

[42] This analysis is the most thoroughly undertaken in the Report using the recommended best practice probabilistic approach – in contrast to the simpler 'building block' approach used for other hazard zones in the Report, which is considered adequate (for example, in the Ramsay et al 2012 government guidance document). Shoreline erosion at the dune toe was investigated with Monte-Carlo simulations including the probabilities of 4 contributing components - short term/horizontal coastline fluctuations including short-term fluctuations (ST), dune stability (DS), long term change (LT) (in this case accretion) and sea level rise induced shoreline change (SL). The outcome is affected by the distributions assigned to each component.

[43] The estimation of ST values incorporated in the Monte-Carlo simulation are primarily based on the analysis of the dune toe position over time from ECan beach profile surveys. For each profile

the maximum negative residual, the maximum cumulative erosion and 3xSD (standard deviation) of the residuals of the dune toe position from the fitted linear trend are determined (Table 4.4). These are subsequently used in determining the centre and bounds of an erosion triangular distribution for ST. The focus is only on the erosion effects. Limited SBEACH modelling has been undertaken with the indicated maximum erosion of 10 m from two consecutive 1% AEP storms being adopted as the lower bound of a triangular ST distribution. The Report adopts a single triangular distribution (Table 4.7) for only erosion for all open coast beach cells A to F (noting that cell G is separately analysed using the inlet migration method). The upper bound for the adopted ST erosion distribution then surprisingly uses the maximum 3xSD of the beach profile residuals from profile C0300, which is within cell G. The adoption of 3xSD as an upper bound to the ST short term fluctuation erosion is not accepted practice internationally and is stated in the Report as being based on the experience of Tonkin & Taylor (2004 and 2006).

[44] The single short-term erosion distribution from 10 to 20 m with a centre value of 15 m (Table 4.7) is applied to all cells on the open coast, and incorrectly does not include any of the positive short term fluctuations of the dune toe around the linear regression trend indicated in the beach profile data. A more appropriate distribution of the short term fluctuations within a cell, should be based on all the residuals from all the profiles within the cell – the resulting central value will be zero with the bounds defined by a histogram plot of the residuals – the distribution is unlikely to be triangular and may be skewed. The impact of seawalls, carparks or major dune modifications on beach profile behaviour needs to be recognised and not included in the ST analysis. Separate ST distributions should be applied to each cell as has been applied for the LT long term components.

[45] It is recommended that the ST values be re-assessed as indicated above and the Monte-Carlo simulations be re-run for each cell with the CEHZ open coast mapping revised for planning purposes -the outcome may result in a reduction of the landward extent of the CEHZ. Better use of the ECan beach profile data for estimation of short-term storm erosion and longer term behaviour is recommended for inclusion in the first reassessment/review. It is recommended that the first review include a volume based approach as well as the shoreline excursion methodology used in the Report.

[46] The dune stability method is appropriate and follows accepted international practice.

[47] The longer term rates of coastline horizontal movement LT are based on analysis of 5 aerial photos from 1941 to 2011. The variation in shoreline movement rate was calculated at 10 m intervals along the open coast. The spatial variation is shown in Figure 4.7 and the adopted triangular distribution values for each cell given in Table 4.9. Whilst undertaking the recommended re-analysis for ST indicated above it is also recommended that the LT distributions be re-assessed (considering normal rather than triangular distributions). Incorporation of new photography, LIDAR and ongoing ECan beach profile data is recommended in the first reassessment/review.

[48] The SLR values adopted in Table 4.10 for 2065 and 2115 are based on the middle and 5-95% range of projections from process based models from IPCC AR5 in Figure 2.3 (this band of values is considered 'likely' by the IPCC panel of scientists). A minor error appears to have been made in listing a value of 1 m for 2115 in the Table when the Figure indicates 0.94 m.

[49] The Bruun rule is applied to estimate erosion due to SLR utilising appropriate estimates of the slope for central, upper and lower bounds based on different estimates of the closure depth. As stated by Ramsay et al (2012), the Bruun rule is applicable on open coast sandy beaches – this is consistent with common practice in the application of the probabilistic approach. Some researchers propose the use of a more sophisticated model for estimating response to SLR. However, such a more sophisticated modelling approach is reliant upon having extensive beach monitoring data with which to calibrate and verify the model to be used (viz Fitzgerald et al, 2008; Woodroffe et al, 2012; Shand et al, 2013; Mariani et al 2013).

[50] The Christchurch coast is currently supplied with the sand size sediment needed to nourish its beaches predominantly by local rivers. The most substantial river sediment input comes from the Waimakariri River, which discharges to the coast north of the city, with sediments carried south to nourish the New Brighton coastline via longshore drift.

[51] This longshore drift is driven by remotely- and locally-generated wind waves as well as an eddy of the current that typically flows northward along the east coast of the South Island of New Zealand, but which is reversed in the lee of Banks Peninsula due to sheltering and wave refraction processes (Reynolds-Fleming & Fleming, 2005[7]). The open coast beaches have historically been accreting with sediment supplied from the Waimakariri River – notionally 360,000 m^3 per year being supplied to the coast, of which around half is estimated by Hicks (1998[8]) to come south to the beaches considered in the Report (note that estimates vary between sources such as Hicks 1998; Duns 1995[9]; and Kirk 1979[10]).

[52] The Report relies on Hicks' (1998) research (cited by Tonkin & Taylor, 2015 as 'NIWA 1998') for information on the Pegasus Bay sediment budget. This is appropriate since the Hicks (1998) research represents the most recent quantitative assessment available, although comparisons with

[7] Reynolds-Fleming, JV, & Fleming, JG (2005). Coastal circulation within the Banks Peninsula region, New Zealand. NZJMFR 39(1): 217-225. DOI: 10.1080/00288330.2005.9517301

[8] Hicks, DM (1998) Sediment Budgets for the Canterbury Coast: A Review, with Particular Reference to the Importance of River Sediment. Canterbury Regional Council Report CRC80506, NIWA, Christchurch.

[9] Duns, RA (1995) A sediment budget analysis of Pegasus Bay. Unpublished Master's Thesis (Geography), University of Canterbury, 156pp. Available from: http://www.ir.canterbury.ac.nz/bitstream/handle/10092/3938/Thesis_fulltext.pdf?sequence=1&isAllowed=y

[10] Kirk, RM (1979) Dynamics and management of sand beaches in Southern Pegasus Bay. Morris and Wilson Ltd.

earlier work on this topic by Duns (1995) and Kirk (1979) indicate a level of uncertainty in the Pegasus Bay sediment budget. This uncertainty grows when considering that wind and wave climates could undergo directional shifts with future climate changes.

[53] Sediment budget analysis is an area where an up-to-date report on the data gathered from the ECan beach profile monitoring network, including comparison of the beach profile data with the results produced by Hicks (1998) would be very helpful. We recommend that a Pegasus Bay coastal monitoring analysis report, including careful analysis of beach volume indices, is produced before the first reassessment/review of the coastal hazards assessment.

[54] The Report uses the short to medium term climate change predictions from NIWA to assess the future potential sediment supply to Pegasus Bay from the Waimakariri River. Based on these forecasts, the assumption that climate change effects on river sediment supply to the coast are likely to be minor over the short to medium term are reasonable when considering natural processes of catchment sediment delivery alone. This takes account of the nature of the Waimakariri as a large braided river, fed by headwaters in the Southern Alps.

[55] Previous research indicates precipitation over the Canterbury Plains is affected by large atmospheric circulation patterns, such as ENSO and IPO, which are expected to respond to projected climate change resulting in a change in the frequency, magnitude and seasonal distribution of rainfall, for example (Ummenhofer and England, 2007; Ummenhofer et al, 2009). NIWA also forecasts that the Canterbury Plains will likely experience less rainfall over the short to medium term[11]. The Canterbury plains represent a dryland and drought prone environment under current conditions and the plains agriculture is already heavily reliant on irrigation water, with the region's catchments having been under extreme water use pressures for over a decade (e.g. OECD 2007; Glubb et al, 2012[12]).

[56] Further to the water resource pressures on the Waimakariri, there are currently significant pressures on the river's sediment resources, with gravel and its associated sand 'bycatch' being extracted from the lower reaches of the river, near the State Highway bridge, in an area flanked by stopbanks to protect surrounding settlements from the hazard of Waimakariri River flooding. This sediment extraction pressure is likely to increase with future demand from the construction industry as well as with the desire to maintain the river channel depth and thus the design standard of the stopbanks.

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[11] See: https://www.niwa.co.nz/our-science/climate/information-and-resources/clivar/scenarios

[12] Glubb, R, Earl-Goulet, J and Ettema, M (2012) Canterbury Region water use report for the 2011/12 water year. Environment Canterbury Report No. R12/105, 90pp. Available from: http://ecan.govt.nz/publications/Reports/CanterburyWaterReport2011-12.pdf.OECD (2007) OECD Environmental Performance Reviews: New Zealand. OECD Publishing, 245pp.

[57] Given the range of future anthropogenic water resource management options under NIWA's regional climate change predictions, and alongside sediment resource and flood hazard considerations, significant future alterations to the Waimakariri River sediment supply to Pegasus Bay are possible. In this context, the sediment budget assumptions made in the Report could be described as optimistic. The Report assumes no change in longer term sediment supply from the Waimakariri River, and hence adopts the aerial photo analysis for historical long term (LT) accretion rates. However, with the probabilistic model established, the sensitivity of the CEHZ results to possible changes in sediment supply can be readily examined by changing the input LT accretion distribution in the modelling. We recommend that such probabilistic modelling is undertaken for the sediment budget component of the open coast CEHZ calculations in the first reassessment/review.

[58] Despite the specific issues raised above with associated recommendations for re-analysis, the new CEHZ for the open coast results in the additional inclusion of less than 100 properties beyond those previously considered susceptible to coastal erosion hazard in the Canterbury Regional Coastal Environment Plan's (2005) Coastal Hazard Zones. The CEHZ 2065 and 2115 zones are qualitatively consistent with cursory extrapolations of the ECan beach profile responses to storm events monitoring and panel experience for similar dissipative beach systems. It is noted that the mapping does not allow for the effects of seawalls. It is recommended that the location and condition status (poor/inadequate OR good/engineering design standard) be indicated in the CEHZ mapping.

Open coast beach Coastal Inundation Hazard Zone (CIHZ)

[59] A 'building block' approach as discussed in section 3.2.1 of the Ramsay et al (2012) best practice guide is carried out incorporating the components of storm tide (with its various components), wave setup and SLR.

[60] The storm tide values for 1% and 2% AEP were based on water level gauge analyses for Lyttelton and Sumner Head by Goring et al (2009, 2011). These two water level monitoring sites appropriately have record lengths (exceeding 20 years) to allow reasonable analysis for predicting 2% and 1% extreme water levels for 2065 and 2115 respectively – the prediction of the 1% 2115 extreme storm tide levels being less reliable than those for 2% 2065 value. Extreme water levels within the harbour embayments are complex with varying contributions at varying timescales including tides, storm surges, waves, winds, seasonal effects, El Niño Southern Oscillation/ Inter-decadal Pacific Oscillation, long period edge waves and resonance, (Goring & Henry, 1998; Borrero et al, 2013; Goring 2014, 2015; Borrero & Goring, 2015). It is recommended that an updated thorough analysis for extreme water levels of all water level monitoring stations in the Canterbury area be undertaken prior to the first reassessment/review. The surge components of the extreme 1% and 2% extreme storm tides are not expected to change significantly in the reassessment.

[61] The wave set-up estimated for New Brighton, Sumner, and Taylors Mistake was derived from deep-water wave height and period data AEP distributions and the beach slope, using the methodology in section II-4-3 of the Coastal Engineering Manual. The deep water wave climate 1% and 2% values given in Table 4.1 are noted as being from Tonkin & Taylor (1998). The values of wave setup given in Table 4.2 are a significant component of the total CIHZ. It is recommended that the deep water wave climate be updated (from Tonkin & Taylor, 1998) and wave setup with transformation across the surf zone be re-evaluated using both the CEM and alternative methodologies (for example, consider use of the Dally et al (1985) surf zone wave transformation model that is incorporated in SBEACH). It is recommended that this be undertaken, the effect on total CIHZ level assessed, and where necessary the CIHZ mapping amended.

[62] Although wave runup is discussed no calculations of likely levels and/or overwash with assessment of safety for people or vehicles and damage to property is presented – such analysis and considerations are common internationally, (and recommended by Ramsay et al, 2012) especially in areas where overwash is likely such as the pier and library area at New Brighton. This aspect is recommended for inclusion in the first reassessment/review.

[63] SLR values used in Table 4.2 are 0.4 m for 2065 and 1 m for 2115 – the stated basis being recommendations from Bell (2013) and Tonkin & Taylor (2013a) – the values are reasonable for inclusion of regional/local effects in consideration of the IPCC AR5 values shown in Figure 2.3.

[64] The simple ‘building block’ approach and outcomes are summarised in Table 4.2. The result assumes extreme storm tide is co-incident with the peak of the wave setup and as such is conservative (an over-estimate). It is recommended that prior to the first reassessment/review and in conjunction with the recommended update of extreme water levels from monitoring stations the likelihood of concurrence of extreme waves and coincidence of peak wave setup with extreme storm tide be investigated.

[65] The impact of the projected inundation was assessed in the Report by the derivation of CIHZ lines corresponding to the 2065 and 2115 inundation elevations. The CIHZ appropriately enclose areas that are connected to the open coast by a pathway that would allow the ingress of seawater as sea level rises.

[66] Overall, the various approaches used for determination of the CIHZ lines for the open coast have been consistent with the ‘building block’ approach of Ramsay et al (2012). They are likely to have over-predicted the extent of inundation for both 2065 and increasingly so for 2115.

Harbour Coast Science

Harbour Coast CEHZ

[67] The approach is different to that used for the open coast beaches – this is appropriate considering the different geomorphology, soils and wave exposure. Two different approaches are applied: the ‘equilibrium profile’ method and the ‘high tide translation’ method.

[68] In the ‘equilibrium profile’ method (based on the Bruun rule) a simple ‘building block’ approach is applied with the summation of the same 4 components considered for the open coast – ST, DS, LT and SL.

[69] DS and LT are taken as zero based on published research and local knowledge. ST is taken as -5 m for all sites – this appears an oversimplification as the sites have varying exposure to waves and varying soils. Better estimates of likely short term ST erosion in extreme storms can be made. For example, the Stevens and Giles (2010) paper cited in the Report gives a simple method based on wave climate and water depth/underwater slope. It is recommended that the DS, LT and ST values be reassessed in the first reassessment/review.

[70] The simple equation 8 is used to estimate shoreline adjustment with SLR – the slope to be used being determined from analysis of aerial photos or LIDAR between the HAT contour and the beach toe (noticeable break of slope). The adopted SLR values used in Tables 4.18 and 4.19 are the mean 50% RCP8.5 values from Table 4.10 adjusted for the historic rate of SLR.

[71] The ‘equilibrium shoreline’ erosion values given in Tables 4.18 and 4.19 are considered adequate indicators of likely erosion for the harbour coast sites, even though conservative. The high values for Teddington arise from the very flat slope adopted – it is recommended that this be re-assessed in the field and, if necessary, the CEHZ mapping amended.

[72] The second ‘high tide translation’ method results in CEHZ mapping for many harbour sites (including the Avon-Heathcote and Brooklands areas) is misleading and clearly of concern to the affected communities. The ‘high tide translation’ method results in CEHZ lines that look more like CIHZ lines. The analysis claims to be based on the eShoreance method of Stevens and Giles (2010), yet it does not follow Stevens and Giles (2010) exactly. Specifically, the Report uses HAT as the baseline, whereas eShoreance is based on changes from MSL, and the eShoreance method is not applicable if the future mean high water exceeds the estuary bank crest height.

[73] The mapping of the CEHZ for the harbour sites, including the Avon-Heathcote Estuary and Brooklands Lagoon, is taken as the upper envelope of erosion by either the ‘equilibrium profile’ or ‘high tide translation’ methods: the mapping and report do not indicate for the different shorelines which method controls the indicated CEHZ zones. The areas incorrectly mapped using the ‘high tide

translation' method can be generally discriminated by the considerable change in mapped hazard: for example, at the northern end of the Akaroa site in Figure Appendix D.12

[74] The mapped CEHZ lines for all harbour sites including the Avon-Heathcote Estuary and Brooklands Lagoon are misleading and should not be considered as indicative of likely erosion hazard. It is recommended that they be re-assessed with more attention to detail and on-ground inspections. The 'high tide translation' method values must be discarded and only the 'equilibrium profile' values considered. The zones should not extend up small inlets. It is noted that the extent of the indicated CEHZ erosion hazard are contained within the wider extent of the CIHZ coastal inundation hazard zones discussed below.

Harbour Coast CIHZ

[75] Two approaches were used for assessing the CIHZ for harbour coasts depending on the availability of high-resolution topographic data and pre-existing flood models. The simplest being the 'bath-tub' approach using the 'building block' approach for determining inundation levels: this projects the extent of inundation based on the elevation of land connected by a pathway. This approach does not account for estuarine hydrodynamics and frictional losses when water flows across wide areas of relatively flat land. The Report applied the bath-tub approach to most sites around Banks Peninsula, and a different approach for the Avon-Heathcote Estuary, Sumner[13], and Brooklands Lagoon (Waimakariri River Entrance – Styx Catchment).

[76] For the Banks Peninsula sites, a 'building block' approach as recommended by Ramsay et al (2012) incorporating the components of storm tide (with its various components), wave setup, wind setup and SLR is used to conservatively estimate extreme total inundation levels. It is slightly different to that for the open coast with the inclusion of wind setup.

[77] The storm tide values for 1% and 2% AEP were appropriately based on water level gauge analyses for Lyttelton and Sumner Head by Goring et al (2009, 2011). As noted in the discussion on CIHZ for the open coasts, these two water level monitoring sites appropriately have sufficient record lengths to allow reasonable analysis for predicting 2% and 1% extreme water levels for 2065 and 2115 respectively – the prediction of the 1% 2115 extreme storm tide levels being less reliable than those for 2% 2065 value. Extreme water levels within the harbour embayments are complex with varying contributions at varying timescales. It is noted that there are other monitoring stations within the harbour and surrounding areas (Kaikoura, Timaru, Sumner, Port Lyttelton, Akaroa, Canterbury Bight) that may provide useful extreme water level information. It is recommended that

[13] Appendix F does not provide any information about the modeling undertaken for Sumner. It only discusses the model coverage for the Styz, Avon and Heathcote urban catchments. Further, the legend for the CIHZ plotted in Appendix E, Figure 1A indicates that the results are not based on TUFLOW (no mention of Freeboard unlike the legends for the Avon-Heathcote Estuary and Broadlands Lagoon. Tables 4-1 and 4-2 suggest that, consistent with the figure caption, Sumner was treated as an open coast site, not a harbour site as implied by section 4.2.1.6.

an updated thorough analysis for extreme water levels of all water level monitoring stations in the Canterbury area be undertaken prior to the first reassessment/review.

[78] Wave and wind setup at each of the harbour sites was calculated using standard estimation methods based on 1 h duration winds determined from extreme 3 s wind gust data. Both the wind and wave setup values (Table 4.15 for 2115 and Table 4.16 for 2065) are upper limit values since they were calculated assuming the wind blows along the longest fetch to the site. The contributions of wave and wind setup to the total inundation levels are significant. Numerical modelling of waves within Lyttelton Harbour has been undertaken by the Lyttelton Port of Christchurch as part of its recovery plan (e.g., Goring 2014, 2015). These results could be used to assess the wind and wave set-up around the harbour, including the potential effects of future dredging scenarios. It is recommended that in the first review the wave and wind setup values be re-evaluated for each site – specifically the assumption that the extreme 1% and 2% winds will blow along the longest fetch needs to be tested.

[79] As for the open coast, SLR values used in Tables 4.16 and 4.15 are 0.4 m for 2065 and 1 m for 2115 – the stated basis being recommendations from Bell (2013) and Tonkin & Taylor (2013) – the values are reasonable for inclusion of regional/ local effects in consideration of the IPCC AR5 global values shown in Figure 2.3

[80] The resulting total inundation levels based on the building block approach used in mapping of the CIHZ for harbour coasts assumes sea level rise is added to extreme storm tide which is co-incident with the peak wind and wave setup arising from winds blowing from the worst direction along the longest fetch and as such is conservative (an over-estimate). Ramsay et al (2012) note that '*Whilst the various components combining to result in an extreme storm tide level are typically correlated in some way, very rarely does an extreme high-tide level coincide with both a high storm surge and high wave conditions*'. Therefore, the 'building block' approach used in the Report to assess current inundation hazard '*will tend to overestimate inundation risk*'. As for the CIHZ open coast, it is recommended that prior to the first reassessment/review and in conjunction with the recommended update of extreme water levels from monitoring stations the likelihood of concurrence of extreme winds and waves with coincidence of peak wind and wave setup with extreme storm tide be investigated.

[81] Mapping takes an appropriate bathtub approach as outlined above for the majority of the harbour sites. For the Avon-Heathcote estuary and Brooklands areas where tidal propagation will encounter overland flows and friction effects can be expected to significantly affect water levels, Tonkin & Taylor have undertaken TUFLOW modelling. This has only been possible because Tonkin & Taylor had a TUFLOW model previously developed for another study.

[82] For the estuaries modelled using TUFLOW the effort is considerable as outlined in Appendix F of the Report. Digitisation of the Avon, Heathcote and Styx catchments, incorporation of

available bathymetry (underwater survey), stormwater drainage and overland flow paths are all required and necessary model inputs. The modelling effort is rigorous but without thorough calibration and verification the accuracy is uncertain. As expected, TUFLOW indicates lower inundation levels than the bathtub approach as the distance upstream of the estuary entrance increases.

[83] The TUFLOW model was run for only two future downstream tidal boundary conditions as defined in Table 4.17 and outlined in more detail in Appendix F section 4.2. The tidal boundary conditions were chosen to have peak water levels being the sum of storm tide (2% AEP=1.8 m and 1% AEP = 1.85 m), sea level rise (2065 = 0.4 m and 2115 = 1.0 m) and a 'freeboard' of 0.4 m. The storm tide and SLR values are consistent with those adopted for the harbor coasts mapped using the bathtub approach. The tidal boundary condition included an allowance of 0.4 m on top of extreme tide and SL, which is stated as a 'freeboard' to compensate for wave and wind setup. The calculations to justify the value of 0.4 m allowance for wave and wind setup should be included in the Report. CAUTION is needed as this is not a freeboard in the sense of 'freeboard' that is normally added to CIHZ by CCC in planning to set floor levels in areas vulnerable to flooding.

[84] The TUFLOW modelling did not include river baseflows, or the effects of coincident rainfall, which could increase the extent of flooding. These factors were not included in the bathtub modelling undertaken for other sites. A partial analysis based on a short duration rainfall record was undertaken by Tonkin & Taylor as part of an assessment of increased flooding vulnerability arising from the Canterbury Earthquake Sequence (Tonkin & Taylor, 2014a, b,c). It is recommended that these factors, and the influence of climate change on them, be incorporated in the first review/reassessment of the coastal hazard zones.

LiDAR and earthquake effects

[85] The Report used a digital elevation model (DEM) of the Christchurch city ground surface elevations produced using the 2011 LiDAR data supplied by the 'Council' (Tonkin & Taylor, 2015, p 10). LiDAR is a remote sensing technique that uses a pulsed laser to measure distances to the ground from, in this case, a sensor mounted on an aircraft. For the inundation modelling, additional data were incorporated into the DEM from an earlier 2010 LiDAR survey, and hydrographic surveys of the Avon-Heathcote Estuary by NIWA in March/April 2010 and January 2013 (Tonkin & Taylor, 2015, Appendix F). The methodology used to derive the DEM is described in Tonkin & Taylor (2014)

[86] The May 2011 Christchurch LiDAR dataset was collected after the first two significant earthquakes of the Canterbury Earthquake Sequence (CES, that is, September 2010 and February 2011) to measure the significant ground elevations changes and displacements that had occurred. As such, any uplift or subsidence experienced in the Southshore and other areas during the September 2010 and February 2011 earthquakes has been incorporated into the baseline ground elevations

that the Report has used for their hazard assessments, although changes since 2011 have not been incorporated.

[87] Another significant land elevation process accounted for in the 2011 LiDAR DEM is the growth of the open coast dunes that occurred between the 2011 LiDAR survey and the previous survey, which was conducted in 2003.

[88] More recent aerial LiDAR surveys have been flown for parts of Christchurch city after each major earthquake since 2011, but the spatial extent of these surveys is more limited than the 2011 survey. Given that the 2011 LiDAR survey accounts for a large proportion of the ground elevation change that has so far occurred in the CES, and given the spatial limitations of post-2011 LiDAR surveys, it is appropriate that Tonkin & Taylor relied on the 2011 survey for its baseline DEM in their 2015 report.

[89] However, since the GNS (Geological and Nuclear Sciences) forecasts indicate that the Canterbury aftershock decay sequence will continue for years to decades, it would be appropriate that any subsequent reassessment/review of this coastal hazards assessment include an examination of new data on ground elevation changes. This would be particularly relevant to the estimation of the inundation extent and erosion hazard lines associated with the waterways and low-lying flood plains upstream from the mouth of the Avon-Heathcote Estuary Ihutai.

[90] Further, we recommend to CCC, ECan and Government that future LiDAR surveys of Canterbury cover the areas predicted to be affected by coastal hazards over the next 100 years in the Report, plus adjacent low-lying land.

[91] In areas of Christchurch that have undergone earthquake-induced changes in ground elevations, the relationship between the land surface and the groundwater table has been altered: that is, depths to groundwater have decreased where subsidence occurred and increased where uplift occurred (Hart et al, 2015).

[92] The depth to groundwater is important for at least two reasons related to hazard assessments. Firstly, when ground water levels are high, there is little capacity for water falling on, or running across, the ground surface to infiltrate into and/or be stored in the soil. As such, a decrease in depth to groundwater can enhance the flood hazard. Secondly, significant decreases in the depth to groundwater has increased liquefaction hazard in low-lying areas of Christchurch where the dry layer of the surface crust has been substantially reduced (Russell and van Ballegooy, 2015; Quilter et al, 2015).

[93] The Mayoral Taskforce made an initial summary of the post-quake increases in flood hazard that have affected several different inland and coastal areas of Christchurch city (CCC 2014).

Their examination of this phenomenon was prompted, in part, by the March 2014 extreme rainfall event (see Allen et al, 2014 for details).

[94] Increased Flooding Vulnerability (IFV) and Increased Liquefaction Vulnerability (ILV) are now both recognised as an earthquake 'land damage' categories by the Earthquake Commission (EQC).

[95] In terms areas covered by the Report, post-quake flood hazard changes are of particular concern in the lower reaches of the Avon River and northern Avon-Heathcote Estuary Ihutai. The southerly storm conditions that produce elevated estuary water levels and conditions conducive to inundation in this the Ōtākaro Avon River mouth area also tend to be correlated with rainfall over the city resulting in a combined fluvial and coastal flood hazard (Lamb, 1997).

[96] CES-induced increases in the flood hazard were not examined in detail in the Report but were previously examined as a series of reports produced for EQC (Tonkin & Taylor, 2014 a,b,c). It is appropriate that the CES-increased flood hazard was not studied as part of the Report's assessment of 2065 and 2015 likely and potential coastal erosion and inundation zones, and that the latter assessment used post-earthquake land elevations. This is because the detailed assessment of the CES-induced increases in flood and other hazards should instead form part of the earthquake effects assessment, and be dealt with under EQC provisions.

[97] It is worth noting that the full picture of changes in the Christchurch flood hazard after the CES is yet to be known, and continues to change as lifelines systems repairs proceed, including those to the stormwater and wastewater networks. Of note for areas of overlap with the coastal hazards assessment, it would be advisable to undertake a further analysis of the extent of the IFV (increased flood vulnerability) for the estuary margins of New Brighton Spit, since changes in this area are complex and relate no only to CES-induced subsidence but also to the subsequent red zoning of residences and the eventual removal of some infrastructure in this area. However, this should be undertaken as a separate exercise from the Report's coastal hazard assessment.

Areas of scientific uncertainty

[98] Ramsay et al (2012) recommends that a range of sea-level rise scenarios be assessed for the future timeframe(s) under consideration and the sensitivity of the resulting coastal change/ inundation ascertained (Box 3 - Key checklist for coastal hazard assessments). Such scenarios can incorporate possible regional variations from global sea level projections. Based on discussions with CCC, the hazard assessment has been restricted to considerations of climate change SLR projections based on RCP 8.5. With more time it would be useful to have the assessments for CEHZ and CIHZ also undertaken for other RCPs. It is recommended this be done in the first reassessment/review when the likely RCP pathways may be clearer.

[99] It is noted that few scientists believe the RCP2.6 pathway is now possible, so this emission scenario could reasonably be excluded from any future scenario sensitivity assessments.

[100] It is also noted that RCP8.5 is a very high scenario, also referred to as a 'business as usual' scenario, with atmospheric concentrations based on the continuation of current emission levels. It is commonly adopted as an upper level scenario in hazard assessments.

[101] Although it is likely that sea level rise will affect the processes that result in coastal inundation, Ramsay et al (2012) state that a pragmatic approach is to add future sea level rise to current inundation levels to estimate the future hazard as has been done in the Report. The result is, however, noted as being conservative – that is, an over-estimate

Distributions and the probabilistic approach

[102] Use of the probabilistic approach in determining hazard zones is highly desirable and is recommended in Ramsay et al (2012). The approach requires a suitable probability distribution for each component of Equation 2 in the Report. These distributions should reflect uncertainty from many different sources including coastal processes, lack of data, in estimates obtained from available data, and uncertainties from future changes.

[103] Assessments of parameters for and selection of the form of the component distributions can have substantial consequences for the position of hazard zone lines drawn using the distribution of the sum of components. Assessments are difficult, have to be made carefully, use all available information, and not add biases to the resultant hazard zones.

[104] The use of triangular probability distributions for the probabilistic approaches is recommended for coastal modelling by Ramsay et al (2012) and used in Cowell et al (2006). Triangular distribution forms, while being easy to sample have some undesirable properties. There are many situations where other forms of probability distribution should be used. For example, where thick-tailed or highly skewed distributions appear to apply. Normal distributions can also better represent the uncertainty in some cases.

[105] It is very difficult if not impossible to introduce correlations between components when the (marginal) shapes are triangular. Not having correlations between components where it is obvious that it should be so can strongly affect the hazard lines, especially where the lines have small tail probabilities beyond their determined locations. It is relatively easy to introduce correlations where the components have normal uncertainty distributions, but it can also be done in skewed cases.

[106] An issue has been raised by the community in the form a statement that 'the best international guidance is that 1 m sea level rise in 100 years is very unlikely'.

[107] This statement follows from a probability calculation that gives a probability of approximately 4% that the sea level rise by 2115 exceeds 1 m (4% approximately = 17% × 25%) In fact what has been calculated is the 'probability' that the two events *'the sea level rise to 2115 exceeds 1 m'* and *'emission levels to 2115 have followed pathway RCP8.5'* have <u>both</u> occurred. This is because it is the product of the conditional 'probability' that *'the sea level rise in 2115 exceeds 1 m'* given that '*emission levels to 2115 have followed pathway RCP8.5*' and the 'probability' that *'emission levels to 2115 have followed pathway RCP8.5'* is 25%. The 'probability' that *'emission levels to 2115 have followed pathway RCP8.5' being 25%* for the calculation cannot be taken seriously. Is the RCP8.5 pathway the only pathway among the myriad possible pathways for which a sea level rise of greater than 1 m is possible? Clearly not. The only way to use pathways to calculate the probability that *'the sea level rise in 2115 exceeds 1* m' is to calculate this for each pathway (this will vary over all possible pathways) and then average all these conditional probabilities over some probability distribution for all the pathways.

[108] The IPPC does not attach any probability to each of its four RCP scenarios for very good reasons. In Chapter 13 of the IPCC AR5 publication it is stated that for the RCP8.5 scenario it is likely (66%-100%) that the global mean sea level rise will be in the 5% to 95% range of projections from processed based models of 0.52 m to 0.98 m by 2100. The 90% bounds are calculated from an ensemble of process based model results and therefore the interval defined by the range cannot be interpreted as a 90% confidence interval as it not based on data which has a random nature. There does not appear to be a probability anywhere here. Furthermore, the IPCC then attaches a likely weighting of 66%-100% to the interval because of uncertainties not considered in the process based model results. Even if it were a 90% confidence interval it is still not a probability interval in the strict frequentist interpretation. Furthermore, projections in Figure 2-3 of the Report, which is taken directly from Figure SPM.9 in the IPCC AR5 report, suggest that the mid-line is approximately 0.94 m in 2115. If it were possible to assign a conditional probability to *'the sea level rise to 2115 exceeds 1 m'* given that *'emission levels to 2115 have followed pathway RCP8.5'* then it would be much closer to 50% than 17%.

[109] The 25% used as a probability that *'emission levels to 2115 have followed pathway RCP8.5'* is at best subjective and seems to be related to the fact that for reporting purposes the IPPC chose four different emission scenarios of which RCP8.5 projects the highest sea level rise. There is an infinite number of possible emission pathways to the 2115 endpoint and it is impossible to enumerate all pathways or assign a probability to the event that a particular group of pathways contains the actual pathway that will happen.

[110] There are some very large assumptions made in this calculation with little justification. In addition, the calculation treats the weighting numbers from the IPCC AR5 report as probabilities when the IPCC does not. The calculation has no validity.

Are the Report's findings relevant in terms of new research?

[111] The assessment by this Review has been restricted to the TOR and conditions agreed between Tonkin & Taylor and CCC. In this respect the Report has met most reasonable expectations. As noted above, there are some omissions and errors that should and can readily be recalculated and mapping amended. There is no new research that brings into dispute the work presented.

[112] The methodology used to assess coastal hazards is likely to continue to evolve over time, as are the legislative frameworks within which the results are applied, and the scientific evidence and observational data on which the assessments are based.

[113] The discussion of Key Question 1 has identified aspects that should be amended within the Report, addressed by specific research to address knowledge gaps, or incorporated into the first reassessment. The suggested research and first reassessment should also consider new research available when that work is undertaken.

[114] Therefore, while there is no specific new research that necessitates a modification of the Report, it is recommended that a review of published research be incorporated into each reassessment/review of coastal hazards.

Has the Report taken account of relevant statutory documents in providing technical or expert advice (refer Appendix E for full purpose statements)?

[115] In identifying the scope of this peer review, GHD set out what is expected of the panel. In addition to reviewing the science that underpins the Report, the panel is to review whether Tonkin & Taylor correctly accounted for the legislative and policy framework outlined in the document.

[116] The panel may also provide observations or recommendations on the steps or actions CCC should undertake to meet its legislative requirements.[14]

[117] Under the heading 'The expert and the law' GHD set out the relevant provisions of the statutory framework and the law that [could] apply to the Report.[15]

Statutory provisions

- **Resource Management Act 1991 (RMA)**

  The relevant provisions in the GHD document are listed as the Resource Management Act 1991 (1-11) which encompass:

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[14] GHD Bundle of Documents 3 Scope of the Peer Review, p 3.
[15] Ibid Appendix E Legal Reference Document, pp 1-3.

district plans and the process for preparing them (s 31);

the matters to be considered in preparing or changing plans (s 74);

the fact that the Act identifies a plan must give effect to any New Zealand coastal policy statement and any regional policy statement (s 75(3));

an evaluation report under s 32;

the fact that preparation, change and review of plans is prescribed in Schedule 1 RMA.

- **Canterbury Earthquake (Christchurch Replacement District Plan) Order 2014**

  The regulatory process outlined here, we are advised, is not the context within which the report(s) commissioned by CCC and prepared by Tonkin & Taylor were undertaken.[16]

- **New Zealand Coastal Policy Statement (NZCPS 2010)**

  Objective 5, relevant policies including 3, 24, 25, 26, 27 (see below).

- **Canterbury Regional Policy Statement (CRPS) 2013**

  This provides an overview of the resource management issues of the region. Chapters 8 and 11 set out objectives and policies in respect of the coastal environment and natural hazards. This statement was developed under the NZCPS.[17]

- **Local Government Official Information and Meetings Act 1987**

  This requires councils to put certain material relating to individual properties into a land information memorandum. Section 44A(2) states:

  > The matters which shall be included … are –
  >
  > (a) information identifying each (if any) special feature or characteristic of the land concerned, including but not limited to potential erosion … being a feature or characteristic that –
  >
  > (i) is known to the territorial authority; but
  >
  > (ii) is not apparent from … a district plan …'

[16] GHD Bundle of Documents Appendix E, pp 3-4.
[17] Canterbury Regional Policy Statement 2013, p 88.

- **Building Act 2004**

  This provides for hazard notices on titles of land if certain building work is carried out and if the land 'is subject or is likely to be subject' to one or more natural hazards which is not mitigated (ss 71-74).

Tonkin & Taylor's reference to statutory documents

[118] In its letter referring to the Terms of Reference Tonkin & Taylor suggested:

> Hazard mapping from previous high level mapping studies needing to be referred to and the second stage mapping be suitable to be included in the district plan. The phrase 'mapped to be suitable in the district plan' is repeated in the Project Purpose in the Terms of Reference.[18]
>
> Reassessment of the CHZs because they do not adequately incorporate the potential effects of sea level rise as requested under the NZCPS.

[119] And:

> A risk-based approach to managing coastal hazard is advocated by the NZCPS (2010). For example, the policy statement suggests consideration of areas both 'likely' to be affected by hazard (Policy 27) and areas 'potentially' affected by hazard (Policy 24). … While the term likely may be related to a likelihood over a defined timeframe based on guidance provided by MfE (2008b), (i.e. probability greater than 66% as shown in Table 1), the term potential is less well defined. This assessment therefore aims to derive a range of hazard zones corresponding to differing likelihoods which can be selected based on planning methods.

[120] In the Terms of Reference, Timeframe, it is mentioned that CCC is working to a limited timeframe to accommodate the requirements of the Canterbury Earthquake (Replacement District Plan) Order 2014 which replaces the requirements of the RMA for the District Plan Review.[19]

[121] There is reference to a district plan and NZCPS Policy 24 and Policy 27. These few references indicate to the panel that very little assessment of the NZCPS (2010) found its way into the Report.

[122] The NZCPS is the only mandatory statement under the RMA that directs what decision-makers are required to take into account for planning issues around the coastal environment (s 57 RMA). The district plan must give effect to NZCPS (2010).

[18] GHD Bundle of Documents Appendix B – Original Terms of Reference for Tonkin & Taylor and Variation.
[19] This it appears from the reference at para [160] above is not correct.

Resource Management Act processes

[123] The proposal for which the Report was commissioned was to provide a technical scientific basis from which the identification of Coastal Erosion and Inundation Areas could be considered for Stage 3 of the CRDP under a Plan Change.

[124] The focus of the Terms of Reference between CCC and Tonkin & Taylor circumscribe what the Report is to provide – identification of areas around the main coastal settlements of Christchurch City susceptible to coastal hazards, namely those particularly affected by inundation and erosion and sea level rise. The areas are termed coastal erosion zones (CEHZ) and coastal inundation zones (CIHZ). The zones are to be mapped over a suitable 50 year (2065) projection for sea level rise for CIHZ (to be agreed with CCC and ECan), and for the Open Coast, assessment is to be made of CHZ2 distance for both 2065 and 2115 time frames. The mapping for those areas is to be to a standard suitable for including in the District Plan.[20]

[125] The contents of the Report subsequently agreed upon by CCC and Tonkin & Taylor as set out in the Terms of Reference are thus essentially technical. The proposed purpose, scope of services etc of the works is attached to this review as Appendix 1. But because the mapping of these areas is to be a standard suitable for including in the CRDP, as a matter of law the process and the mapping 'standard' is required to meet the relevant provisions of the RMA that are administered by CCC.

[126] Section 5(1) RMA requires the *active promotion* of the sustainable attributes of the RMA by the CCC. In commissioning the Report, CCC's action was an initial initiative to meet the requirements of the NZCPS, the purpose of which is to state policies in order to achieve the purpose of s 56 RMA in relation to the coastal environment as noted above. As noted above, the NZCPS is the only mandatory statement in the legislation setting of objectives and policies to inform decision makers how to sustainably manage various aspects of the coastal environment, including climate change (s 57).

[127] Under s 75(3)(b) a district plan must give effect to the NZCPS (2010). That provision identifies that 'this NZCPS is to be applied as required by … persons exercising functions and powers under the RMA'. It is therefore the role of CCC to apply the NZCPS provisions as it requires.

[128] Policy 15 NZCPS is designed to guide the formulation of regional and district planning documents which in turn guide consent authorities such as CCC when considering resource consents, formulating plans, and plan changes.

[20] Original Terms of Reference for Tonkin & Taylor and Variation. Appendix B of Bundle of Documents, Agreement Variation between Tonkin & Taylor Limited and Christchurch City Council. Appendix A1 Scope, Purpose, Program and Completion Date for a Coastal Chapter – Coastal Hazard Assessment - Stage Two Project Purpose, b, 1.1.

[129] In the normal course of events, what is to be achieved here is an initial technical assessment to assist the CCC's purpose in providing for the sustainable management of the city's natural and physical resources, and its communities, as defined in s 5(2). This provision requires the CCC to:

- manage the use, development and protection of natural and physical resources;
- in a way or at a rate that enables the communities of those coastal settlements to provide for their social, economic and economic wellbeing and for their health and safety;
- sustain those resources to meet the reasonable needs of future generations of the Christchurch coastal communities; and
- safeguard the life supporting capacity of the water, soil and air; and
- avoid or remedy any adverse activities on the environment.

[130] But this Report was intended to form a technical basis for a Plan Change. On the authority of *Sustain our Sounds Inc v The New Zealand King Salmon Company Ltd*[21] the Supreme Court held that when dealing with a plan change application in the coastal environment, the decision maker should undertake the necessary analysis under the NZCPS. Section 5 RMA therefore is not to be treated as the primary operative decision-making provision. The Report only introduced Policies 24 and 27 as relevant to what it encompassed, and that was in a letter outside the Terms of Reference. And in fact, as we have noted above, only Policy 24 is relevant at this initial stage.

[131] CCC's functions still, arising from s 57(a) however, are mandated to the extent that the council is required to pay 'particular regard to the effects of climate change' under s 7(a) RMA. This provision imposes a duty on CCC to be on inquiry about 'a change of climate that is directly or indirectly attributable to human activity that alters the composition of the global atmosphere'. And that is in addition to natural climate variability observed over considerable time periods. The 'considerable time periods' identified in the Report are identified as 50 years and 100 years.[22]

[132] The matters to be considered in preparing (or changing) a district plan are set out in s 74 and include the territorial authority's functions under s 31, the provisions of Part 2 (which includes the purpose of the RMA), and an evaluation of alternatives, benefits and costs. Section 74(1)(e) states:

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[21] [2014] NZSC 38, (2014) 7 ELRNZ 442.

[22] T&T Report 3 Previous Assessment Methodology. Environment Canterbury Regional Council (ECan) developed 2 CHZs for the Canterbury region set out in the Operative Regional Coastal Environment Plan (RCEP 2005), p 12.

(1) A territorial authority must prepare and change its district plan in accordance with –

…

(e) its obligation to have particular regard to an evaluation report prepared in accordance with section 32; and …'

[133] Section 75 'Contents of district plans' is the initiating provision for what may be contained within them, s 75(1) and (2). A commentary to the legislation identifies that the required contents of the district plan here are key, and that there are three substantive stages in deciding its contents plan:

- identification of the facts and the significant issues for the district arising out of the facts;
- the s 32 analysis;
- the ultimate issue of whether implementing the proposal would more fully serve its statutory purpose.[23]

[134] The community's questions 5, 9 and 11 all relate to an analysis being undertaken for an evaluation report under s 32. Economics, future land use and the drafting of future rules are referred to in these questions and are introduced because it is considered by the community to relate back to the hazard areas mapped to a sufficient standard in the Report to be incorporated in the CRDP.

[135] In the panel's opinion this Report is intended to address *the first stage* in a s 75 analysis - an identification of the facts to establish what may constitute hazard areas arising from coastal inundation and erosion and climate change. And to establish those facts an analysis under NZCPS Policy 24(1)(a)-(h) is required.

[136] The second part of that initial stage – identification of the significant issues arising out of these facts – encompasses NZCPS Objective 5 and Policies 25 and 27, and the application of risk management techniques and the precautionary approach to issues arising in those policies.

[137] Only when that second stage is completed can an analysis for an evaluation report under s 32 be undertaken.

[138] The Report therefore does not have the status of an evaluation report under s 32 RMA. There is nothing in the Terms of Reference that this should be so. And the provisions of s 32(1) and (2) preclude that. We have identified those provisions below as a guide to what a s 32 evaluation

[23] Salmon 'Resource Management' Vol 1, RM 75.01, p 542.

report should encompass. It addresses many of the concerns of the community identified in their questions to the panel. [24]

[139] On inquiry we asked the CCC planners whether we could view their Section 32 Report on Natural Hazards, Chapter 5 Part 2. It is a large document, largely addressing flood risk, slope stability, some interim provisions in relation to climate change and sea level rise, changes in ground surface from earthquakes, and others. From this can be seen the extensive assessments that have to be undertaken for any s 32 evaluation report.

[140] We note that in the s 32 Natural Hazards chapter of the CCC August 2014, Tonkin & Taylor's Study of the Effects of Sea Level Rise for Christchurch 2013 (Stage One) is mentioned, suggesting a review of existing flood management areas based on its study[25]. The study is thus but one of a number of reports assessed by CCC's planners forming part of a foundation for their work.

Canterbury Regional Policy Statement

[141] We looked briefly at this document and appreciate the information it provides on climate change and its predictions. We note, however, that it applies in Objective 11.2.1 and related policies to new developments so any assessment under those requirements may not yet at the present time assist the community, although they will in the future. And in terms of Policy 11.3.5(1) General Risk Management, the 'likelihood' of the natural hazard event stands to be interpreted as it has under the national guidance and IPCC directives already analysed in the sections of this review above.

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[24] Section 32 states:

(1) An evaluation report required under this Act must –
  (a) examine the extent to which the objectives of the proposal being evaluated are the most appropriate way to achieve the purpose of this Act; and
  (b) examine whether the provisions in the proposal are the most appropriate way to achieve the objectives by –
    (i) identifying other reasonably practicable options for achieving the objectives; and
    (ii) assessing the efficiency and effectiveness of the provisions in achieving the objectives; and
    (iii) summarising the reasons for deciding on the provisions; and
  (c) contain a level of detail that corresponds to the scale and significance of the environmental, economic, social and cultural effects that are anticipated from the implementation of the proposal.

(2) An assessment under subsection (1)(b)(ii) must –
  (a) identify and assess the benefits and costs of the environmental, economic, social, and cultural effects that are anticipated from the implementation of the provisions, including the opportunities for –
    (i) economic growth that are anticipated to be provided or reduced; and
    (ii) employment that are anticipated to be provided or reduced; and
  (b) if practicable, quantify the benefits and costs referred to in paragraph (a); and
  (c) assess the risk of acting or not acting if there is uncertain or insufficient information about the subject matter of the provisions.

[25] Section 32 Natural Hazards Chapter, p 8.

Provisions of the NZCPS

[142] The GHD Bundle of Documents[26] identifies an objective and policies of the NZCPS and several provisions that are directly relevant to the assessment of coastal hazard. It goes on to identify 'relevant' policies to include:[27]

- Objective 5 NZCPS - ensures that coastal hazard risks, taking account of climate change, are managed by locating new development away from areas prone to these risks, considering responses, including managed retreat for existing development in this situation, and protecting or restoring natural defence to coastal hazards.[28]

- Policy 3 – requires a precautionary approach in the use and management of coastal resources potentially vulnerable to effects from climate change, so that avoidable social and economic loss and harm to communities does not occur.

- Policy 24 – identifies areas in the coastal environment that are potentially affected by coastal hazards (including tsunami) and giving priority to the identification of areas at high risk of being affected. These should take into account national guidance and the best available information on the likely effects of climate change for each region.

- Policy 25 – promotes avoiding increasing the risk of social, environmental and economic values to erosion hazard in areas potentially affected by coastal hazards over at least the next 100 years.

- Policy 27 – promotes reducing hazard risk in areas of significant existing development likely to be affected by coastal hazards.[29]

[143] Questions from the community on the NZCPS query whether the document refers to sea level rise at all; another questions whether Policy 3 Precautionary approach applies to what the Report should encompass; another queries whether the Report appropriately has regard to each of the required matters in NZCPS Policy 24(1)a)-h); and finally, is the interpretation given in the Report to the words 'likely' and 'possible' as used in Policies 24 and 27 turned into quantitative analytical parameters, and is the interpretation and application of those terms appropriate?

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[26] Report Appendix E.
[27] Report Section 2 Background Information, Statutory Legislation, New Zealand Coastal Policy Statement 2.1.1.1, p 2.
[28] footnote
[29] footnote

[144] Objective 5 NZCPS is not relevant to what the Report is required to identify at this initial technical stage under the Terms of Reference. Objective 5 relates more directly to Policies 25-27 (above) and not to Policy 24.

[145] One of the community questions whether the NZCPS does in fact refer to the term 'sea level rise' at all. It does in several places:

> Policy 10(2) Reclamation and de-reclamation
>
> (a) … the potential effects on the site of climate change, including sea level rise, over no less than 100 years.
>
> Policy 19 Walking access –
>
> Maintain and enhance public walking access to and along the coastal marine area by …
>
> 2(c)(iv) identifying opportunities to enhance or restore walking access resulting from subdivision use or development where 'the long-term availability of public access is threatened by erosion or sea level rise …'
>
> Policy 24: Identification of coastal hazards
>
> (i) … 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) …
>
> (c) cumulative effects of sea level rise, storm surge and wave height under storm conditions …
>
> taking into account the most recent available national and international guidance on the likely effects of climatic change on the region or district.

[146] There can be no issue that sea level rise has been omitted from the NZCPS.

[147] It is also identified as a characteristic of climate change in the two key national documents relevant here – MfE (2008b) and Ramsay et al (2012).[30]

[148] Meanwhile, Policy 24 is the *only* NZCPS policy that has direct relevance to what the Report has been asked to assess (see below).

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[30] MfE (2008) 9 Glossary, p 92. 'Sea-level rise – Trend of annual mean sea level over timescales of at least three or more decades. Must be tied to one of the following two types: global – overall rise in absolute sea level in the world's areas; or relative net rise relative to local landmass (that may be subsiding or being uplifted).

Policy 3 The Precautionary approach

[149] The statutory status of the precautionary approach (Policy 3) is an issue, one important to clear up as a further step in the evaluation of the relevant parameters of the NZCPS (2010) because it affects one part of its scientific assessment.

[150] Policy 3 Precautionary approach is required to apply towards 'proposed activities' whose effects on the coastal environment are uncertain, unknown or little understood, and to apply to the 'use and management of those activities' in the coastal environment. But the Report has applied it to determining sea level rise projections in the following manner:

> **Adopted sea level values 4.1.4.5 Effects of sea level rise ('SL')**
> Utilising the most recent projections (IPCC, 2014) and adopting a precautionary approach required by NZCPS (2010) and in keeping with recommendations in MfE (2008), this assessment has adopted sea level rise values projected for the *RCP8.5 scenario – emissions continue to rise in the 21st century* ('business as usual'). This is considered prudent until evidence of emission stabilising justify use of a lower projection scenario. These sea levels range from 0.27 to 0.47 metres by 2065 and 0.62 to 1.27 metres by 2115 (refer to Section 2.2.1.5).[31]

[151] Adopting a precautionary approach in the Report to the identification of areas susceptible to coastal hazards (inundation and erosion) is wrong. Policy 3 relates directly to the management of risks identified around specific social, economic and environmental issues (among others) identified in Policies 25, 26 and 27. The Report is inappropriately using the wrong directive statutory terminology. Its use in the document also predicates uncertainty around its 'likely' and 'probable' statistics referred to below.

[152] One submitter summarised the difficulty directly on behalf of CCRU:

> The whole trigger for the application of the precautionary approach (Policy 3(1)) is where matters 'are uncertain, unknown, or little understood, but potentially significantly adverse'. This can only be known once the scientific assessment has been done. If the science ignores the uncertainties and consistently errs on the side of caution as it estimates relevant information, it becomes impossible to know the cumulative effect.
>
> This is one area where DoC[32] has developed guidance in respect of the NZCPS 2010 and it is clear:
>
> The application of the precautionary approach is a risk management approach rather than a risk assessment approach (NZCPS 2010 Guidance note Policy 3: Precautionary approach, page 6, Department of Conservation).

[153] Thus in the context of climate change, the use and risk management of coastal resources (including coastal properties) that are required to be identified in regional and district plans, should be precautionary having regard to economic losses and other damage that may result from the

[31] Tonkin & Taylor Report 4.1.4.5 Effects of Sea Level Rise (SL), p 26.
[32] GHD Bundle of Documents, 4.2 Legal.

physical changes in the coastal environment to people, making them vulnerable, and to property that will be at risk owing to climate change (among a number of other issues).

[154] The good practice guide (Ramsay et al, 2012) for defining coastal hazard zones for setback lines makes this approach clear in several parts of its document.[33] It refers to the key principles to be incorporated in all aspects of local authority planning, identifying one of them to be a 'Precautionary Approach':

> **Precautionary approach:** A precautionary approach is adopted when making planning decisions relating to **new development**, and to **changes to existing development** within coastal margins. Decision-making takes account of the level of risk, utilises existing scientific knowledge and accounts for scientific uncertainties.

[155] The guide identifies that after assessing the various drivers that cause coastal change through sea level rise (Policy 24), the planners, coastal scientists, economists and engineers are then required through NZCPS Policy 25 and Policy 27 to avoid increasing the risk of harm from coastal hazards in affected areas through careful management of subdivision, land use and coastal protection works. 'The most common approach where existing development is at risk from coastal hazards is to apply the above information in the form of coastal setbacks through a range of rules in planning documents.'[34]

[156] It is therefore not appropriate in Section 4.1.4.5 Effects of sea level rise[35] for Tonkin & Taylor to take a Policy 3 'precautionary approach' to its identification of 'adopted sea level values' because the phrase has confused the community, and those who read this assessment about the Report's purpose in bringing in issues that are not within the coastal scientists' expertise at this stage, or the Terms of Reference.

[157] But even then, in section 4.3.2 of the good practice guide 'Moving from deterministic predictions to probabilistic projections', that document identifies current approaches to defining uncertainties in one of the three ways as follows:

- Direct application of a multiplication factor of safety to some or all of the setback terms.
- Detailed calculations of error for each setback term.

[33] Ramsay et al. Defining coastal hazard zones for setback lines: a guide to good practice, p 7 Box 1, p 9, p 89.
[34] Ramsay et al. Defining coastal hazard zones for setback lines – a guide to good practice. Appendix 1 Section 7 Legislative framework, p 89.
[35] T&T report (2014) Vol 2 4.1.4.5; IPPCC (2014) Chapter 13, 1181.

- Application of '**precaution**' throughout process (e.g. taking maximum likely values for each factor rather than averages).[36] [Emphasis]

[158] The third criterion here possibly confuses the use of the word 'precaution' further in the applied science of climate change. This is what may have prompted the scientists in the Report to include the precautionary approach. But the statement above does not appear to be related to activities to do with an application of Policy 3 which relates only to more identifiable matters like people, housing, land, soils, economics in the context of coastal hazards and sea level rise. It may simply be use of an ordinary use of the word in everyday speech, which is what the panel came to.

[159] On reflection, we do not consider that Ramsay et al mean the Policy 3 Precautionary approach here. We consider the authors are specifically saying that when dealing with events like climate change and risks, a competent scientist errs on the side of over rather than under estimation. This might grate against the meaning in the NZCPS if it wants scientists not to be cautious, but we consider that cautious/conservation is a good scientific principle in hazard assessment.

[160] In a telephone conference with Richard Reinen-Hamill, Project Director for the Report, he was questioned as to whether the scientists added some percentage around those projected for sea level rise to give the results identified in 4.1.4.5 SL because of the precautionary approach (Policy 3 NZCPS) to the *determination* of the hazard rather than the *consequences* of the hazard. His response was no, that the only use of precaution in effect was in use of the RCP8.5 scenario [RCP IPCC 2014] rather than a lower projection and that its mention was unnecessary in this part of the report.

[161] We concluded the reference to the Policy 3 precautionary approach should be removed from the Report for it does not add anything and does not apply to the relevant issues to which it applies.

NZCPS Policy 24(1)(a)-(h)

[162] As noted earlier, the Terms of Reference itself makes no mention of NZCPS Policy 24 – it was introduced in some of its aspects by Tonkin & Taylor on its own initiative.[37] The details of the policy are set out here:

> **Policy 24 Identification of coastal hazards**
>
> (1) Identify areas in the coastal environment that are potentially affected by coastal hazards (including tsunami), 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:

[36] PCE etc

[37] GHD Bundle of Documents Appendix B Original Terms of Reference for Tonkin &Taylor and Variation 2014. Consultancy Services Agreement for Coastal Chapter – Coastal Hazard Assessment between Tonkin & Taylor Ltd and Christchurch City Council, p 22.

(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.

[163] These provisions require aspects of the definition of 'hazard risk' to be applied as appropriate to the coast and harbour – identification of areas of the coast 'potentially' subject to coastal hazards - that is, an assessment of its likelihood and consequences. 'Risk' is expressed in the NZCPS in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence[38]. This requires a close examination of the 'likely' effects of climate change on the Christchurch jurisdictional district. Policy 24(1) also accords a priority assessment to areas of high risk.

Identification of areas potentially subject to coastal hazard risk

[164] Environment Canterbury Regional Council (ECan) developed two CHZs for the Canterbury region as set out in the Operative Regional Coastal Environment Plan (RCEP, 2005):

- Coastal Hazard Zone 1 (CHZ1) – landward limit of the active beach system including any long-term rates of erosion to **50 years**.
- Coastal Hazard Zone 2 (CHZ2) – landward limit of the active beach system including any long-term rates of erosion to about **100 years.**

[38] AS/NZS ISO31000.2009 *Risk Management – Principles and Guidelines* – November 2009.

[165] These coastal hazard zones were identified on the basis of the previous NZCPS (2004) and not NZCPS (2010), and by definition do not include inundation.

[166] The Report indicates areas of coastal hazard risk from inundation and erosion and climate change (sea level rise) and its scope identifies the extent of the coastal settlements and communities located on non-consolidated sediment shorelines within the Christchurch region:

Open coast

- Southern Pegasus Bay from Waimairi Beach to Southshore including the South Brighton spit.

(The Southern Pegasus Bay shoreline was assessed to be an accreting shoreline and therefore only CHZ1 was mapped at the landward limit of the active beach system in this area.)

- Sumner and Taylors Mistake

Harbour coast

- Avon-Heathcote Estuary
- Lyttelton Harbour
- Allandale
- Teddington
- Charteris Bay
- Purau
- Akaroa Harbour
- Akaroa Township
- Takamatua
- Duvauchelle
- Wainui
- Brooklands Lagoon[39]

Policy 24(1)(a) Physical drivers in processes that cause coastal change including sea level rise

[167] Understanding these aspects of the causes of coastal change is a key issue that must be carried out to enable a robust hazard assessment.

[168] The physical drivers and processes are set out in clear detail under 2.2 Coastal Processes. These include water levels with their key components (including medium term fluctuations such as astronomical tides, atmospheric factors such as seasons, El Nino-Southern Oscillation (ENSO) and Inter-decadal Pacific Oscillation (IPO) which can all affect the mean level of the sea at a specific time (refer to Figure 2-2). The combined effect of these fluctuations may be up to 0.25 m according to Bell (2012).[40] These fluctuations should be measured when time allows. Storm surge, storm tide levels,

[39] T&T Report, 3 Previous Assessment Methodology, p 12.
[40] Bell, R (2012). *Sea Levels for New Zealand Give us a Number Please. Presentation at Sea Level Rise*: Meeting the Challenge Conference, Wellington 10-11 May 2012.

wave effects, long term sea levels and the Waimakariri River sediment supply are also drivers.[41] The Waimakariri River is a major source of sediment for the Southern Pegasus shoreline, resulting in an historic trend of shoreline and a major source of accretion.

Policy 24(1)(b) Short and long term dynamic fluctuations of erosion and accretion

[169] Dynamic shoreline fluctuations are taken to be variations about an assumed equilibrium or baseline position due to the effects of erosion and accretion.

[170] The variations can occur in space – locations along the coast respond differently to specific drivers. In the case of the open coast in Christchurch evidence indicates that the patterns of shoreline response vary between southerly and northeasterly storms.

[171] More importantly for Policy 24(1)(b), variations can occur at a range of different time-scales. The Report has effectively considered two time scales as identified in their Equation 2 for the Open Coast CEHZ:[42]

- Short-term fluctuations that include storm cut (and subsequent post-storm recovery); this determined by analysis of approximately 6 monthly beach profile data for 1990-2014, and hence represents the cumulative shoreline response to a range of processes as observed via the almost 30 years of 6 monthly monitoring data. This would include effects of storms, fair-weather periods, and any seasonal effects (winter versus summer).

- Long-term rate determined by DSAS analysis of aerial photographs between 1941 and 2001. This represents the cumulative shoreline response to a range of processes over 70 years.

Policy 24(1)(c) Geomorphological character

[172] As the methodology used for assessing coastal hazards evolves towards a probabilistic assessment of risk, issues like this should be addressed. The Tonkin & Taylor Northland Report sets out an extensive description of Northland's geomorphological character.[43] For this Report, the geomorphology was treated as being the same for all coastal cells, and all low-lying areas fringing the harbours and estuaries. Given the time-frame that this Report was prepared in, it can be argued that application of a non-linear baseline would have required too much time.

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[41] T&T Report 2.2 Coastal Processes, pp 3-7.
[42] T&T Report 1999: Study of the Effects of Sea Level Rise for Christchurch, p 74.
[43] Tonkin &Taylor Report: Coastal Erosion Hazard Zone Assessment for Selected Northland Sites 2014, 3 Coastal Processes, 3.1 Geology and Geomorphology, p 14.

Policy 24(1)(d) The potential for inundation of the coastal environment, taking into account potential sources, inundation pathways and overland extent

[173] All of these issues are summarised in Section 1 Findings and Recommendations in the Report.

[174] We note the word 'potential' is identified as a qualification to the meaning of 'effect' under s 3 RMA Meaning of Effects.[44] The Environment Court has held under s 104(1) RMA (a resource consent application) that each potential effect raised in evidence should be assessed quantitatively and/or qualitatively in the light of the principles of the RMA and relevant objectives and policies.[45]

Policy 24(1)(e) Cumulative effects of sea level rise, storm surge and wave height under storm conditions

[175] The cumulative effects of these factors are included in the historical data. The difficulty arises with the assessment of the future cumulative effects. Due to the specific identification of climate change in Policy 24(1)(h), Policy 24(1)(e) suggests that the evaluation of coastal hazard should include assessment of the future cumulative effects of these processes *without the effects of climate change*, before the additional effects of climate change are incorporated.

[176] In other words, the Report should include a scenario that only applies historical trends in Equation 2 to illustrate what the risks would be without climate change, for that is the way the particular sub-policies are worded. The suggestion appears to come from the Tonkin & Taylor (Options) Report (1999) Conclusions and Recommended Responses[46] but was not identified within the Terms of Reference. We note, however, that the previous ECan CHZ may have all the data required as it assessed coastal hazards without climate change effects.

Policy 24(1)(f) Influences an assessment that humans have had or are having on the coast

[177] For the purposes of this Report, the dune system along the coast and inundation pathways are one of the issues: see Table 4-2 Coastal Inundation Hazard and Component Values. The results indicate:

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[44] **3 Meaning of effect**
In this Act, unless the context otherwise requires, the term **effect** includes –
(a) Any positive or adverse effect; and
(b) Any temporary or permanent effect; and
(c) Any past, present, or future effect; and
(d) Any cumulative effect which arises over time or in combination with other effects – regardless of the scale, intensity, duration, or frequency of the effect;
(e) Any potential effect of high probability; and
(f) Any potential effect of low probability which has a high potential impact.

[45] *Clifford Bay Marine Farms Ltd v Marlborough District Council* (EC) C131.03.

[46] T&T Report 1999: Study of the Effects of Sea Level Rise for Christchurch, p 74.

- The elevation of the foredunes located along the open coast from Waimari to the Avon-Heathcote Estuary mouth are agreed as generally sufficient to mitigate coastal inundation hazard. These foredunes covered in Marram grass are the constant focus of maintenance and care from CCC's Rangers. Originally these dunes were covered in native vegetation such as pingao but early European Christchurch pastoralists grazed the New Brighton Spit dunes, leading to the loss of their palatable vegetation. When it was realised that this had created a sand stability problem, the spit was replanted but using the introduced marram grass as a dominant species. Marram grass creates tall, narrow dunes. It is arguable that space may no longer exist for the lower profile, wider pingao dunes to be fully re-established along the spit due to the presence of backsore infrastructure and development, although this concept is worth scientifically testing through the trial plantings undertaken.

- Many areas of the Southshore suburb are at risk from inundation from both the Avon-Heathcote Estuary side as well as from open coast dune inundation or erosion (note the dunes at the southern end of the New Brighton Spit are relatively low compared to most other locations along this coast).

- There are three sites at New Brighton where the foreshore dunes have been highly modified such that they are left with inundation pathways through the foredunes because of the siting of the New Brighton Library, the North Brighton Community Centre and North Brighton Beach Surf Lifesaving Club. Placing inundation in such a sensitive area gives pause for reflection.

- But because the inundation pathways are relatively narrow, the volume of water able to travel inland will be restricted within the time period of a typical storm event. But what of the effect of sea level rise over and above a typical storm event? These three locations also represent significant tsunami inundation vulnerabilities today[47].

- The Main Road behind the dunes may be vulnerable in the long term.

- Creation and modification of sea walls along the southern Sumner beach may be a major issue for the future, depending on the rate of inundation and erosion. Hard protection structures can be eroded away, leaving land, infrastructure, and buildings behind at risk (as have the foundations of the Esplanade at St Clair, Dunedin).

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[47] Hart, DE, and Knight, GA (2009). *Geographic information system assessment of tsunami vulnerability on a dune coast*. Journal of Coastal Research, 131-141.

Policy 24(1)(g) The extent and permanence of the built environment

[178] The Terms of Reference identify the locations that Tonkin & Taylor were expected to assess. These are identified above. Thus the extent of the study includes the coastal settlements based on non-consolidated sediment shorelines within CCC's boundaries. The permanence of the built environment in these areas is not within the Terms of Reference and will be more appropriate when Policies 25 and 27 are addressed in the second and third stages of adaptive management and/or under s 32 RMA.

Policy 24(1)(h) The likely effects of climate change on the district on all of the above (a) to (h) of the policy

[179] This provision indicates an over-ride to all of the above – clearly separated out in the wording of the policy.

[180] The Report has focused on one process (sea level rise) as the issue for potential changes over and above other processes.[48] The Bell (2001) assessment[49] of the impacts of climate change for the Canterbury Coast notes that 'Sea-level rise gets the publicity, but climate change will also affect other important coastal 'drivers' such as waves, winds, river flow, and storms, which in turn could substantially alter sediment supply to the coast with the potential to cause further erosion in some areas'. Nevertheless, we do consider that Tonkin & Taylor did try to take into account the effects of climate change on river flows and on sediment budget. It used NIWA's medium term forecast for this. We consider, however, that these NIWA forecasts are too narrow and conservative as they don't take account of anthropogenic water demand. The company did follow NIWA, however, on the climate change aspects of river flow and sediment budget which is arguable following the lead authority.

[181] The Report's authors need to be mindful that the preamble in Policy 24(1) has a caveat: [50] Are the areas identified in the Report those of *high* risk?

[182] It would be helpful if the Report could identify more clearly any baselines apart from sea level rise to distinguish between that and other drivers to the impact of the change in climate?

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[48] Tonkin & Taylor (2015). Coastal Hazard Zone Assessment for Christchurch City – Stage Two. Coastal Erosion Hazard, p 5. 'The mapping will identify areas susceptible to coastal erosion hazard by using the passive inundation extent (erosion due to sea level rise) as a baseline and applying an additional buffer to allow for both the SF and LT parameters.'
[49] Bell, R., 2001. Impacts of climate change on coastal margins in Canterbury. NIWA Client Report CHC01/69, prepared for Environment Canterbury, July 2001. 22 pp.
[50] Appendix A1 Scope, Purpose, Program and Completion Date for Coastal Chapter – Coastal Hazard Assessment Stage Two, p 29 ff.

[183] In the MfE (2008b) Guidance Manual[51] a definition of climate change is provided as 'a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer)'.

[184] The definition of climate change in s 2 RMA identifies that the concept means 'a change of climate that is attributed directly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability over a considerable time period'.[52]

[185] The constant in both definitions appears to be:

- a statistical variation in either the mean state of the climate or its variability …

- a change of climate that allows for the changes in the composition of the global atmosphere due to human activities and **that is in addition** to natural climate variability …

[186] Thus what NZCPS Policy 24(1) requires is an examination of the mean state of the current climate and its variable adjustments, a statistical characterisation of that data, or an assessment of potential climate change in addition to natural climate variability in order to provide (with medium confidence) the likely effects on the Christchurch district.

[187] IPCC AR5 Table 25-1 provides a chart of climate variables including mean air and sea surface temperatures, precipitation (rainfall), fine weather, drought, severe storms, snow and ice. The categories include projected change, its direction, examples of projected magnitude of change relative to, for example, 1990 with additional comments.[53]

[188] An assessment incorporating those factors would assist the community in identifying statistical shifts in the statistics.

[189] It is also identified as a characteristic of climate change in the two key national documents – MfE (2008b) and Ramsay et al (2012).[54]

[190] The term 'likelihood' is defined in MfE (2008b) as 'Likelihood is a qualitative (and possibly quantitative) measure of the probability or chance of something happening'. Ramsay et al (2012) consider that 'Quantifying uncertainty to underpin risk-based decision making' identifies that

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[51] Ministry for the Environment (2008) Coastal Hazards and Climate Change: A Guidance Manual for Local Government in New Zealand, Glossary, 9 pp 87.
[52] Resource Management Act 1991, s 2.
[53] IPCC AR5 Chapter 25 25.3 Australasia Socioeconomic Trends Influencing Vulnerability and Adaptive Capacity, pp 1380-1381.
[54] MfE (2008b) 9 Glossary, p 92. 'Sea-level rise – Trend of annual mean sea level over timescales of at least three or more decades. Must be tied to one of the following two types: global – overall rise in absolute sea level in the world's areas; or relative net rise relative to local landmass (that may be subsiding or being uplifted).

quantification of this uncertainty can bring a much richer level of information to hazard decision making as it is required in New Zealand'.

[191] Ramsay et al (2012) consider that a way to capture quantification is to apply it in a probabilistic way, which is what has happened in this Report since it provides a range of projections with associated probabilities.

Conclusion

[192] After this review of the Report in the context of the statutory documents, only one stands out that has direct relevance to mapping to a standard suitable for the district plan – and that is Policy 24(1)(a)-(h). There is no cross-reference in the Report to indicate it was followed in all its directives and the panel was left to surmise.

[193] In this case of such importance to CCC, the community, and the authors of the Report, it was important for CCC officials/lawyers to brief the authors of the Report as to the statutory underpinnings of what the authors would be expected to assess. Such briefing may have occurred here, but the documentation around the Terms of Reference and the 20 day completion limit for the Report may well be a factor that prevented such a briefing, with the result there is a lack of clarity whether the appropriate provision NZCPS Policy 24 met what was legally required.

[194] But this does not affect our overall conclusion as to whether the Report is fit for purpose.

Are the findings in the Report appropriate for their intended purpose – informing planning for future land use? Do the methods and assumptions made in the report compare to those used nationally and internationally to inform decisions on a response to sea level rise?

[195] There are two inter-related aspects generally considered as a consequence of sea level rise: coastal inundation due to higher mean sea levels, and the interaction of higher sea levels with the processes that contribute to extreme water levels such as gravity waves (wave set-up), storm surges, and extreme tides (king tides); and coastal erosion. Ramsay et al (2012) provide a national guide to good practice, which is similar to those produced for individual states in Australia (Victoria, New South Wales, and Queensland[55]) as well as overall for engineers in Australia. The Ramsay et al (2012) good practice guide is also similar to approaches used in the USA and EU.

[196] The Ramsay et al (2012) guide identifies community involvement in the very early stages and throughout the process as being 'often of critical importance in the ease of acceptance by the

[55] That a member of the panel is aware of and has viewed.

community', and highlights this aspect in Figure 1[56]. Section 2.4 of the guide[57] provides a checklist of good practice for coastal hazard assessments where relevant for community stakeholders. This checklist includes aspects raised by the local community in their questions for the panel.

[197] The Tonkin & Taylor reports (V1 and V2) do not follow this practice for community involvement as indicated in Figure 1 and Box 3 of Ramsay et al (2012). However, Table 1 in Ramsay et al (2012)[58] does not identify community involvement as a key consideration in scoping a coastal hazard assessment. It appears Tonkin & Taylor follow the model in Table 1 and predominantly rely on their coastal hazard expertise. This may have been due to the limited time available for the preparation of the reports.

[198] The panel is endorsing no community involvement in the technical first stage of identifying areas of coastal hazard risk, but community involvement in the second and third stages before maps are included in the CRDP and LIM reports.

[199] It is reiterated that the Ramsay et al approaches give rise to conservative over-estimates of both CEHZ and CIHZ – also that by agreement with CCC the report only considered RCP8.5 – for future community assessments of adaptation options and pathways through time additional RCPs are needed to better inform the community.

[200] CEHZ open beaches – it is noted that the best practice probabilistic approach as established can readily be used to reassess the impacts of new information. It is recommended that the Monte-Carlo simulations be re-evaluated with the inclusion of spatially variable distributions being applied to the ST short term erosion components prior to the finalisation of the CEHZ – the outcome may result in a reduction of the landward extent of the CEHZ. Additional recommendations for the first reassessment/review are to include more detailed analysis of beach profile data for estimation of short and long term erosion, and to examine the uncertainty in the sedimentation transport feed from the Waimakariri. Future analyses for CEHZ should include beach volume change as well as dune toe horizontal movement.

[201] CIHZ open beaches – building block approach taken to include storm surge, wave set-up and sea-level rise – 2065 hazard zones fit for purpose but would benefit from an early re-assessment of the wave setup values which are a significant proportion of the total inundation levels – 2115 hazard zones overestimated due to adopting 1% surge with 1% wave set-up and 2115 RCP8.5 sea-level rise It is recommended that an updated thorough analysis for extreme water levels of all water level monitoring stations in the Canterbury area be undertaken prior to the first

[56] Figure 1 indicates local community involvement/input at each stage of the hazard assessment process.
[57] Box 3 page 13.
[58] Ramsay et al identify local residents as potential sources of information on the importance of different processes, and suggests the local community may contribute (inter alia) to deciding on the interpretation, synthesis and presentation of results, p 10.

reassessment/review . It is recommended that the first reassessment/review should include probability analyses of likelihood of peak wave set-up occurring at same time as peak storm surge.

[202] CEHZ harbour sites - the indicated coastal erosion hazard zone for all harbour sites including the Avon-Heathcote Estuary and Brooklands Lagoon are not fit for purpose, are misleading and should not be considered as indicative of likely erosion hazard. It is recommended that they be re-assessed with more attention to detail and on-ground inspections. The ‘high tide translation’ method values must be discarded and only the ‘equilibrium profile’ values considered. The zones should not extend up small inlets. It is noted that the extent of the indicated CEHZ erosion hazard are contained within the wider extent of the CIHZ coastal inundation hazard zones discussed below.

[203] CIHZ harbour sites - building block approach taken to include storm surge, wave set-up, wind set-up and sea-level rise – 2065 hazard zones fit for purpose but would benefit from an early assessment of the over-estimate arising from the inclusion of 2% AEP wave and wind set-up estimates for wind along longest fetch. The 2115 hazard zones are likely to be significantly overestimated due to adopting 1% surge with 1% wave and wind set-up along longest fetch with 2115 RCP8.5 sea-level rise. It is recommended that an updated thorough analysis for extreme water levels of all water level monitoring stations in the Canterbury area be undertaken for the first reassessment/review. It is recommended that the first reassessment/review should include probability analyses of likelihood of peak wave set-up occurring at same time as peak storm surge.

Does the Report focus on upper end scenarios at the expense of more likely scenarios?

[204] IPCC’s AR5 RCP8.5 is based on a very high emission scenario, atmospheric concentrations, air pollutant emissions and land use conditions, and is broadly comparable to previous IPCC assessments. It is categorised to be a best estimate of trends but excluding the collapse of the West Antarctic ice shelf.

[205] Based on Tonkin & Taylor’s understanding, the RCP8.5 represents an upper band of what is likely in terms of sea level rise based on what is currently known. It is termed a ‘very high scenario’ because global emissions give no indication that there is evidence from additional efforts to constrain emissions leading to pathways ranging between RCP6.0 and RCP8.5.

[206] The IPCC AR5 used for Representative Concentration Pathways (RCP) possibilities – RCP2.6, RCP4.5, RCP6.0 and RCP8.5 – to represent possible future outcomes. The ‘likelihood’ range for sea level rise presented for each possibility is based on a particular emission occurring. It is not a trend projection set in stone and is based on the collective judgement of the coastal scientists.

[207] In its Summary for Policy Makers (SPM 2015) the IPCC uses the following definitions of likelihood:

Virtually certain: 99-100%

Very likely: 90-100%
Likely: 66-100%
As likely as that: 33-66%
Unlikely 0-33%
Very unlikely 0-10%

[208] IPCC also uses five qualifiers – very low, low, medium, high and very high.[59] The word 'likely' in Policy 24(1) is used in the context of 'taking into account national guidance and the best available information on the *likely* effects of climate change on the region or district', that is, with *medium confidence*. The likely projections for GMSLR lie within the 0.2 m range until the middle of the 21st century (Figure 13.11).

[209] The Parliamentary Commissioner for the Environment identifies that sea level is projected to rise by about 30 cm between 2015 and 2065, calculated by a base level of 27 cm with 10% added on,[60] because IPCC considers New Zealand regional sea rise may project up to 10% more than global SLR. The Commissioner's assessment takes the average of the midpoints in IPCC (2015) as about 26 cm. The additional 10% rise proposed by the IPCC gives a figure of 28.6 cm, rounded out to a value of 30 cm. We note too that the Parliamentary Commissioner expresses the results in her document in terms of exceedances of high water levels that are currently expected to occur only once every hundred years – or a 1% chance in any one year at present (with the predicted rate of exceedances changing over time).

[210] In the relevant IPCC documents, it is stated that 'It is *likely* (with *medium confidence*) that the annual mean significant wave heights will increase in the Southern Ocean as a result of wind speeds. While Southern Ocean-generated swells are *likely* (with *medium confidence*) to affect heights, periods, and directions of waves in adjacent basins'.[61] El Nino Southern Oscillation effects can raise or lower the level of the sea around New Zealand by as much as 12 cm. Interdecadal Pacific Oscillation effects can raise or lower sea level by about 5 cm.[62] These are temporal uncertainties, the practical effects of which may be factored into more detailed possible scenarios for sea level rise.

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[59] IPCC Chapter 13 Sea Level Change: 13.5 Projections of Global Mean Sea Level Rise, p 1179-1180.
[60] Parliamentary Commissioner for the Environment (2015) *Preparing New Zealand for Rising Seas: Certainty and Uncertainty*. Notes, 7, p 82, citing IPCC 2014 Working Group 2, Chapter 25, p 1381. Hannah and Bell 2012, para 32.
[61] Ibid Chapter 13 Sea level Change, pp 1179-1181.
[62] NIWA 2015 b, p 31.

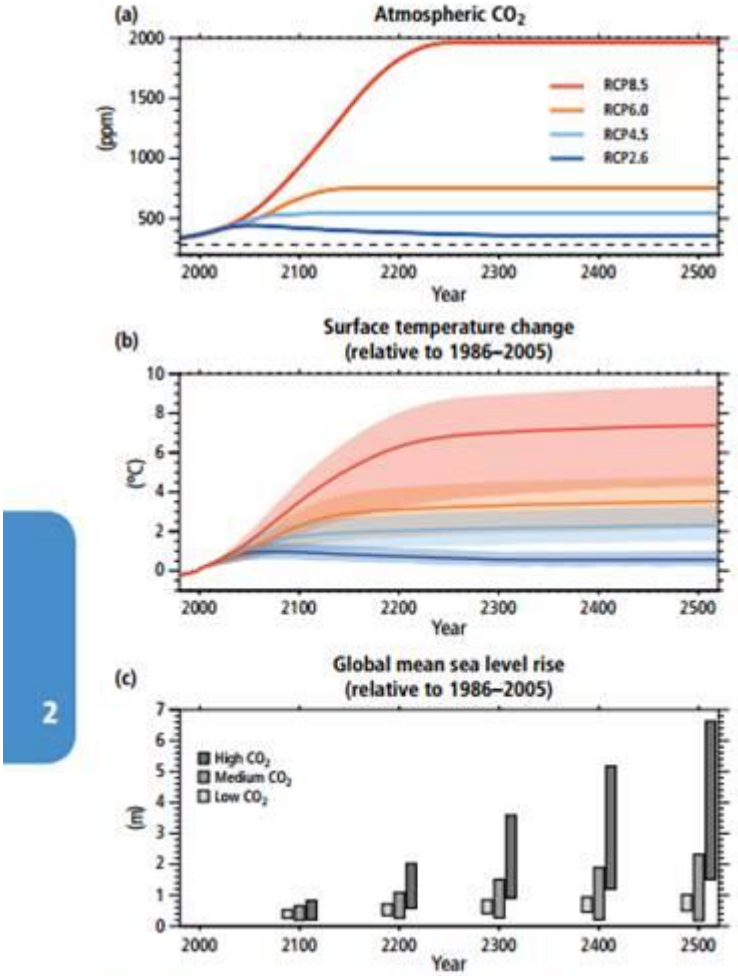

Figure 2.8 | **(a)** Atmospheric carbon dioxide (CO_2) and **(b)** projected global mean surface temperature change as simulated by Earth System Models of Intermediate Complexity (EMICs) for the four Representative Concentration Pathways (RCPs) up to 2300 (relative to 1986–2005) followed by a constant (year 2300 level) radiative forcing. A 10-year smoothing was applied. The dashed line on (a) indicates the pre-industrial CO_2 concentration. **(c)** Sea level change projections grouped into three categories according to the concentration of greenhouse gas (in CO_2-eq) in 2100 (low: concentrations that peak and decline and remain below 500 ppm, as in scenario RCP2.6; medium: 500 to 700 ppm, including RCP4.5; high: concentrations that are above 700 ppm but below 1500 ppm, as in scenario RCP6.0 and RCP8.5). The bars in (c) show the maximum possible spread that can be obtained with the few available model results (and should not be interpreted as uncertainty ranges). These models *likely* underestimate the Antarctica ice sheet contribution, resulting in an underestimation of projected sea level rise beyond 2100. *{WGI Figure 12.43, Figure 13.13, Table 13.8, WGII SPM B-2}*

Appropriate use of 100 year and 50 year time frames?

[211] 'Over' 100 years is the timeframe identified in the NZCPS (2010), with scientists noting that sea level rise is anticipated to continue well over the next century. Meanwhile, action taken to reduce greenhouse emissions will make little difference to the rate of sea level rise for several

decades as a result of the past effects of greenhouse gas emissions moving slowly through the Earth's system.[63]

[212] This is why the qualification 'over' 100 years in the NZCPS Policy 24 was ruled more appropriate than a 'fixed' horizon.

[213] The panel scientists have a high degree of confidence in the IPCC projections for sea level rise over the next 50 years. Some talk about sea level rise being 'locked in' as emission reductions cannot affect this 50 year time frame response in earth systems, with significant scenario variability only possible after that. But the panel considers that while the emissions tracking scenario is reasonable, it is not necessary to insist on a range of values for RCP2.6.

[214] For beyond 50 years, emissions, and therefore temperature and sea level responses, are less certain.

Did the Tonkin & Taylor assessment allow the subsequent use of adaptive planning responses by CCC?

[215] The answer is yes and no. It was not required to under its Terms of Reference. But in effect, the Report does not close off adaptive planning responses by identifying a possible scenario for 2100 by using IPCC RCP 8.5 as its benchmark thus:

> Modelling presented within the most recent IPCC report (ARS; IPCC, 2014) show predicted global sea level rise values by 2100 to range from 0.27 m. which is slightly above the current rate of rise, to 1 m depending on the emission scenario adopted (Figure 2-3). The Representative Concentration Pathways (RCP) 8.5 scenario assumes emissions continue to rise in the 21st century on a 'business as usual' rate. We consider assessing the effects of this scenario is prudent until evidence of emission stabilising justify use of a lower projection scenario. Extrapolating the RCP 8.5 scenario to 2115 results in a potential sea level range from 0.62 to 1.27 m by 2115 (Figure 2-3). We note these figures do not include for the collapse of the marine-based sectors of the Antarctic ice sheet. However, this contribution is not likely to exceed several tenths of a metre of sea level rise during the 21st century (IPCC, 2015).

[216] The IPCC assigns no probabilities, only possibilities, to the scenarios it describes as RCP2.6, RCP4.5, RCP6.0 and RCP8.5. Accordingly, the projection of sea level rise should be described as a range of scenarios in order to be able to identify the resulting hazard lines.

[217] The IPCC, as does the Report, provides this range of possibilities over a 50-100 year time frame where sea level rise issues will have some effect. The likelihood range for sea level rise presented for each scenario by IPCC is based on a particular emission level possibly occurring. What

[63] Parliamentary Commissioner for the Environment, Preparing New Zealand for rising seas: Certainty and Uncertainty, Note 6, p 82.

is described above is only one likely scenario that can then be used to inform ongoing discussions and the development of adaptive pathways.

[218] The residential stakeholders have a right to be informed at the various key stages the different possibilities provide, and plan accordingly after the technical report is completed.

[219] Once the technical science surrounding the identification of areas in the coastal environment potentially affected by coastal hazards has been established with priority given for areas of 'high risk',[64] and the requirements in NZCPS Policy 24(1)(a)-(h) have been addressed more thoroughly, then the first stage in the planning process will be complete.

[220] Then, as the Parliamentary Commissioner advises 'decision makers [after this first stage] should then take the modelling outputs including estimates of uncertainty, and openly and transparently decide how cautious to be in delineating hazard zones'.[65] Establishing the levels of coastal hazard and climate change risks to the communities and the local and national infrastructure is a second stage in planning with its own technical implications.

[221] Thus, for the time being, the conclusions in the first and second stages should not extend to firm hazard lines designed to go into the LIM reports or for inclusion in the CRDP as maps or zones.

[222] The question of 'risk' from coastal hazards arises firstly in NZCPS Policy 24 in the 'Identification of areas affected by coastal hazards' giving priority to the identification of areas of 'high' risk. Assessment of 'risk' and its consequences arises more broadly under NZCPS Policy 25 'Subdivision use and development' in the areas of 'coastal hazard risk'; and in Policy 27(1) 'Strategies for protecting significant existing development from hazard coastal risk'.

[223] Adaptive management in evaluating options to avoid and manage the expected effects from climate change (Policy 27(2)(b)) enters the planning frame at this stage, as does the application of the Policy 3 Precautionary approach to evidence of the risk related to management of coastal resources potentially vulnerable to effects from climate change so that available social and economic loss and harm to communities does not occur.

[224] This second stage of coastal hazard assessment from climate change should provide a number of levels of risk technically established with input from the community – not just at the high

[64] Parliamentary Commissioner for the Environment (2015). *Preparing New Zealand for Rising Seas: Certainty and Uncertainty*, p 78. The Parliamentary Commissioner sees the first stage of defining areas of coastal hazard risk as the gathering and provision of information, including accurate maps of elevation in coastal areas.
[65] Ibid n 1. 8.6 Engaging with Communities, p 78.

end with which to inform authorities of how to deal with the identified risk. Some of the community questions around the Report relate to this issue.[66]

[225] Analysis of defined risk and adaptive management planning processes which go with it can provide pathways for stakeholders to go hand in hand with management of the risk and should apply also at the third stage of the planning process. These processes can develop implementation pathways that can be developed for the range of scenarios predicated in the RCPs and to an even more detailed extent after consultation, so that a full range of consequences can be established. Open communication among stakeholders in a time of such uncertainties particularly around climate coastal hazard risk, is required.

[226] Adaptation pathways are a sequence of linked strategies that are triggered by a change in environmental conditions, and in which initial decisions can have low regrets and preserve options for future generations. Central to these approaches is the principle that adaptation cannot be solved through a single action, but is rather a process to be managed over time. An adaptation pathway is a decision strategy that entails a vision for the entity exposed to climate risks, to be met through a sequence of manageable steps over time, each of which is triggered by a change in environmental or social conditions – adaptation trigger points. Process is as important as outcomes – because it is essential the process endures.

[227] The adaptive pathways planning approach is used at the options analysis stage and helps develop an implementation pathway which can be done for a range of scenarios (across the RCPs) so the full range of possible consequences can be investigated. Otherwise, picking a number for decisions today runs the risk that it will be redundant or wrong, and the activities that last at least 100 years will be detrimentally affected. Ways have to be found of generating a number of different pathways and identifying decision points along the way at which the course can be changed and still meet the objectives of the adaptive plan. A researcher of the New Zealand Climate Change Research Institute (NZCCRI) here has investigated a dynamic adaptive pathways planning approach (DAPP) for crafting flexible decisions that are robust over whatever outcomes evolve, and it is being put into practice. [67]

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[66] See GHD Bundle of Documents, Appendix F Sumner Community Residents Association: Questions and Requests for Clarification on Coastal Hazard Report (Tonkin & Taylor). Questions 1, 2, 10, 11, 13.

[67] Lawrence, J citing Haasnoot et al (2013). *Dynamic adaptive policy pathways: A method for crafting robust decision for a deeply uncertain world*. Global Environmental Change 23 (20) 485-490.

The NZCCRI at Victoria University of Wellington ran a series of Adaptive Management seminars that have demonstrated how and what can be achieved around the concept. The results of emerging issues from these seminars resulted in projects in the Wellington, Tasman and Nelson regions with engineers, planners, council officers and politicians involved adopting the notion of the process. From these seminars the NZCCRI then developed risk-based framings of climate change impacts which the communities were fully involved with. The end result in the Wellington region around the flood risk from the Hutt River has resulted in the following plan provision which has been adopted:

[228] The Parliamentary Commissioner also recommends a much slower process that actively engages with those affected before final (planning in this case) decisions are made.[68]

Conclusion

[229] We consider that overall the Report is fit for purpose, subject to revision of the calculations undertaken to determine the open coast CEHZ, and deletion of the mapped harbour coast CEHZ lines. We have also identified areas that should be considered for further research before the first reassessment of the coastal hazard zones, and suggested improvements to methodologies that should be incorporated in the first reassessment.

Greater Wellington Regional Council Climate Change Strategy and Implementation Plan 2015
'GWRC commits to an approach that enables us to make decisions in the face of uncertainty.'
Adaptation policy includes:
'Consider the effects of climate change as an integral part of planning and decision-making. Increase long-term adaptive capacity through the use of adaptive planning tools and techniques.
Implementation plan includes:
'Use adaptive planning concepts to understand and evaluate the potential long-term consequences of different policy actions using Sustainable Delta Game workshops which are underway.'

The first stage of the process should be to collect that information with most certainty, that is, land levels, geomorphology, asset exposure, land use.
The second stage of the process should be to overlay a series of scenarios for sea level changes in discussion with those most affected.
The two sets of information create an adaptation map which collates expert and local knowledge while establishing a mutually agreed level of risk exposure.

[68] Ibid.

Summary of recommendations

For the present Report and assessment exercise:

[230] We recommended that the **open coast CEHZ maps** are revised before they are used for planning purposes as follows:

(a) The short-term (ST) and long-term (LT) component values should be re-assessed as indicated in this report. Specifically, ST and LT component estimates should be evaluated based on the measured probability distribution (ST) and a normal distribution (LT). Normal, rather than triangular, distributions should be considered for the other components in the probability analysis.

(b) The Monte-Carlo simulations should be re-run taking into account the new ST and LT component estimates, and these should be based on individual coastal cell distributions.

[231] For the **harbour coast CIHZ**, with respect to the Avon-Heathcote Estuary TUFLOW model, the calculations to justify the value of 0.4 m allowance for wave and wind setup should be included in the Report.

[232] We recommended that for **all harbour coast sites that the CEHZ** mapping is re-assessed, including the following:

(a) The harbour CEHZ as currently mapped in the Report should be discarded.

(b) More attention should be paid to detail and on-ground inspections, and profile slopes should be reviewed.

(c) The ‘high tide translation’ method values should be discarded and only the ‘equilibrium profile’ values considered.

(d) The zones should not extend up small inlets.

Other

[233] We recommend that the Report with the observations the panel has made is to be taken as a trigger for further study to ensure a revised report on the subject is fit for purpose.

[234] We recommend that a revised report be used as a starting point to further identify adaptive planning procedures for coastal hazard identification and the adverse effects of climate change. Only after this should any revised planning maps be included in the CRDP.

[235] The Report needs to be revised taking into account the requirements of Policy 24(1)(a)-(h) and to identify the hazard lines fit for purpose to create a series over the identified time span. Taking account of this statutory policy in this way would help land use planning to forecast and map.

[236] It is recommended that some thought be given to NZCPS Policy 4 Integration, a directive that should apply around coastal hazards and climate change. Both ECan and CCC together could well benefit.

For the first reassessment (that is, the future, '10 year' reassessment):

[237] For both the open coast and harbour coast CIHZ and CEHZ:

(a) It is recommended that a review of published research be incorporated into each reassessment.

(b) We recommended that future reassessments consider multiple RCPs, acknowledging that the likely RCP pathways may have become clearer at this stage.

[238] Where applicable:

(a) We recommend the incorporation of new photography, LiDAR or other ground elevation data, and ongoing ECan beach profile data in the first reassessment.

(b) With respect to the above, we recommend to government that future LiDAR surveys of Canterbury cover the areas predicted to be affected by coastal hazards over the next 100 years in the Report, plus adjacent low-lying land.

(c) We also recommend that government undertake a thorough analysis of the extent of the increased flood vulnerability of estuary proximal areas once remediation of the red zone areas is fully completed.

[239] For both the open coast and harbour coast CIHZ:

(a) We recommended that an updated thorough analysis is undertaken of extreme water levels for all water level monitoring stations in the Canterbury area for inclusion in the first reassessment.

(b) In conjunction with the above, we recommend that the likelihood of concurrence of extreme waves and coincidence of peak wave setup and wind setup be investigated for inclusion in the first reassessment.

[240] For the open coast CIHZ:

(a) We recommended that the deep water wave climate is updated, and that wave setup with transformation across the surf zone is re-evaluated using both the CEM and alternative methodologies (e.g. consider use of the Dally et al. (1985) surf zone wave transformation model that is incorporated in SBEACH). The effect of these updates on the total inundation levels should be assessed and, where necessary, the CIHZ mapping amended at the first reassessment.

(b) We recommend that wave runup calculations are performed for likely levels and/or overwash, with assessment included of safety for people or vehicles and damage to property, especially in areas where overwash is likely such as the pier library area at New Brighton.

[241] For the open coast CEHZ:

(a) We recommend that a Pegasus Bay coastal monitoring analysis report, including careful analysis of beach volume and excursion indices, is produced before the first reassessment. This report should include comparisons of beach profile analyses with existing sediment budget research.

(b) We recommended that the above monitoring report is used to inform the ST and LT components used in the first reassessment.

(c) We recommend that probabilistic modelling is undertaken for the sediment budget component for the first reassessment. A range of sediment budget scenarios should be considered, with the current 'no change' scenario forming the middle scenario.

[242] For both the open coast and harbour coast CEHZ mapping: We recommended that the location and condition status (poor/inadequate OR good/engineering design standard) be indicated in the first reassessment.

[243] For the harbour coast CIHZ mapping: With respect to the TUFLOW modelling, it is recommended that the factors of river baseflows and coincident rainfall, and the influence of climate change on them, be incorporated in the first reassessment.

Glossary

AEP — Annual Exceedance Probability. Defines the probability of some phenomenon exceeding a specified condition (eg Coastal water elevation) at least once during a year. Commonly probabilities of 1% or 2% are used for hazard assessments.

AR4, AR5 — The 4th and 5th Assessment Reports produced by the IPCC, which are sub-divided into 3 main working group reports (WGI, WGII, and WGIII). The earlier reports are referred to as the FAR, SAR and TAR for the 1st, 2nd and 3rd reports respectively.

Bathtub approach — A bathtub approach uses a DEM to represent the topography (normally within GIS software). All areas with an elevation below a specified water level, which have a connection to the flooding source (river or sea), are considered to be submerged.

CCC — Christchurch City Council

CEHZ — Coastal Erosion Hazard Zone

CES — Canterbury Earthquake Sequence. A series of earthquakes starting in 2010, including two significant damaging events in September 2010 and February 2011.

CHZ — Coastal Hazard Zones (under the Regional Coastal Plan 2005)

CIHZ — Coastal Inundation Hazard Zone

CRPS — Canterbury Regional Policy Statement

CRDP — Christchurch Replacement District Plan

DEM — Digital Elevation Model

DS — Dune Stability factor

DSAS — Digital Shoreline Analysis System. This was developed by the US Geological Survey (USGS) for determining shoreline changes from digitized shoreline data.

ECan — Environment Canterbury (Canterbury Regional Council)

ENSO — El Niño-Southern Oscillation. A 2-7 year fluctuation in ocean and atmospheric circulation in the tropical Pacific Ocean characterised by two extremes: El Niño; and La Niña. ENSO is correlated with changes in precipitation, temperature, winds, sea level and wave conditions affecting New Zealand.

EQC — Earthquake Commission

GHD

GIS	Geographical Information System
GNS	Geological and Nuclear Sciences
HAT	Highest Astronomical Tide. The highest water level that can be expected to occur under average meteorological conditions over an 18 year period.
IFV	Increased Flooding Vulnerability
ILV	Increased Liquefaction Vulnerability
IPCC	Intergovernmental Panel on Climate Change
IPO	Interdecadal Pacific Oscillation. Multidecadal fluctuation in ocean and atmospheric conditions in the Southern Hemisphere. A similar pattern known as the Pacific Decadal Oscillation (PDO) occurs in the northern Pacific Ocean. The IPO is correlated with variations in sea level and precipitation patterns for New Zealand.
LiDAR	Light Detection and Ranging. A remote sensing technique that uses a pulsed laser to measure distances
LT	Long-term Trend for shoreline changes
MfE	Ministry for the Environment
NIWA	National Institute of Water and Atmospheric research
PCE	Parliamentary Commissioner for the Environment
RCP	Representative Concentration Pathway. The RCPs specify scenarios consisting of a time series of historical and future projected greenhouse gas concentrations, which are used to determine overall radiative forcing. The RCPs have also been expressed in terms of greenhouse gas emissions to meet the requirements of some models used to simulate climate. IPCC AR5 used 4 scenarios: RCP2.6, RCP4.5, RCP6.0 and RCP8.5. These correspond to an increase in radiative forcing relative to pre-industrial conditions of 2.6, 4.5, 6.0 and 8.5 $W.m^{-2}$ respectively.
SBEACH	Numerical model for simulating storm-induced beach profile changes. Originally developed by the Coastal Engineering Research Center of the US Army Corps of Engineers, it has evolved into a widely used model for predicting beach profile response to varying storm conditions.
SD	Standard Deviation
SL	Shoreline response to sea level rise
SLR	Sea Level Rise
ST	Short Term shoreline fluctuations
Tonkin & Taylor	Tonkin & Taylor Ltd

TOR	Terms of Reference
TUFLOW	A commercial numerical modelling package designed to simulate river flooding and coastal inundation by storm surges. It can also be used to simulate tidal flow behaviour in estuaries. It accounts for the effects of friction across land surfaces, and flow constrictions within urban drainage networks

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