Extreme sea-level elevations from storm-tides and waves along the Gisborne District coastline

Prepared for Gisborne District Council

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Executive summary

NIWA was commissioned to provide estimates of coastal storm inundation elevations along the open coast of the Gisborne region. By "open coast" we mean outside of sheltered harbours and estuaries, in locations subject to ocean swell or bay-wide wind waves. However, we have applied a wave-sheltering algorithm to transform the wave data from offshore, to the inside of coastal embayments that are common along the Gisborne coastline. Therefore, this study estimates the frequency and magnitude of high sea levels (storm-tide), large waves and the total combined sea-level from the two, at 33 locations along the Gisborne District coastline.

Results of the study have been built into a Microsoft Excel spreadsheet tool, supplied to Gisborne District Council. This "Coastal Calculator" makes the study outcomes and substantial data, instantly and easily accessible for coastal-inundation hazard risk assessments including the effects of sea-level rise, as required by the NZ Coastal Policy Statement.

This report introduces the Coastal Calculator. It supports the Calculator by explaining the data, models, methods and assumptions used to calculate the sea-level elevations that are presented in the Calculator.

The results from the Coastal Calculator will not need to be updated for some time, as the user can select the sea-level rise to add in that is appropriate for the particular design or planning requirement.

Beach slope is also another parameter the user can select, but will require some care in its application, as the wave run-up and setup are quite sensitive to the slope used (higher slopes will produce higher final inundation levels). The wave setup and runup formulae in the Calculator are state-of-the-art for sandy beaches and are widely applied worldwide. However, other wave setup and runup equations may work better on sections of the coast with complex vertical profiles and/or hard coastal defences. The Calculator (and this report) provides information on where to find these formulae and the working section of the Calculator allows for various wave setup and runup formulae to be applied, using the supplied offshore storm-tide and wave data.

The Coastal Calculator does not replicate all the information or processes involved in an extreme storm-tide and wave runup event and it is not intended as a complete replacement for detailed site-specific inundation studies or empirical evidence. Nevertheless, the Coastal Calculator supplies regionally consistent and statistically robust calculations of the wave climate and associated wave setup and runup, plus storm-tide elevations, along the entire regional coastline, underpinned by the state-of-the-art wave and storm-surge modelling. The Calculator should prove highly relevant to GDC.

Finally, the Coastal Calculator only provides vertical inundation levels at the coastline and does not produce the extent, depth or volume of inland inundation. This additional information would require the application of a static inundation methodology (e.g., GIS modelling) as a 1st order approach or a dynamic 2nd order approach using a coupled storm-tide and wave hydrodynamic model that use the elevated sea levels from the Coastal Calculator as offshore boundary conditions. Section 3 addresses methods to establish coastal inundation zones using the information contained in the Coastal Calculator.

1 Introduction

Gisborne District Council (GDC) is seeking more quantitative information on a specific combination of coastal-storm hazards for the Gisborne district coastline. GDC was granted an Envirolink medium advice grant (1428–GSDC112) for NIWA to develop defensible coastal inundation elevations and likelihoods as a result of combinations of elevated storm-tide, wave setup and wave runup, along the “open coast” of the Gisborne district coastline.

This project supports the Council’s work with its sustainable development requirements associated with coastal margins. These are required by councils to give effect to the 2010 NZ Coastal Policy Statement (NZCPS), Objective 5, and coastal hazard Policies 24-27. These results will improve on the current approach to coastal inundation hazard risk management as they provide probabilities of joint occurrence of extreme storm-tides and wave setup and runup. The inundation elevations provided in this Report exclude tsunami runup.

This study aimed to develop defensible coastal inundation elevations and likelihoods as a result of combinations of elevated storm-tide, wave setup and wave runup, along the “open coast” of the Gisborne district coastline. By “open coast” we mean outside of sheltered harbours and estuaries, in locations subject to ocean swell or Bay-wide wind wave. However, we have applied a wave-sheltering algorithm to transform the wave data from offshore, to the inside of “open” coastal embayments, as opposed to constricted tidal inlets and/or estuaries.

Gisborne District Council indicated areas of interest for NIWA to estimate inundation elevations along the coastline, which NIWA has represented using 33 output locations as shown in Figure 1-1.

Results of the study have been built into a Microsoft Excel 2013 spreadsheet tool, supplied to Gisborne District Council. The Coastal Calculator makes the study outcomes and substantial data, instantly and easily accessible for coastal-inundation hazard risk assessments including the effects of sea-level rise, as required by the NZ Coastal Policy Statement.

The Coastal Calculator supplies regionally consistent and statistically robust calculations of the wave climate and associated wave setup and runup, plus storm-tide elevations, along the entire regional coastline. This information is underpinned by the state-of-the-art wave and storm-surge modelling from the Waves And Storm-surge Projections (WASP) modelling project. Thus it supplies sea-level inundation elevations for locations where none exists, and supplies robust likelihoods of occurrence for high sea-level elevations. The Calculator is a step forward in terms of regional coverage, regional consistency and statistical robustness. Furthermore the Calculator is “future-proofed” in that it easily incorporates future updates of mean sea level datum shifts and/or sea-level rise estimates, and these values are transparent to the user. Thus the information in the Calculator will stay relevant for a long time. The Calculator was built using Microsoft Office 2013 and could require minor upgrading for use in future Microsoft Office releases.

However, there are unavoidable uncertainties surrounding the wave runup estimates in particular that the user should be aware of before applying the Calculator. As described in Section 2.5 the extreme wave analyses have considerable uncertainty due to lack of long-term wave records along the Gisborne coastline, and there is further uncertainty in translating the offshore wave heights into wave setup and runup at the shore. The study also indicates that (tsunami aside) the most extreme total elevations on the Gisborne coastline are likely to be driven by large wave events. So the main driver of coastal inundation and erosion, the wave climate, is also the most difficult hazard to quantify.

The uncertainty, and ways to account for it, are discussed in Section 2.5, and we have taken care to compare the Coastal Calculator with field-based evidence for extreme storm wave runup elevations in Section 2.6. The comparisons show that the Calculator gives results consistent with field-based studies and can be tuned to match accordingly.

Nevertheless, we emphasise that the Coastal Calculator does not replicate all the information or processes involved in an extreme storm-tide and wave runup event. For example, it does not include the details of wave shoaling and transformation over the surfzone across complex nearshore bathymetry. It is not intended as a complete replacement for detailed site-specific inundation studies or empirical evidence. However, these highly-detailed site-specific studies can be data intensive (and expensive), or suffer from similar data shortages, and have their own uncertainties. The Coastal Calculator should prove highly relevant to GDC.

Section 2 contains all of the information required to undertake an extreme inundation assessment for the Gisborne district coastline, and it explains how to use the Coastal Calculator. The reader may look no further than Section 2 if they simply wish to apply the outcomes of the work. Section 3 provides an explanation of a method to convert the sea-level elevations obtained from the Coastal Calculator into inundation hazard maps. Section 3 was included in the main body of the report as it was of specific interest to GDC. The remaining appendices support the workings of Section 2, by explaining the methods and models used to derive the outcomes of the study, including wave and storm-tide modelling, data analysis, and extreme-value and joint-probability analysis.

Appendix A introduces the basic method followed to calculate extreme storm-tide plus wave runup elevations. The sea-level components contributing to extreme runup are described, along with the study datums and a description of extreme-value terminology and probability is given. Appendix B describes the sea-level gauge analysis. Appendix C describes the storm-tide modelling and analysis and Appendix D describes the wave modelling and analysis. Appendix E describes joint-probability modelling, and finally, Appendix F includes tables of extreme storm-tides and significant wave heights, and their joint-probabilities at 33 output locations along the Gisborne coastline.

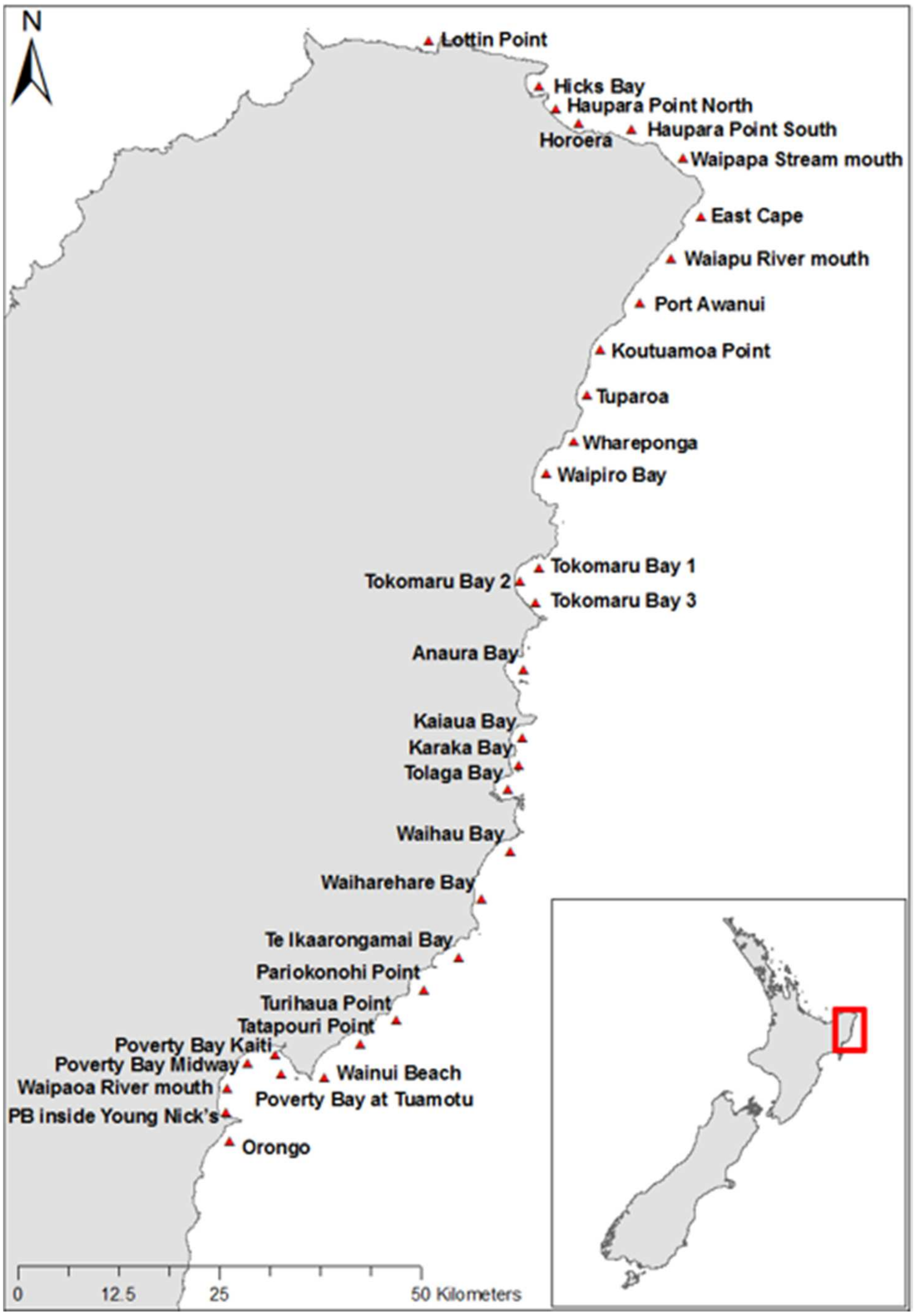

Figure 1-1: Location map of study area including the 33 model output sites along the Gisborne district coastline.

2 How to derive wave heights, storm-tide levels, or inundation levels from combined effects, using this report

2.1 Processes contributing to sea-level variability (and extreme sea levels)

2.1.1 Sea level (excluding waves)

There are a number of meteorological and astronomical phenomena involved in the development of extreme sea level events. These processes can combine to inundate low-lying coastal margins. The processes involved are:

- Mean sea level (MSL).
- Astronomical tides.
- Storm surge.
- Mean sea level anomaly (MSLA), which is the variation of the non-tidal sea level about the longer-term mean sea level on time scales ranging from a monthly basis to decades, due to climate variability. This includes ENSO and IPO patterns on sea level, winds and sea temperatures, and seasonal effects.
- Climate-change effects including sea-level rise. Sea-level rise was considered in this study as +1 m, and +2 m above present-day mean sea level, but the Coastal Calculator has an interactive entry for any value of sea-level rise.
- Tsunami – not considered in this study.

These sea-level components are explained in more detail in Appendix A.

Storm-tide is a combination of MSL (includes datum offset) + MSLA + tide + storm-surge. Storm-tide values in the Calculator are not subject to user input. Wave setup and runup ride on top of storm-tide. Wave setup and runup calculations require user input, as explained below.

2.1.2 Wave setup and runup

Waves also raise the effective sea level at the coastline (Figure 2-2). Wave setup describes an average raised elevation of sea level at the coast when breaking waves are present. Wave runup is the maximum vertical extent of wave "up-rush" on a beach or structure above the instantaneous still-water or storm-tide level (that would occur without waves), and thus constitutes only a short-term fluctuation in water level relative to wave setup, tidal and storm-surge time scales. Wave runup in this report includes the wave setup component. When offshore waves are large, wave setup and runup can raise the water level at the beach substantially, especially on steeper beach slopes or steep-face structures such as rock revetments or seawalls.

Which of wave *setup* or wave *runup* is most important to widespread inundation of the coastal margin? Wave runup elevations are considerably higher than wave setup elevations. The two processes are important for different reasons.

Wave setup is an integral component of the total water level that potentially could cause direct or near-continuous inundation of “green water” onto coastal margins. The combined storm-tide plus wave setup level is therefore important for large-scale coastal inundation. The combined storm-tide plus wave runup level is important to any overtopping of dunes and seawalls, beach erosion and wave impact on seawalls.

Wave runup is highly relevant to beach erosion and wave impact on seawalls and sand dunes, and can result in wave overtopping. Overtopping by wave runup involves “wave splash”, “wind spray” and sporadic shallow overwash of “green water” (depending how high up the wave setup level is) and may not necessarily cause substantial flooding, compared to more direct inundation from wave setup, but this also depends on the capacity of the drainage system behind the overtopped barrier. Recent experience modelling wave setup, runup and overtopping in Nelson has shown that wave runup overtopping can induce considerable flooding behind low seawalls, and that wave runup is arguably the most relevant design criterion for open-coast locations, when considering properties directly adjacent to the coast. For seawalls, formulae exist to calculate the number of waves overtopping in one hour, the probability of overtopping per wave, and the mean overtopping discharge per metre of coastline that enables estimates of damage to buildings and seawalls (EurOtop 2007).

Whereas wave runup is arguably the most relevant design criterion for properties directly adjacent to the coast, flooding and erosion by wave runup and overtopping is often very localised and site-specific, and the overtopping discharge volume is unlikely to cause widespread inundation at locations several tens of metres back from the coast (notwithstanding barrier collapse).

There are a number of different approaches to calculating wave setup and runup on natural beaches. The Stockdon et al. (2006) formula were developed from empirical measurements made on 10 sandy beaches on USA and Netherlands coastline with different morphologies; so it is expected to be appropriate for sandy beaches along the Gisborne District coastline. Depending on the nature of the coastline at each location, it may be more appropriate to use empirical formulae designed for offshore reef, gravel beaches, rock revetments or sea walls (e.g., EurOtop 2007; HR Wallingford ; Van Rijn 2010)[1]. The Stockdon et al. (2006) formula estimates wave setup using the offshore significant wave height[2] and wavelength and the slope of the upper beach face.

Wave setup is highly sensitive to the beach profile shape (Stephens et al. 2011) and likewise, calculations made using the empirical wave setup are also sensitive to the beach slope parameter. Thus there is considerable uncertainty around the use of empirical wave setup calculations, because beach profiles are in a constant state of evolution, and it is often difficult to pick a representative beach slope from a profile. Wave runup is similarly highly sensitive to the beach profile shape.

What beach slope should be used in the wave setup and runup equations?

For future planning purposes, a sound approach is to use historical beach profiles where available, locate the upper beach face near the high tide mark (as we are dealing with

[1] http://www.overtopping-manual.com/calculation_tool.html
[2] The average wave height of the highest 33% of waves.

extreme water levels), examine the beach slope variability and choose a relatively steep beach slope to be conservative (steep beach = larger setup and runup). For sandy beaches the calculated wave setup and runup are more sensitive to choice of beach slope than to calibration factors or the particular equation chosen.

As noted in Section 2.6, a steep beach slope of 0.15 gives the approximately 1:1 relationship between offshore significant wave height and maximum storm wave runup suggested by Gibb (2001) for Wainui Beach.

Equation 2-1: Empirical wave setup formula (Stockdon et al. 2006).

$$\text{Wave setup (m)} = 0.35\beta_s(H_0L_0)^{\frac{1}{2}}$$

where H_0 = Deep-water wave height (m)

L_0 = Deep-water wave length (m) = $\dfrac{gT_0^2}{2\pi} = \dfrac{H_0}{0.022}$

T_0 = Deep-water wave period (s)

g = 9.81 m s^{-2}

β_s = Beach slope (dimensionless) (see Figure 2-1 below)

Equation 2-2: Empirical formula for 2% exceedance value of runup peaks on natural beaches (Stockdon et al. 2006). Note: this wave runup formula includes the wave setup component (Equation 2-1).

$$\text{Wave runup (m)} = 1.1\left(0.35\beta_s(H_0L_0)^{\frac{1}{2}} + \frac{\left[H_oL_o\left(0.563\beta_s^{\,2}+0.004\right)\right]^{\frac{1}{2}}}{2}\right)$$

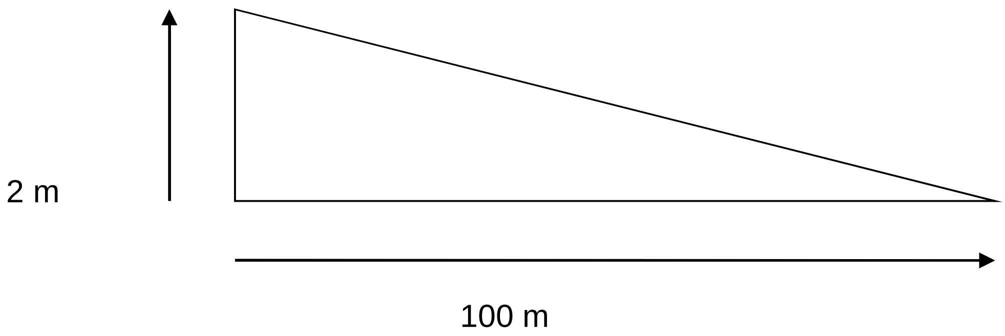

Figure 2-1: How to calculate beach slope β_s. Beach slope = 2 ÷ 100 = 1 in 50. β_s = 0.02. Note: many beaches have a composite slope with smaller slopes at lower tide mark and steeper slopes at high-tide mark – in this case we recommend use of the steepest beach slope, as this will conservatively return a higher wave setup and runup value. The beach gradient should be measured over the upper beach-face close to the high-tide mark where the active wave swash occurs, because this is where the data were collected for the development of the equations.

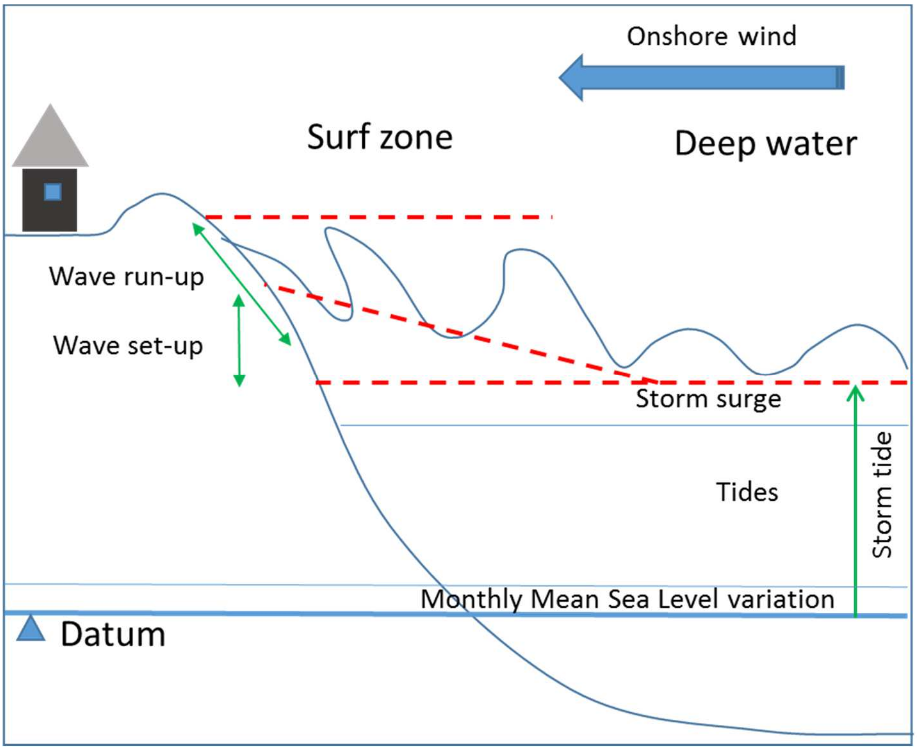

Figure 2-2: Schematic illustrating the various processes that contribute to coastal inundation.

2.2 Sea-level datum and mean sea level

All data in this report are referenced relative to Gisborne Vertical Datum–1926 (GVD-26), which is routinely used throughout the Gisborne region. GVD-26 is 1.052 m above Chart Datum. Based on the sea level measurements from this gauge Land Information New Zealand (LINZ) have set the MSL from 2004-2012 to 1.26 m above Chart Datum (LINZ, 2014), which is 0.208 m above GVD-26.

2.3 Explanation of extreme event probabilities

The **annual exceedance probability** (or AEP) describes the chance of an event reaching or exceeding a certain water level in any one year. Appendix A explains the meaning of the term AEP in more detail and discusses other extreme-value terminology such as *average recurrence interval* (ARI), asset lifetime exceedances, and joint probability.

2.4 How to derive inundation elevations using the Coastal Calculator

The Coastal Calculator tool that accompanies this report makes the study outcomes and substantial data analysis and modelling instantly and easily accessible for coastal inundation elevation assessments. Relevant results and parameter input choices are available to the user, while the data analysis and output from NIWA's models is contained in protected "behind-the-scenes" look-up worksheets within the Calculator. This section describes the Coastal Calculator and how to use it. The remainder of the report is devoted to the data analysis and modelling undertaken by NIWA that underlies the Calculator.

2.4.1 Mean sea level

Figure 2-3 displays the first worksheet page for entering the mean sea level (MSL) offset to the datum and a future sea-level rise. Elevations in this study are specified relative to a zero mean sea level (MSL = 0), and thus a vertical offset must be added to convert to Gisborne Vertical Datum 1926 (GVD-26). The Calculator undertakes this step and builds the MSL–datum offset in, as shown on Figure 2-3. At present (2014), the recommended selection is MSL (2004–2012) – Gisborne. Once this option is chosen, all the subsequent Calculator output is then relative to GVD-26 and includes present-day MSL offset from GVD-26.

Mean sea level changes through time, due to climate variability and long-term sea-level rise. Storm-tides result primarily from the combination of high tide and storm surge that ride on top of the underlying monthly mean sea level anomaly, which in turn is tied to a longer-term mean sea level. Therefore, it is important to define the mean sea level or MSL epoch that relates to any calculated extreme sea level (Table 2-1). These can be selected using the drop-down menu shown in Figure 2-4. The user can define their own mean sea level using the “user-defined” option (Figure 2-5). For example, in future and after a period of further sea-level rise, the user can enter the mean sea level for that future epoch.

Table 2-1: Description of pre-calculated mean sea level epochs. The Gisborne Vertical Datum was established based on sea level measurements earlier last century, which have since risen. The current mean sea level is based on sea level measurements from the Port of Gisborne tide gauge and is set by LINZ.

Mean sea level epoch	Epoch description	MSL relative to GVD-26
~1926	Original GVD-26 defining period	+ 0 m
2004-2012	Mean Sea Level at Gisborne	+ 0.208 m

2.4.2 Sea-level rise

The user can input a future sea-level rise elevation (lower part of Figure 2-3). This sea-level rise is then included into sea-level elevation calculations. The user-defined sea-level rise is linearly added to the calculated extreme sea levels and mean high water springs levels as a first order approximation that no non-linear effects will occur as the sea level increases.[3] The page includes some guidance on a range of appropriate sea-level rise values, and references to the sources of that information.

The range of sea-level rises suggested for major Greenfields developments e.g., a new suburb or large subdivision, are not tied to any specific planning time frame, but should extend substantially beyond “at least 100 years” and be larger than those applied to existing development, given: a) permanency of established development; b) that sea-level rise is expected to continue for several centuries, and; c) the NZCPS encourages avoidance of risk for new developments [Objective 5 and Policy 25(a)].

[3] However, for shallower estuaries, inlets and lowland sections of rivers, they are likely to be non-linear changes in tidal characteristics depending on how sedimentation on the bed responds to sea-level rise.

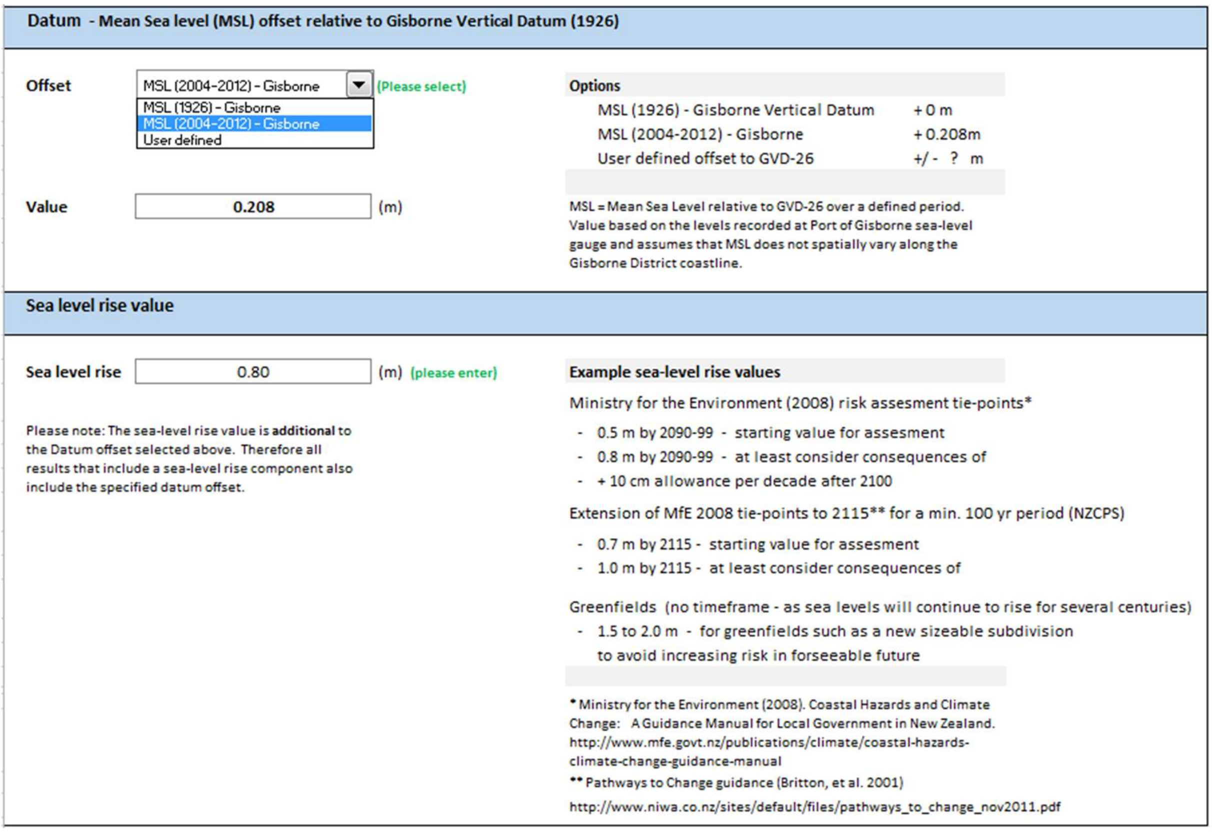

Figure 2-3: The Coastal Calculator mean sea level datum offset and sea-level rise selection page.

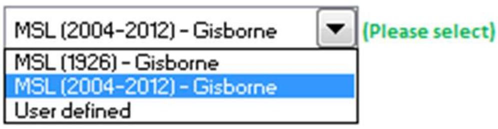

Figure 2-4: Mean sea level datum offset drop-down menu.

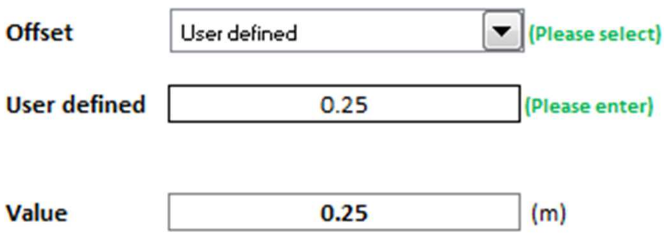

Figure 2-5: User-defined mean sea level option. Useful for future MSL updates, for example after a period of sea-level rise, provided the entered future sea-level rise projection does not double-dip and only includes the projected rise beyond that MSL epoch baseline.

2.4.3 Site selection

Tide, storm-tide and wave statistics were calculated offshore from 33 locations along the Gisborne coastline. The first section of the second worksheet in the Coastal Calculator allows the user to define their site of interest using the drop-down menu; in this example Wainui Beach was chosen (Figure 2-6).

The 33 locations are: Lottin Point, Hicks Bay, Haupara Point North, Haupara Point South, Horoera, Waipapa Stream mouth, East Cape , Waiapu River mouth, Port Awanui, Koutuamoa Point, Tuparoa, Whareponga, Waipiro Bay, Tokomaru Bay 1, Tokomaru Bay 2, Tokomaru Bay 3, Anaura Bay, Kaiaua Bay, Karaka Bay , Tolaga Bay, Waihau Bay, Waiharehare Bay, Te Ikaarongamai Bay, Pariokonohi Point, Turihaua Point, Tatapouri Point, Wainui Beach, Poverty Bay at Tuamotu, Poverty Bay Kaiti, Poverty Bay Midway, Waipaoa River at Poverty Bay, Poverty Bay (PB) inside Young Nick's (Head), Orongo.

2.4.4 Beach gradient

The user is then asked to define a beach gradient. The beach gradient is used to calculate wave setup and runup using the Stockdon et al. (2006) equations that are built into the Calculator (Equation 2-1; Equation 2-2). **The beach gradient should be measured over the upper beach-face close to the high-tide mark** where the active wave swash occurs, because this is where the data were collected for the development of the equations. The Stockdon et al. (2006) wave setup and runup equations were developed using data from 10 sandy beaches with a range of beach morphology and beach gradients, and should represent sandy beaches along the Gisborne coastline reasonably well. Because the equations are based on data from a broad range of beaches, they are now widely-applied for sandy beach locations.

However, it should be noted that there are numerous other studies of wave setup and runup and a numerical study showed that for some beach morphologies with offshore bars, wave setup can be under-predicted by the Stockdon et al. equations; Stephens et al. (2011) provided an equation for the upper-limit of expected wave setup. Many beaches have a composite slope with smaller slopes at lower tide mark and steeper slopes at high-tide mark. We recommend use of the steepest beach slope as this will conservatively return a higher wave setup and runup value using the Stockdon et al. (2006) equations.

Furthermore, many beaches along the coastline of the Gisborne district are mixed sand/gravel beaches, and/or have rocky reef located offshore.

Gravel beaches or beaches with sea walls require different equations. In such situations the user may wish to consider alternative wave setup and runup formulae such as van Rijn, 2010 (http://www.conscience-eu.net/documents/deliverable13b-modelling.pdf), EurOtop, 2007 (http://www.overtopping-manual.com/manual.html) or HR Wallingford online calculator (http://www.overtopping-manual.com/calculation_tool.html). The user can edit the “worked example” (Figure 2-8) section of the Coastal Calculator if using these alternative equations.

The example in Figure 2-6 shows an upper beach slope of 0.15, which gives the approximately 1:1 relationship between offshore significant wave height and maximum storm wave runup postulated by Gibb (2001) for Wainui Beach. A 0.15 beach slope returns an ~1:1 relationship at all locations.

We have not examined beach profile data along the Gisborne coastline. However, as part of a different study (Stephens et al. 2013) we have examined historical beach profile data along the east coast of the Auckland region, and share that experience here:

- Many beaches have a composite slope with flatter slopes at lower tide mark and steeper slopes at high-tide mark. At most profile locations, numerous beach profiles were available over many years, showing considerable profile variability over time.
- Profiles from each location were split into a number of profile sets depending on length of record, with an approximately equal number of profiles in each set. Splitting the records was necessary to enable a clear visual examinations of the profiles; plots containing all profiles were too cluttered to analyse.
- The MHWS elevation was marked relative to the profile datum, based on known MHWS elevations in the region.
- For each of the profile sets, a line was fitted by eye to the *steepest slope* that crossed the MHWS line.
- The representative beach slopes obtained from the profile sets were averaged at each location.
- Beach slopes for all locations were compared. They were remarkably consistent around the coastline, probably as a result of tending to fit to the steepest profiles over the steepest part of the beach.
- A representative beach profile slope of 1 in 9 was adopted for Mangawhai/Pakiri, and a slope of 1 in 7 was adopted for all other beaches in the Auckland region.
- These beach slopes were considered conservative in that they were relatively steep representations of the measurements over the profile near the MHWS elevation (the steepest part of the beach). Thus they will tend to return higher wave setup calculations than the use of shallower slopes in equations such as Equation 2-1.
- Beach slopes of 1 in 9 (0.11) and 1 in 7 (0.14) are similar to the ~0.15 slope as used in Figure 2-6 for Wainui Beach.

2.4.5 Mean high water springs (MHWS)

The MHWS elevation is output relative to GVD-26 (Figure 2-7) and includes the MSL offset defined by the user. There are a number of definitions of MHWS (e.g., nautical, perigean-spring), but we have output the 10% exceedance level, which is the level equalled or exceeded by only the highest 10% of all high tides at that site. MHWS-10 was adopted by NIWA because it is a pragmatic elevation that can be used to define the Coastal Marine Area (CMA) boundary and is consistent with the MHWS (perigean) level.

2.4.6 Extreme storm-tide elevations

Storm-tide elevations are output relative to GVD-26 (Figure 2-7) and include the MSL offset defined by the user. Calculated extreme storm-tide magnitudes are provided for a range of frequencies. The measure of frequency has been described in terms of 1. annual exceedance probability, 2. average recurrence interval and 3. average number of exceedances during a user-specified planning timeframe. Note that the storm-tide elevations *include* the astronomical high tide; storm-tides result from a combination of astronomical high tide and storm surge, plus mean sea level anomaly (MSLA) contribution[4].

2.4.7 Extreme wave heights and wave setup and runup

Extreme wave height, wave setup and runup elevations are output relative to the instantaneous sea level (Figure 2-7). The calculated wave setup and runup depends on the user-defined beach gradient. The frequency measures (e.g. AEP, ARI) used for storm-tide also apply to the independent wave parameters. The technique used to derive the extreme wave height elevations is described in more detail in Appendix D, with a discussion on uncertainty in Section 2.5 and cross-checking against field measurements in Section 2.6.

To account for uncertainty in the extreme wave height distribution the user can add 10% to the wave runup elevation for conservatism (see Section 2.5).

2.4.8 Combined (joint-probability) storm-tide and wave setup and runup elevation

Combined storm-tide and wave setup and runup elevations are output relative to GVD-26 (Figure 2-8) and include the MSL offset and sea-level rise defined by the user. For the user-defined location, a worked example is provided to calculate the maximum combined storm-tide and wave setup and runup elevation. The user must define the relevant annual exceedance probability (AEP) for the worked example. The purpose of the worked example section is to provide greater detail about the various combinations of storm-tide and wave parameters that might occur, for the chosen AEP. This greater level of information allows the user to customise the output from the Calculator; for example a user-defined wave runup equation can be appended to the worked example.

A frequency–magnitude table is provided that includes the maximum combined storm-tide and wave setup and separately wave runup elevation for each joint AEP.

2.4.9 Summary plot

The summary plot illustrates the extreme sea level elevation data selected for output by the user (Figure 2-9). The plot includes the MHWS-10 level, the storm-tide extreme-value curve, the maximum combined storm-tide and wave *setup* extreme-value curve and the maximum combined storm-tide and wave *runup* extreme-value curve. It also shows the effect of user-defined sea-level rise on these curves (assuming there is no non-linear response in the components contributing to elevated sea levels).

[4] MSLA defines the monthly (and greater) sea level anomaly above or below the longer-term MSL due to climate variability such as seasonal effects, ENSO and IPO.

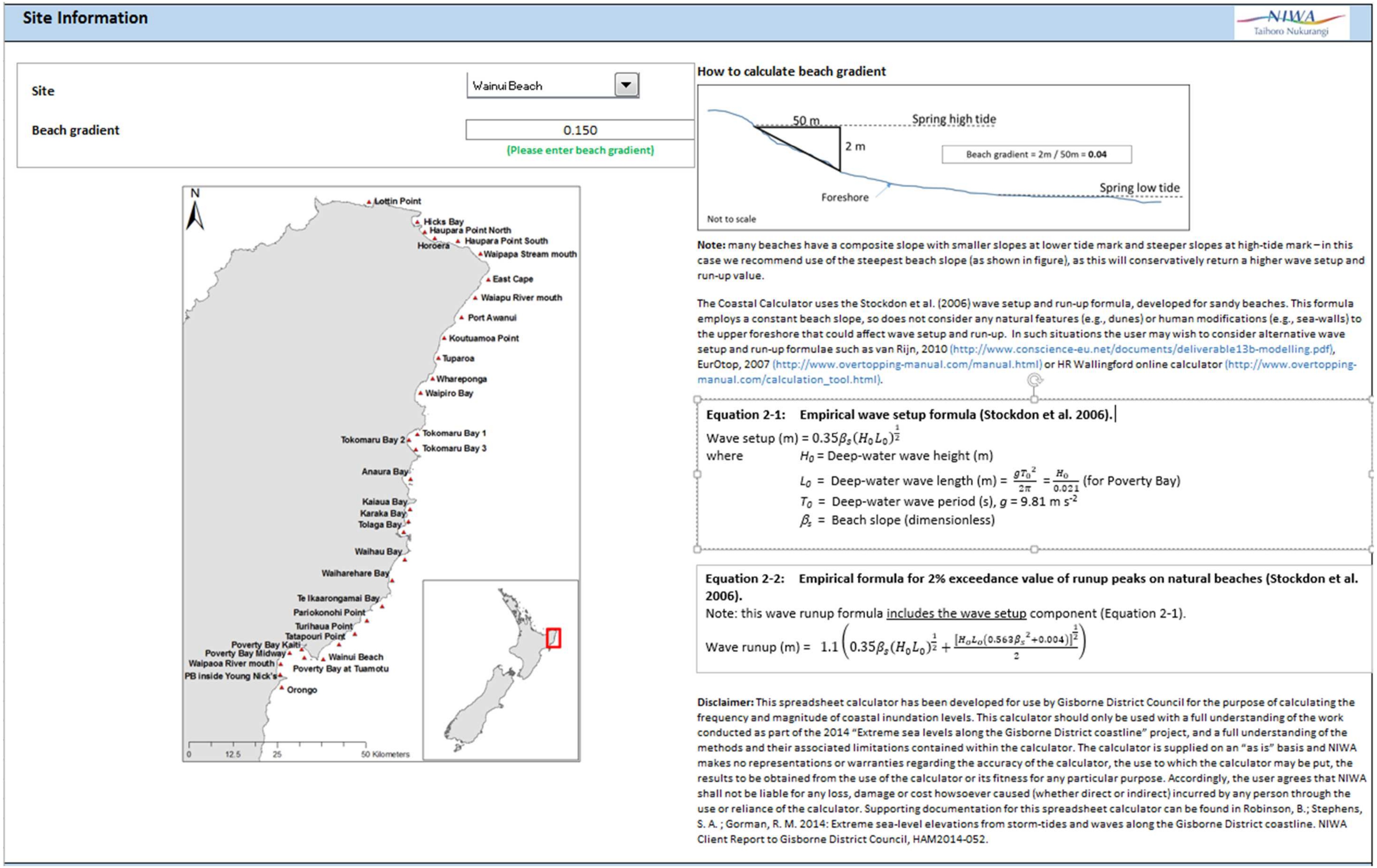

Figure 2-6: Site selection and user defined beach gradient specification. The beach gradient is used to calculate wave setup and runup using the Stockdon et al. (2006) formulae.

Mean High Water Spring elevation

Wainui Beach

Relative to GVD-26 including +0.21 m offset for baseline MSL (2004-2012 average)

MHWS* elevation:	1.00 (m)
MHWS* elevation +0.8m sea level rise	1.80 (m)

*Based on an elevation exceeded by the highest 10% of all high tides

Ways to describe extreme value likelihood

Annual Exceedance Probability (AEP) (%)	**63**	**39**	**18**	**10**	**5**	**2**	**1**	**0.5**
Average Recurrence Interval (ARI) (years)	**1**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Asset lifetime exceedance calculator								
Asset planning life time (years)	100	(Please select)						
Likelihood of at least one exceedance in life time (%)	100	100	100	100	99	86	63	39
Expected **average** number of exceedances in life time	100	50	20	10	5	2	1	

Storm-tide elevations independent of wave conditions

Wainui Beach

Relative to GVD-26 including +0.21 m offset for baseline MSL (2004-2012 average)

AEP (%)	**63**	**39**	**18**	**10**	**5**	**2**	**1**	**0.5**
ARI (years)	**1**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Storm tide elevation (m)	1.26	1.29	1.32	1.35	1.37	1.40	1.43	1.45
Storm tide elevation +0.8 m sea level rise (m)	2.06	2.09	2.12	2.15	2.17	2.20	2.23	2.25

Wave height and setup elevations independent of storm tide

Wainui Beach

Relative to instantaneous storm tide level

Beach gradient used to calculate wave setup and run up is 0.150

Offshore *significant wave height (m)	3.73	4.59	5.55	6.21	6.84	7.63	8.22	8.80
Wave setup only (m), Stockdon et al. 2006	1.35	1.66	2.01	2.25	2.48	2.76	2.98	3.19
Wave run up (m) (includes wave setup), Stockdon et al. (2006)	3.31	4.08	4.93	5.52	6.07	6.78	7.30	7.82

*Defined as: The average of the highest 33% of wave heights over a several minute period

Figure 2-7: Mean high water springs, storm-tide, and wave setup and runup elevations. These are the marginal storm-tide and wave heights, considered by themselves, independently of each other.

Joint storm tide and wave setup elevation

Wainui Beach

Relative to GVD-26 including +0.21 m offset for baseline MSL (2004-2012 average)

Beach gradient used to calculate wave setup and run up is 0.150

Worked example (for selected AEP)

Joint AEP % (for worked example) 1 (please select)

For the selected AEP the highest joint storm tide and wave setup elevation is:

4.46 meters above NVD-55

which comprises of:

0.62	Storm tide elevation (m)
2.83	wave setup* (m)
0.21	datum offset (2004-2012 average) (m)
0.80	sea level rise (m)

The highest joint storm tide and wave runup elevation is:

8.66 meters above NVD-55

0.49	Storm tide elevation (m)
7.16	wave runup* (m)
0.21	datum offset (2004-2012 average) (m)
0.80	sea level rise (m)

* Calculated using Stockdon et al. (2006) formula with a beach gradient of 0.150

Wave setup and runup from equations 2.1 and 2.2

Storm tide (m)	Wave height (m)	Wave length (m)	Wave run up (including setup)	Wave setup (m)	Storm tide + wave setup	Storm tide + wave runup
0.00	8.22	391	7.30	2.98	2.98	7.30
0.31	8.16	388	7.25	2.95	3.27	7.56
0.49	8.05	384	7.16	2.92	3.41	7.65
0.62	7.82	372	6.95	2.83	3.46	7.57
0.72	7.45	355	6.62	2.70	3.42	7.35
0.81	7.07	337	6.28	2.56	3.37	7.09
0.87	6.61	315	5.87	2.39	3.27	6.75
0.93	6.04	288	5.37	2.19	3.12	6.30
0.99	5.48	261	4.87	1.99	2.97	5.86
1.04	4.90	233	4.35	1.77	2.81	5.39
1.08	4.24	202	3.77	1.54	2.61	4.85
1.12	3.50	167	3.11	1.27	2.39	4.23
1.15	2.58	123	2.29	0.93	2.09	3.44
1.19	1.67	79	1.48	0.60	1.79	2.67
1.22	0.00	0	0.00	0.00	1.22	1.22

Highlighted rows illustrate the maximum combined storm tide plus wave setup or runup elevations.

Maximum combined storm tide + wave setup elevations

AEP (%)	**63**	**39**	**18**	**10**	**5**	**2**	**1**	**0.5**
ARI (years)	**1**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Maximum combined storm-tide + wave setup elevation (m)	2.05	2.35	2.71	2.94	3.18	3.45	3.66	3.91
Maximum combined storm-tide + wave setup + 0.8 m sea level rise (m)	2.85	3.15	3.51	3.74	3.98	4.25	4.46	4.71
Maximum combined storm-tide + wave runup elevation (m)	3.92	4.66	5.51	6.07	6.63	7.36	7.86	8.41
Maximum combined storm-tide + wave runup + 0.8 m sea level rise (m)	4.72	5.46	6.31	6.87	7.43	8.16	8.66	9.21

Figure 2-8: Combined (joint-probability) storm-tide and wave setup and runup elevations. A worked example for a single user-specified annual exceedance probability, and maximum combined storm-tide and wave setup elevation for a range of annual exceedance probabilities. Maximum combined storm-tide and wave *setup* is highlighted in pink, while maximum combined storm-tide and wave *runup* is highlighted in gold.

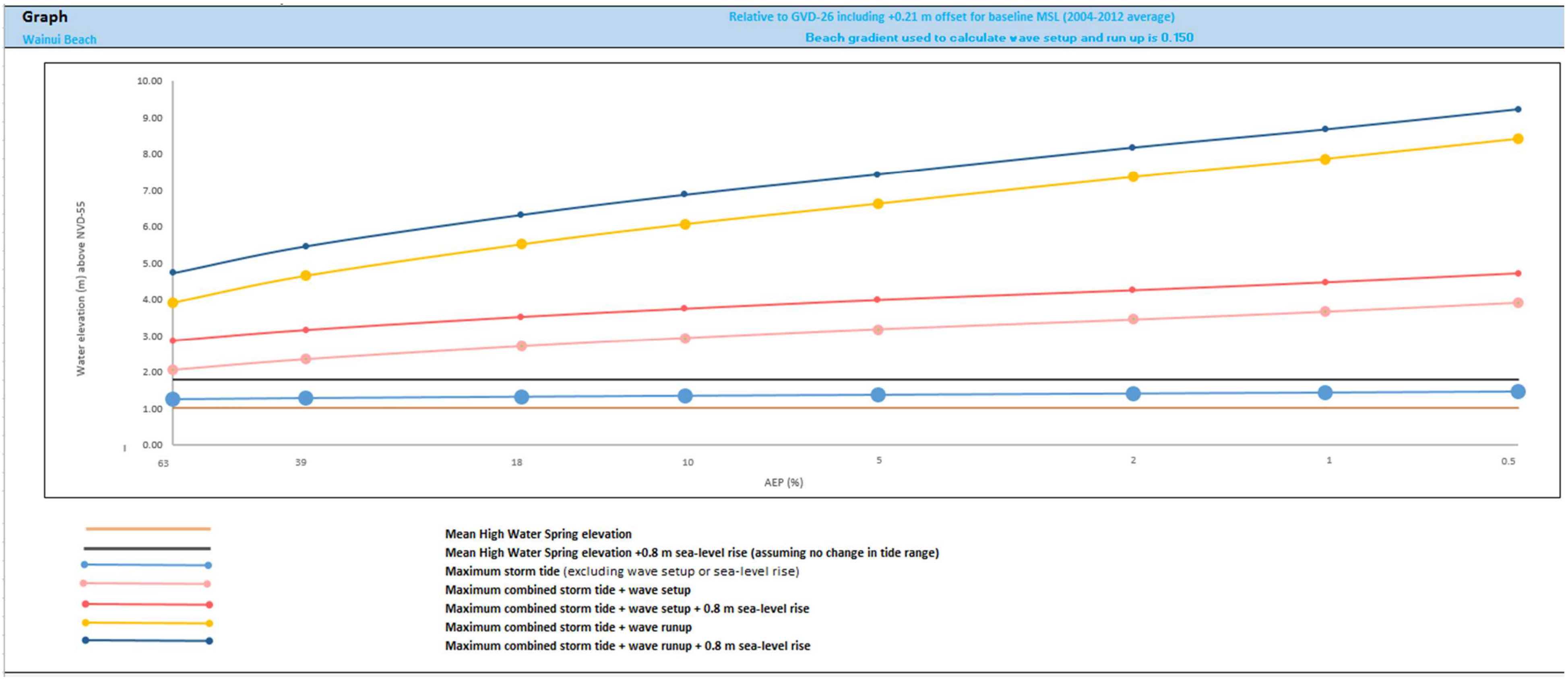

Figure 2-9: Summary plot at the end of the Coastal Calculator results.

2.5 Uncertainty in the calculations

The Coastal Calculator presents the maximum likelihood estimate of storm-tide plus wave setup and runup. However, there are uncertainties surrounding the analysis that the user should be aware of before applying it. The total sea-level elevations are also more sensitive to some parameters.

The extreme storm-tide analyses are relatively robust compared to the extreme wave analyses, because the joint-probability technique used yields accurate extreme storm-tide results from short records (Goring et al. 2010). Furthermore, we have high confidence in predictions of tidal elevations, which make up most of the storm-tide sea-level variability.

The extreme wave analyses have large uncertainty, because they are based on a model hindcast with known bias, validated by only a very short (in terms of extreme-value analysis) 2 year wave record, with few extreme (or even large) wave events. The resulting confidence intervals on the extreme-wave height analyses are wide (Appendix D). A long-term wave gauge record offshore from the Gisborne coast would be highly valuable for these types of hazard analyses.

Furthermore, there is much uncertainty in translating the offshore wave heights (with their own associated uncertainty) into wave setup and runup at the shore.

Figure 2-10 presents a sensitivity analysis for combined storm-tide plus wave setup and runup at Tatapouri Point. Both wave setup and wave runup have been calculated using the maximum likelihood extreme wave estimate and their 95% confidence interval upper limits. Two beach slopes have also been compared, a 1/25 (0.04) slope and a relatively steep 1/10 (0.1) slope.

Wave setup is seen to be a relatively small component of the total sea-level elevation on this coastline; however, wave runup is considerably larger. At 100-year ARI the 95% upper confidence limit of the extreme-wave analysis is 1.1 m (12%) larger than the central (best) estimate, and this translates to about 0.4–0.6 m (8-10%) uncertainty in the wave runup estimates for the two beach slopes considered. Therefore, a workaround is to add 10% to the wave runup estimates to account for uncertainty in the extreme wave analyses.

The wave runup (and wave setup) calculations made using Equation 2-1 and Equation 2-2 are very sensitive to the beach slope used, being ~2.5 m different for the example slopes used, at 100-year ARI. Inclusion of a lower gradient (e.g., 1/100) would have induced further spread. Furthermore, modelling by Stephens et al. (2011) showed that there is considerable natural variability in wave setup relative to that calculated using Equation 2-1 (Figure 2-11). This highlights that wave setup and runup are very difficult to predict, and empirical formulae used have some uncertainty. Furthermore, even if the empirical formulae were perfect, considerable uncertainty is introduced by uncertainty in the measured beach slope. Advice on selecting beach slope is included in Section 2.1.2.

To help account for this uncertainty, and as a check on the Calculator, we have made comparisons with wave runup elevation estimates from field studies in Section 2.6. A steep beach slope of 0.15 gives the approximately 1:1 relationship between offshore significant wave height and maximum storm wave runup suggested by Gibb (2001) for Wainui Beach.

We have not examined beach slope information for the Gisborne coast or Wainui Beach, but relevant experience with beaches along Auckland's east coast is discussed in Section 2.4.4.

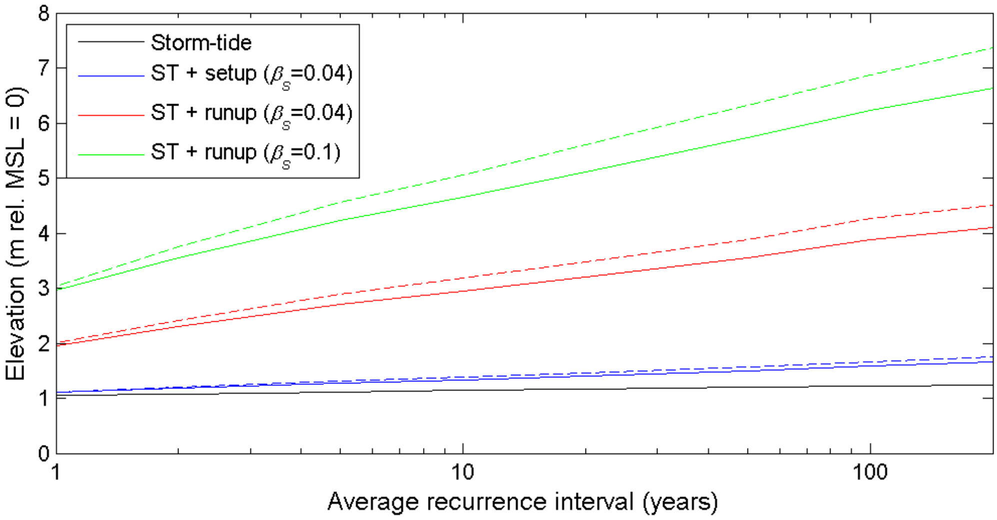

Figure 2-10: Example of variability in wave setup and runup due to extreme wave height uncertainty and beach slope choice. Example uses Tatapouri Point data. β_s = beach slope. Solid line uses the maximum-likelihood estimate wave height and dashed line uses upper 95% confidence limit on wave height.

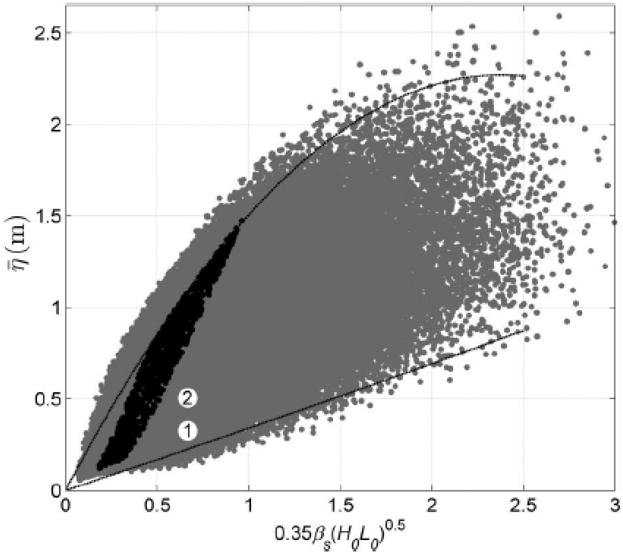

Figure 2-11: Illustration of scatter between Equation 2-1 and 100,000 simulations of wave setup by Stephens et al. (2011). The black dots represent setup predicted from 500 simulations undertaken while varying wave conditions but using a fixed cross-shore beach profile. The dashed curves encompass 99% of all the simulated data. The numbered circles refer to results presented in Stephens et al. (2011).

2.6 Cross-checks with previous studies

The joint-probability analysis allows to quantify the interaction between storm tides and waves in a statistically robust method. This prevents an overly conservative "building block" approach, where extreme elevations of tide, storm-surge and wave setup and/or runup are added together without quantifying the likelihood of such an extreme combination.

The calculations on the Gisborne coastline illustrate that the most extreme total elevations (out to 0.5% AEP) are likely to be driven by large wave events combining with small storm tides, as illustrated in Figure 2-8. This occurs because the Gisborne coast has a relatively small tidal range, but is occasionally exposed to high wave energy. Unfortunately this also means that the main driver of coastal inundation and erosion, the wave climate, is also the most difficult to quantify.

Despite these uncertainties the Coastal Calculator supplies regionally consistent and statistically robust calculations of the wave climate and associated wave setup and runup, plus storm-tide elevations, along the entire regional coastline. Nevertheless, due to the potential variability in wave runup elevations we recommend site-specific wave runup studies for locations with high-value development. These could be informed by the offshore conditions included in the Calculator, but would account for the local nearshore bathymetry and coastal topography and would ideally include physical or anecdotal evidence of previous storm runup elevations. Fortunately, there are already several site-specific assessments of total runup elevation for the main populated areas along the coastline that have undertaken field assessments of historical wave runup elevations and refer to total runup elevation estimates made by other means (e.g., Gibb 1998; Gibb 2001; Gibb 2004; Gibb 2008). In his reports, Gibb refers to a quantity *storm wave runup* that is the resultant of the combination of astronomical tides, barometric pressure set-up, wind set-up, wave set-up and wave runup above the elevated still water level (see Appendix A). This matches the storm-tide + wave runup elevations in the Coastal Calculator.

It is important to realise that while the Calculator holds regionally-consistent storm-tide and offshore wave information – the conversion from offshore wave height to wave runup elevation at the coast is site-specific and remains somewhat subjective through choice of wave runup formula and associated tuning parameters such as beach slope. The following comparisons between the Calculator and previous studies show that the Calculator gives results consistent with historical studies and can be tuned to match accordingly.

Poverty Bay

Gibb (2004) noted that the most significant wave storms to strike Poverty Bay are likely to be those of September 1894, February 1936, February 1953, April 1968 and April 2002 and suggests that these storms would have produced storm wave runup elevations of the order of 4 to 5 m above MSL at Orongo. The Coastal Calculator gave a 5.0 m runup for nearby Maraetaha River mouth, using a beach slope of 0.1 m in Equation 2-2.

Gibb (2008) reports surveyed heights of driftwood 4.3–4.8 m above MSL on northern Poverty Bay foredunes, thought to be from cyclone Bernie and associated with 0.02 AEP. The Coastal Calculator gives similar storm-tide + wave runup elevations for 0.02 AEP at this location, using a beach slope of 0.1 in Equation 2-2.

For Muriwai Beach, which is sheltered from the south by Young Nick's Head, Gibb (2004) estimated that in the absence of historic observations a best approximation here of flood ponding levels from storm wave runup would be 2–3 m above MSL. The Coastal Calculator returned 4.6 m at "Poverty Bay inside Young Nick's Head". The wave sheltering algorithm used to transform waves to inshore sites used the shoreline location to block waves that were sheltered by the coast (see Appendix D for more information on wave sheltering). However, no information on offshore reef structure was used in the wave sheltering algorithm. Therefore the wave heights will be conservatively large in some locations. There is a large area of shallow reef that projects offshore from Young Nick's Head that acts to dissipate wave energy from the east-southeast direction, which is not accounted for by the wave sheltering algorithm. Therefore the Calculator is likely to conservatively overestimate wave height, setup and runup at Muriwai.

Wainui Beach

Gibb (2001) referred to maximum storm wave runup elevations measured from driftwood, ranging from 3.0–7.5 m above MHWS between East Cape and Hawke Bay. Komar (1996) tentatively estimated storm wave runup elevations of 5.2 m for a major storm, 6.1 m for a 0.02 AEP storm, 7.2 m for a 0.01 AEP storm, and 8.3 m for a major cyclone (Gibb 2001).

Gibb (2001) reported that Patterson (pers. comm. Dec. 1997) estimated a storm wave runup level of 6.9 m for Wainui Beach for a significant deep-water wave height of 7 m. At Wainui Beach, storm wave runup levels of 4.1 m above MSL were surveyed by East Cape Catchment Board during the winter of 1976. Similar levels between 4.0 and 4.5 m were surveyed by Gisborne District Council following moderate wave storms in June 1994 and June 1996 from estimated offshore swell heights of 4–5 m. Gibb (2001) suggested that as a rule of thumb, these observations indicate a close correlation between storm wave runup levels and offshore swell heights at Wainui Beach, i.e., offshore swell heights of 7–9 m would produce storm wave runup elevations of 7.2–8.3 m.

The Coastal Calculator gives total storm-tide + wave runup elevations of 5.7, 6.2 and 6.6 m at nearby Tatapouri Point for 0.02, 0.01 and 0.005 AEP events respectively, using a relatively steep beach slope of 0.1 in Equation 2-2. These are in keeping with the aforementioned driftwood elevation measurements along the regional coastline. It is important to realise that the wave runup calculations are highly tuneable via the beach slope parameter in Equation 2-2, and a beach slope of 0.15 gives the approximately 1:1 relationship between offshore significant wave height and maximum storm wave runup postulated by (Gibb 2001). Other wave runup formulae can be built into the working space of the Calculator.

Tokomaru Bay

Gibb (2008) reports surveyed heights of driftwood 3.4–3.7 and 2.7–3.7 above MSL at Tuatini and Te Ariuru respectively. In Tokomaru Bay 3.5–4.5 m along Waiotu Rd, 3.5 m between Waiotu Stream and Mangahauini River, 4.5–5.0 m on north side of the river, and 4.0–5.0 m along Waimea Road. Gibb adopted 4.5 m above MSL for Tokomaru Bay and associated this to a 2% AEP level as cyclone Bernie thought to have produced the largest wave run-up elevations in 50 years. The Coastal calculator returned storm-tide + wave runup elevations of 5.5–5.8 m for 0.02 AEP at this location, using a beach slope of 0.1 in Equation 2-2. These calculations are somewhat higher than Gibb's driftwood surveys, possibly related to the influence of offshore reef not included in the Calculator, but consistent with other sites based on wave energy exposure by local orientation of the coastline.

3 Deriving hazard maps

GDC specifically requested information on methods to map coastal hazard zones using the information contained within the Coastal Calculator. Hence this Section is included in the main body of the report, rather than in the Appendices with other supporting information.

The Coastal Calculator provides extreme sea-level elevations and their associated occurrence likelihoods. In this section a method is demonstrated to transform the inundation elevations into hazard maps using a simple “bathtub” mapping approach (described below).

First, however, a discussion is required on which quantity to map. Policies 24–27 of the NZCPS dictate that coastal hazards be identified and rules be imposed to reduce or avoid risk of social, environmental and economic harm. This dictates that hazard zones be mapped to quantify coastal hazard exposure, and enable appropriate coastal development rules to be imposed for those zones. It is in this context that the choice between wave setup or runup elevations becomes relevant and at the same time difficult.

Whereas wave runup is arguably the most relevant design criterion for properties directly adjacent to the coast, flooding and erosion by wave runup and overtopping is often very localised and site-specific, and the overtopping discharge volume is unlikely to cause widespread inundation at locations several tens of metres back from the coast (notwithstanding barrier collapse). Therefore, the storm-tide + 2% wave *runup* elevation is almost certainly overly conservative for “bathtub” GIS mapping. However, the storm-tide + wave *setup* elevation is a reasonable bathtub mapping option, because a constant flow of water will occur over a coastal barrier lower than this elevation.

Nevertheless, wave runup can cause substantial flooding if the freeboard above the wave setup elevation is small, as seen during the Easter 2014 storm at exposed locations along Auckland’s east coast (Figure 3-1). For mapping inundation by wave runup, a problem is that the actual wave runup discharge over a coastal barrier is unable to be easily quantified and mapped over wide areas using simple models and tools such as the Coastal Calculator and “bathtub” mapping. For example, the 2% wave runup elevation is typically reported (e.g., van Rijn, 2010) and is output by the calculator. A barrier that is only just below the 2% wave runup elevation will experience only a minor amount of overwash, yet if that elevation is mapped using a “bathtub” mapping approach then adjacent low-lying land will be shown as entirely flooded. As the barrier height is lowered below the 2% wave runup elevation and towards the wave setup elevation, an increasing amount of overwash will occur, as demonstrated in Figure 3-1. But the exact amount of overwash and resulting flooding area is highly site-specific (e.g., topography and freeboard) and time-dependent (e.g., overtopping duration). There is no adequate approximation of the runup exceedance elevation that can be defensibly mapped using a simple bathtub mapping approach. Following Ramsay et al. (2012), a solution is to map the wave runup elevation contours as hazard zones “indicative” of potential wave runup inundation effects, rather than as entirely inundated. This indicates that further site-specific hazard assessment might be necessary in the “indicative” zones. Wave setup elevation contours can be mapped as inundation zones, notwithstanding that these are also conservative, as explained below under “limitations”.

The remainder of this Section describes a “bathtub” mapping technique that can be used to generate inundation zones for storm-tide + wave setup elevations.

Other approaches are required to more accurately map inundation and/or erosion or wave impact from wave runup. These include:

1. Modified bathtub approach – a time-limited volumetric approach would need developing within GIS, to account for overwash volume and flow path.

2. Hydrodynamic model – uses detailed bathymetry and topography and simulates the physics of the tide, storm-surge and wave setup and runup to dynamically inundate the coast.

Figure 3-1: Wave runup overtopping and flooding along Tamaki Drive, 17 April 2014. Photo by Victoria Lowman obtained from New Zealand Herald on-line. The gale-force winds coincided exactly with high-tide, reducing the freeboard of the seawall, enabling waves to pump over enough water to inundate the road and adjacent low-lying coastal properties.

GIS "bathtub" mapping of storm-tide + wave setup elevations

The bathtub mapping approach requires a digital elevation model (DEM of the coastal strip. LiDAR data provides detailed topographic information and DEM. Aerial ortho-photogrammetry is another technique that can be used to create detailed coastal DEM. The bathtub mapping technique can be used with any DEM – but the accuracy of the DEM will govern the accuracy of the resulting inundation maps. Using LiDAR data we were able to map the interface separating land from the Coastal Marine Area using the MHWS elevation, to the accuracy of individual property scale (Stephens et al. 2012).

This Section uses examples from a project to map coastal inundation by storm-tides and wave setup in the Auckland region (Stephens et al. 2013).

By intersecting extreme sea-level estimates with a DEM constructed from LiDAR (or other means), a set of flooded coastlines can be generated that represent the inland extent of flooding from the sea. Land lying seaward of the flooded coastlines and below the extreme sea-level elevations can be mapped as flooded.

This section outlines the methods used to produce inundation area maps within GIS. NIWA has developed algorithms to semi-automate this process. To demonstrate the method, results are shown for the 0.01 annual exceedance probability (100-year ARI) event along the east coast of the Auckland region and then focussing on the Whangateau Estuary to illustrate the final mapping. The methods are the same for all regions and all annual exceedance probability scenarios.

The process used to develop the inundation polygon in GIS is now described, for a single AEP scenario:

- Extreme storm-tide + wave setup elevations at model-output locations around the Auckland coastline were loaded into GIS (Figure 3-2a).
- Extreme storm-tide + wave setup elevations were interpolated along connecting lines (Figure 3-2b).
- The sea-level elevations were transferred to the coastline using nearest-neighbour interpolation.

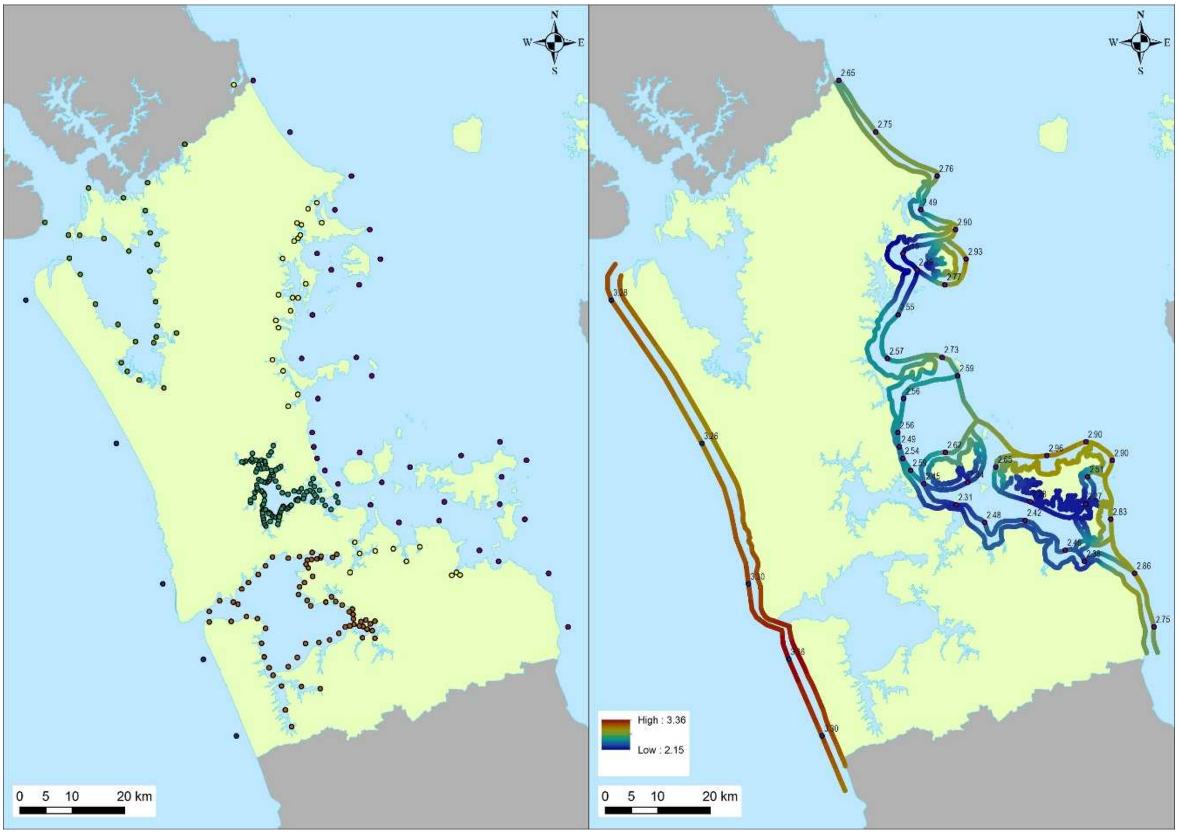

Figure 3-2: Map of the Auckland Region with: LHS – 0.01 AEP storm-tide elevations marked at model-output locations; RHS – interpolated elevations on the lines connecting model output locations, and elevations transferred from offshore lines to points along the coastline.

- The interpolated 0.01 AEP extreme sea-level elevations for the Auckland region are shown in Figure 3-3a.
- A study area polygon was created from approximately the +20 m contour inland and to ~ 1 km offshore, to be used as the analysis area (Figure 3-3b). This study area polygon can be described as a "window" within which the GIS looks for the intersection of the extreme sea-level elevation with the LiDAR DEM.
- 600,000 random points were picked within the study area and assigned the extreme sea level of the near coastal vertex. We used this dataset to create a 1 m raster of the spatially varying extreme sea level. This is shown in Figure 3-4 for the present-day 0.01 AEP extreme sea-level elevation line, up to 1 km from the coastline.
- Sea-level rise scenarios of +1 m and +2 m were added to some of the present-day extreme sea-level scenarios.
- Figure 3-5a and Figure 3-5b give examples of the inundation polygons in Whangateau Harbour (Omaha) for 0.01 AEP extreme sea-level scenarios for present-day mean-sea-level and present-day plus 2 m sea-level rise.

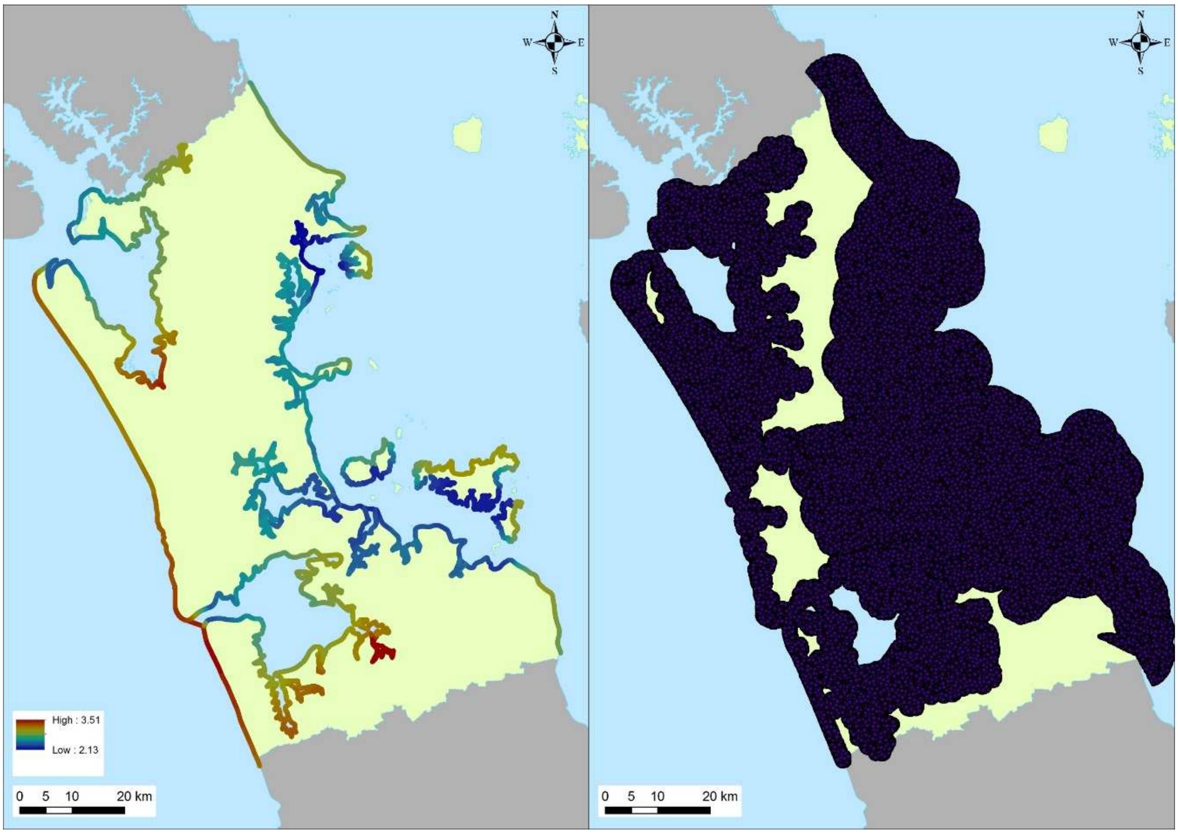

Figure 3-3: Map of Auckland region with: LHS – interpolated elevation values on simplified coastline; RHS – 600,000 random points in the analysis area.

Figure 3-4: Map of Auckland region with water surface for 0.01 AEP (100-year ARI) elevations.

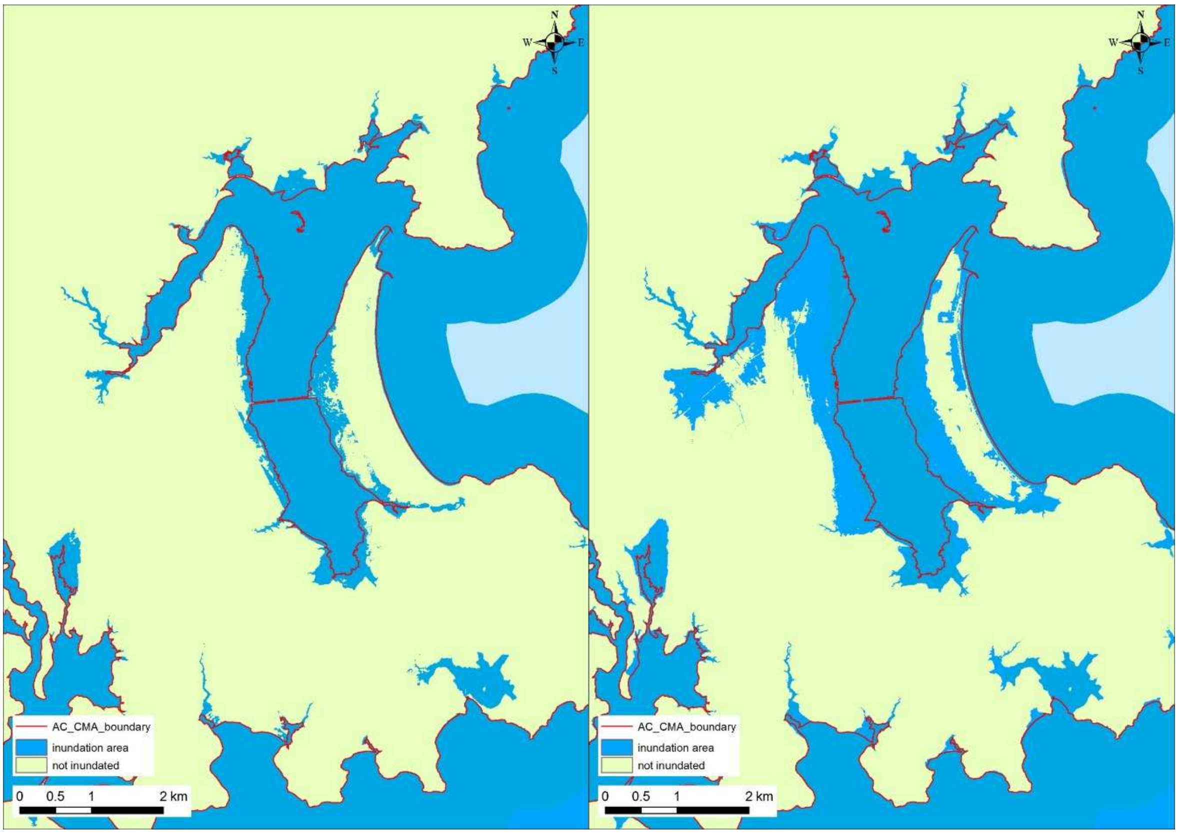

Figure 3-5: Inundation area from 0.01 AEP (100-year ARI) extreme sea-level scenario in Whangateau Harbour (LHS), and including +2.0 m sea-level rise (RHS). AC_CMA_boundary is the CMA boundary for the Auckland region (Stephens et al. 2012).

Connection by rivers and drains

The raw polygons contained numerous ponded areas that were unconnected to the sea. This occurred because they were lower than the extreme sea-level being modelled, but separated from the sea by a strip of higher land. Therefore, the final process was to overlay a GIS layer containing the drainage network. If a ponded area was connected by a river or drain, then it was included in the flood map, and if not it was deleted. In the data layers supplied these areas were flagged 'connected by drain or river'. The connections were based on the storm water and river network locations supplied.

Limitations of the bathtub approach

The 'bathtub' mapping approach described above assumes that if an inland area is connected to the open coast via a drain/river then this area will be inundated to the equivalent level as the adjacent open coast (i.e., no lags or diminished volumes assumed in flooding through these connections. Since most land in the Auckland region rises quite rapidly away from the coast, the bathtub mapping approach is a reasonable approximation there. But, for wide low-lying plains, friction will reduce the volume of water that actually inundates the area whereas the bathtub approach will assume instantaneous flooding of the entire area. Furthermore, the duration of the highest storm-tide elevations often persist for only about 3 hours around a high tide, or a similar duration for a large wave event.

A sensible approach to mapping inundation over wide plains appears to be a time-limited volumetric approach where, in the case of storm tides, a sinusoidal curve is linked to an open-crested weir formula to calculate the inundation volume. NIWA has not applied such a technique, but is working on its development.

See Sections 3.2 and 3.3 in Ramsay et al. (2012) for more on applying these methods to establish coastal inundation zones.

4 Acknowledgements

The original Coastal Calculator was developed on behalf of the Government of Kiribati (Ramsay et al. 2008) and the first New Zealand application was for Bay of Plenty Regional Council (Goodhue et al. 2013) with refinements for Tasman District Council (Robinson et al. 2014). Supply of the Port Gisborne sea-level gauge data and Tatapouri wave buoy data was crucial to the project. The study is underpinned by the WASP modelling project funded by MBIE (formerly MSI and FRST). Development of joint-probability methods for extreme storm-tides were funded by MBIE. The project was jointly funded by Gisborne District Council and an Envirolink Medium-advice grant (MBIE).

5 Glossary of abbreviations and terms

Annual exceedance probability (AEP)	The probability of a given (usually high) sea level being equalled or exceeded in elevation, in any calendar year. AEP can be specified as a fraction of 1 (e.g., 0.01) or a percentage (e.g., 1%).
Average recurrence interval (ARI)	The average time interval (averaged over a long time period and many "events") that is expected to elapse between recurrences of an infrequent event of a given large magnitude (or larger). A large infrequent event would be expected to be equalled or exceeded in elevation, once, on average, every "ARI" years.
Hindcast	A numerical simulation (representation) of past conditions. As opposed to a forecast or future cast that simulates the future.
Joint-probability	The probability of two separate processes occurring together (e.g., large waves and high storm-tide).
Marginal variable	Refers to a single variable (e.g., wave height, or storm-tide) representing one axis, or "margin", of a joint-probability plot.
Mean sea level anomaly (MSLA)	The variation of the non-tidal sea level about the longer-term mean sea level on time scales ranging from a monthly basis to decades, due to climate variability. This includes ENSO and IPO patterns on sea level, winds and sea temperatures, and seasonal effects.
MSL	The mean level of the sea relative to a vertical datum over a defined epoch of several years.
GVD-26	Gisborne Vertical Datum-1926 is the region-wide vertical datum used by Gisborne District Council.
Storm surge	The temporary rise in sea level due to storm meteorological effects. Low-atmospheric pressure causes the sea-level to rise, and wind stress on the ocean surface pushes water down-wind and to the left up against any adjacent coast.
Storm-tide	Storm-tide is defined as the sea-level peak during a storm event, resulting from a combination of MSL + MSLA + tide + storm surge. In New Zealand this is generally reached around high tide.
Wave runup	The maximum vertical extent of sporadic wave "up-rush" or flowing water ("green water") on a beach or structure above the still water or storm-tide level, and thus constitutes only a short-term upper-bound fluctuation in water level compared to wave setup.
Wave setup	The increase in mean still-water sea level at the coast, resulting from the release of wave energy in the surf zone as waves break.

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Appendix A Calculating storm-tide + wave runup elevations

Components of sea level (excluding waves)

There are a number of meteorological and astronomical phenomena involved in the development of extreme sea level events. These processes can combine to inundate low-lying coastal margins. The processes involved are:

- Mean sea level (MSL).
- Astronomical tides.
- Storm surge.
- Mean sea level anomaly (MSLA), which is the variation of the non-tidal sea level about the longer-term mean sea level on time scales ranging from a monthly basis to decades, due to climate variability. This includes ENSO and IPO patterns on sea level, winds and sea temperatures, and seasonal effects.
- Climate-change effects including sea-level rise. Sea-level rise was considered in this study as +1 m, and +2 m above present-day mean sea level, but the Coastal Calculator has an interactive entry for any value of sea-level rise.
- Tsunami – not considered in this study.

The astronomical tides are caused by the gravitational attraction of solar-system bodies, primarily the Sun and the Earth's moon, which then propagate as forced long waves in the ocean interacting in a complex way with continental shelves. In New Zealand the astronomical tides have by far the largest influence on sea level, followed by storm surge (in most locations).

Low-pressure weather systems and/or adverse winds cause a rise in water level known as storm surge. Storm surge results from two processes: 1) low-atmospheric pressure relaxes the pressure on the ocean surface causing a temporary rise in sea-level, and 2) wind stress on the ocean surface pushes water down-wind, or alternatively, to the left of an alongshore wind (in the southern hemisphere) from a persistent wind field, piling up against any adjacent coast.

Storm-tide is defined as the sea-level peak reached during a storm event, from a combination of **MSL + MSLA + tide + storm surge** (see below for description of MSLA). It is the storm-tide that is primarily measured by sea-level gauges such as the Port of Gisborne gauge analysed here. Throughout this report, we refer to storm-tide as the sea-level quantity relevant to coastal inundation before wave runup is applied.

The mean sea level anomaly (MSLA) describes the variation of the non-tidal sea level on longer time scales ranging from a monthly basis (e.g., stormy or calm months), through an annual sea-level cycle, up to decades due to climate variability, including the effects of El Niño–Southern Oscillation (ENSO) and the Interdecadal Pacific Oscillation (IPO) patterns on sea level, winds and sea temperatures, and seasonal effects.

The following bullet points describe mean sea level definitions and how mean sea level measurements were obtained from sea-level gauge records:

- Tidal harmonic analysis was used to resolve the astronomical tide from the sea-level measurement records. The tide was then subtracted to produce a non-tidal residual sea-level record.
- The non-tidal residual sea-level record was then low-pass filtered (using a wavelet filter) to remove variability with periods of less than 1 month. The remaining sea-level time-series contained only sea-level variations with periods of motion of one month or greater, and this low-frequency time-series is termed the "Mean Sea Level Anomaly" (MSLA). Another, simpler way to obtain MSLA is to remove the predicted tidal component of sea-level variability from the sea-level record, and then average the non-tidal residual on a monthly basis. MSLA does not include mean sea-level datum offset and any long-term sea-level trend. MSLA defines the monthly (and greater) sea-level anomaly about a zero MSL due to climate variability such as seasonal effects, ENSO and IPO.
- When the non-tidal sea level is averaged over a defined time period (usually several years), the Mean Sea Level (MSL) is obtained. New Zealand's local vertical datum's were obtained in this way (e.g., Gisborne Vertical Datum–1926 (GVD-26).
- All storm-tide plus wave setup and runup elevations were calculated relative to a zero MSL.
- A MSL offset is subsequently required to relate the above results to a survey datum such as GVD-26. MSL at Gisborne was 0.208 m above GVD-26 based on sea-level measurements 2004-2012.
- The average relative sea level rise in New Zealand derived from historical sea-level records over the last century was 1.7 ± 0.1 mm yr^{-1} (Hannah and Bell 2012). Climate change will also cause acceleration in long-term trends of sea-level rise (Ministry for the Environment 2008) and could cause minor increases in the drivers (winds, barometric pressure) that produce storm surges (Mullan et al. 2011)[5].

Sea-level datum and mean sea level (MSL)

All data in this report are referenced relative to Gisborne Vertical Datum–1926 (GVD-26), which is routinely used throughout the Gisborne region, unless otherwise stated.

Before the introduction of New Zealand Vertical Datum 2009 (NZVD2009) in September 2009, land heights in New Zealand were referred to one of 13 local vertical datums[6].

These local datums were established historically by determining mean sea level (MSL) at a tide-gauge and then transferring this level by precise levelling to benchmarks in the surrounding hinterland.

[5] http://www.niwa.co.nz/sites/default/files/slmacc_extremewinds_slew093_may2011.pdf
[6] http://www.linz.govt.nz/geodetic/datums-projections-heights/vertical-datums/mean-sea-level-datums

Sea level is known to vary around the coast of New Zealand and the local datums were set a different times during last century. This means that the level of MSL determined at each datum's tide-gauge will be different and that offsets will occur between adjacent datums. Also, in most cases the level of MSL for the vertical datums was determined many decades ago and has not been officially updated since then to include the effect of sea-level rise. Recent MSL values relative to these local vertical datums have been reported by Hannah and Bell (2012).

At a particular Standard Port, the level of the water is expressed as a height above a local hydrographic datum which is also the datum used for the depths of the sea on nautical charts, known as Chart Datum (CD). This datum is defined with reference to permanent benchmarks ashore and the zero of the tide gauge. The Chart Datum adopted usually approximates Lowest Astronomical Tide (LAT) which is the lowest tide predicted to occur under normal meteorological conditions.

Gisborne Vertical Datum–1926

A gauge been operating at the Port of Gisborne since 1984. The gauge is surveyed relative to Chart Datum, whereas Gisborne Vertical Datum (GVD-26) is 1.052 m above Chart Datum. Based on the sea level measurements from this gauge Land Information New Zealand (LINZ) have set the MSL from 2004-2012 to 1.26 m above Chart Datum (LINZ, 2014), which is 0.208 m above GVD-26.

Explanation of extreme event probabilities

Coastal inundation, or other hazards such as erosion or structural damage to coastal defences, roads or buildings, is worse when high storm-tides and large waves occur together. This report shows how these processes can be accounted for simultaneously, and quantified by an average joint-recurrence interval or joint exceedance probability, using **joint-probability** analysis. Although there is often some correlation between extreme storm-tides and extreme significant wave heights, they can also be damaging on their own. The coastal calculator includes extreme-value analyses for both storm-tide and wave height on their own (known as **marginal** as opposed to joint-probability analyses).

The likelihoods associated with extreme storm-tides and/or waves, are reported in terms of their probability of occurrence. The **annual exceedance probability** (or AEP) describes the chance of an event reaching or exceeding a certain water level in any one year. For example, if a storm-tide of 1.37 m (GVD-26) has a 5% AEP, then there is a 5% chance of a storm-tide this high, or higher, occurring in any 1-year period. So it is unlikely, but could still happen and should be planned for. Furthermore, although the occurrence probability is only 5%, more than one storm-tide this high or higher could occur in the same year.

Alongside AEP, the likelihood of extreme events can also be described in terms of their **average recurrence interval** (ARI), which is the average time interval between events of a specified magnitude (or larger), <u>when averaged over many occurrences</u>[7]. Table A-1 shows the relationship between AEP and ARI; small relatively common events have a high annual exceedance probability and a low average recurrence interval, and *vice versa* for large, rare events.

[7] Note: this is seldom achieved for short records, so AEP is a better statistic to use.

Table A-1: Relationship between annual exceedance probability (AEP) and average recurrence interval (ARI). AEP = 1 – e(-1/ARI).

AEP (%)	99%	86%	63%	39%	18%	10%	5%	2%	1%	0.5%
ARI (years)	0.2	0.5	1	2	5	10	20	50	100	200

ARI (or its often used surrogate "return period") is an easily misinterpreted term, with the public often assuming that because one large event has just occurred, then the average recurrence interval will pass before another such event. For geological events, such as earthquakes or volcano eruptions, this can be a useful term to describe the average time between events, but it is not informative for meteorological events which can occur at any time. We therefore prefer the term AEP, because it conveys the continuous probability that large events could occur at any time.

This report provides annual occurrence likelihoods for extreme storm-tide and wave height magnitudes. This knowledge is only one aspect of the planning process. Another essential planning component is to consider the planning timeframe, or lifetime, of interest. For example, a typical planning lifetime for residential housing or coastal planning is 100 years. Table A-2 presents the likelihood that events with various occurrence probabilities will occur within a specified planning lifetime. The likelihoods are shaded according to their chance of occurring in the specified timeframe:

- > 85% Almost certain
- 60%–84% Likely
- 36%–59% Possible
- 16%–35% Unlikely
- < 15% Rare

For example, a relatively common (smaller) event with a 39% AEP is *almost certain* to occur over a 20-year lifetime. However, a rare (larger) 2% AEP event is *unlikely* to occur over the same 20-year lifetime. 1% AEP's are a commonly used planning event magnitude, and 100-year planning lifetimes are common for affected infrastructure or coastal planning; Table A-2 shows that a 1% AEP (100-year ARI) event is *likely* to occur over a 100-year planning lifetime.

Table A-2: Likelihood of an event with a specified probability of occurrence (AEP / ARI), occurring within planning lifetimes. P = 1 - e-L / ARI, where L = planning lifetime and P = probability of occurrence within planning lifetime.

AEP (%)	ARI (years)	Planning lifetime (years)						
		2	5	10	20	50	100	200
39%	2	63%	92%	99%	100%	100%	100%	100%
18%	5	33%	63%	86%	98%	100%	100%	100%
10%	10	18%	39%	63%	86%	99%	100%	100%
5%	20	10%	22%	39%	63%	92%	99%	100%
2%	50	4%	10%	18%	33%	63%	86%	98%
1%	100	2%	5%	10%	18%	39%	63%	86%
0.5%	200	1%	2%	5%	10%	22%	39%	63%

Derivation of coastal inundation levels

The following steps were required to derive inundation levels for locations along the Gisborne District coastline shown in Figure 1-1. More detailed descriptions of sea-level processes contributing to extreme storm-tide + wave runup elevations are given in Appendix A, with details of storm-tide modelling in Appendix C, wave modelling in Appendix D, and joint-probability modelling in Appendix E.

Storm-tide

1. Decompose the Gisborne sea-level data into its various sea-level components of: MSLA, tide, storm surge.
2. Predict the astronomical tide levels at Gisborne using the UTide tidal harmonic analysis package (Foreman et al. 2009) and calculate tidal residual.
3. Use the Monte Carlo joint-probability method (MCJP) (Goring et al. 2010) to predict the extreme storm-tide height for a range of AEP’s at Gisborne. This provided **independent** frequency-magnitude relationships for extreme storm-tides.
4. Extract tide and storm-surge time-series from the WASP modelling project (see below).
5. Compare the storm-surge and MSLA distribution at the sea-level gauge with those from WASP at the closest WASP output location to the gauge. Apply derived scaling factors to all WASP output.
6. Use MCJP to calculate extreme storm-tide distributions at all WASP output locations (Figure A-1).

Waves

1. Use a peaks-over-threshold technique to sample a subset of the most extreme wave heights during independent wave/swell events from the Tatapouri wave buoy record. Fit a generalised Pareto distribution to model independent extreme wave height frequencies and magnitudes at Tatapouri.
2. Extract significant wave height and peak wave period from the SWAN model at the SWAN output locations, and at the Tatapouri wave buoy location.
3. Apply a wave sheltering algorithm (Appendix D) to transform the wave data from the SWAN output locations to 33 locations along the Gisborne coastline.
4. Calculate the extreme significant wave height distribution at all locations (Appendix D).
5. Scale up the extreme wave height distributions based on Model/buoy comparisons and expert judgement (Appendix D).

Joint probability analysis

1. For each of the 33 output locations (Figure A-1), use JOIN-SEA to undertake joint-probability analyses using the simulated time-series of waves and storm-tide. This provides the **joint probability** (or likelihood) of various combinations of storm-tide levels and wave heights, and calculates any dependence between the two.
2. Rescale the wave heights and storm-tides using the results from the individual extreme analyses. The re-scaling makes use of the more accurate MCJP extreme sea-level technique and re-scaled marginal wave height distribution, leading in this case to a more accurate result.

Calculating inundation levels using the Coastal Calculator tool

1. Maximum inundation elevations were calculated using the joint-probability results. These elevations include the contribution of storm-tide and of waves in the form of wave setup and separately wave runup. The joint probability and extreme value analysis data for each site was entered into the Microsoft Excel-based Coastal Calculator, which allows the user to output the frequency and magnitude of storm-tide and wave setup and runup elevations, for 33 locations along the Gisborne coastline. The calculator requires the user to select a number of options and input parameters such as datum offset, future sea-level rise allowance, beach slope and AEP.

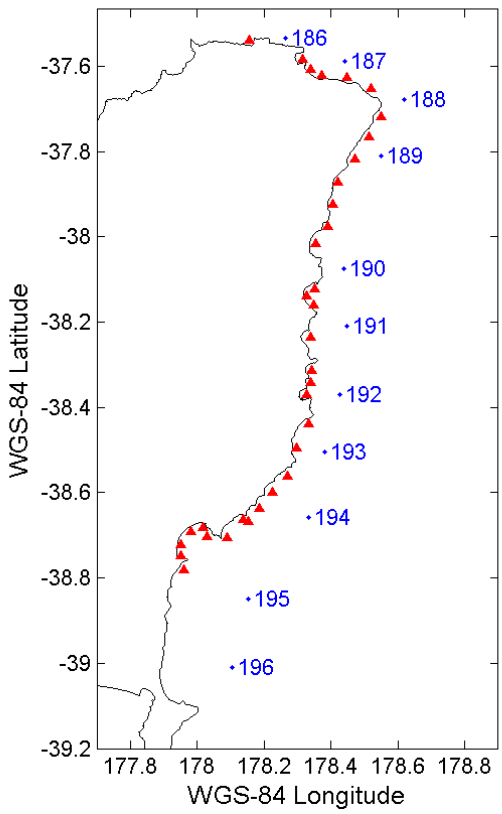

Figure A-1: Locations of 11 WASP model data sites and 33 study output locations. Site numbers are WASP model codes.

The Waves and Storm Surge Predictions (WASP) models

The WASP modelling project recently completed by NIWA produced 45-year (1958–2002) hindcast records of storm surge and waves around the entire New Zealand coast. 30-year future cast projections of future wave and storm surges off the coast were also simulated for two climate change scenarios covering the period 2070–2100 for the B1 and A2 climate change SRES scenarios.

An aim of the WASP project was to produce a nationally-consistent web-based hindcast from which regional information could be extracted. This will help create a more standardised approach by local government, infrastructure operators and coastal communities in their efforts to adapt to climate-change impacts.

The information provides a wider basis for sustainable resource-management planning decisions for the coastal margin that adequately accounts for not only sea-level rise impact (which currently tends to be the main focus), but also potential changes to waves and storm-surge and their impact on coastal hazards.

The WASP project produced data at the 50 m depth contour at regular intervals around the New Zealand coastline. This provides “offshore” conditions that can be used in situ, or as boundary conditions to drive more detailed coastal models.

The hindcast simulation used wind and atmospheric pressure forcing data from the global ERA40 reanalysis (Uppala et al. 2005) which covers the 40-year period 1958-2002 with a resolution of 1.225 degrees (~140 km).

An additional hindcast for the thirty-year period 1970-2000 was computed using dynamically down-scaled forcing data. This "regional climate model" (RCM) has a finer resolution of 0.27 degrees (~30 km) and uses the ERA40 data for boundary conditions. The finer-resolution hindcast was used for this study.

Appendix B Sea-level gauge analysis

The Port of Gisborne has the only tide gauge on the Gisborne District coastline from which to derive extreme sea level data. Numerous errors were present in the tide data at the Port of Gisborne however, and these had to be dealt with before a reliable analysis of extreme coastal inundation could be undertaken. This section describes the methods used to undertake a quality assurance of the Gisborne tide data (Table B-1).

Table B-1: Methods used to undertake a quality assurance of the Port of Gisborne tide data.

QA Action	Method
Delete time double ups	Where there is more than one value recorded at the same time, keep the first value only.
De-spiking	Values of spikes are determined by linear interpolation between the neighbouring non-spiked values.
Correct drifting tide data	This data was deleted (from Nov 2006 to Feb 2008), but the storm-surge components were retained.
Shift misplaced data (assuming no sloping in SL)	Determine the difference between the mean sea level from 10th September 2009 onward and the mean sea level at the misplaced data. Add this difference to the misplaced data.
Identify and correct phase shifts	Shift data points forward by 1 hour (November 2011 to March 2012).
Remove points	Applied to other data errors not described above.

Preparation of tide data for decomposition

Removing erroneous data and de-spiking points wasn't a challenge by itself, but correcting datum shifts or drifting tide data was more difficult as there were uncertainties about where the mean sea level should be. Decomposing the non-tidal residual into its various components can help deal with this issue. The tide data at Gisborne was prepared for deposition using the following method (depicted in Figure B-1a):

1. De-spike raw tide data.
2. Create a running average of 1 hour on the de-spiked data (30 minutes each side).
3. Interpolate processed data to 1 hour intervals.
4. Make a plot which shows raw data, de-spiked data, smoothed data and the hourly smoothed data (points).

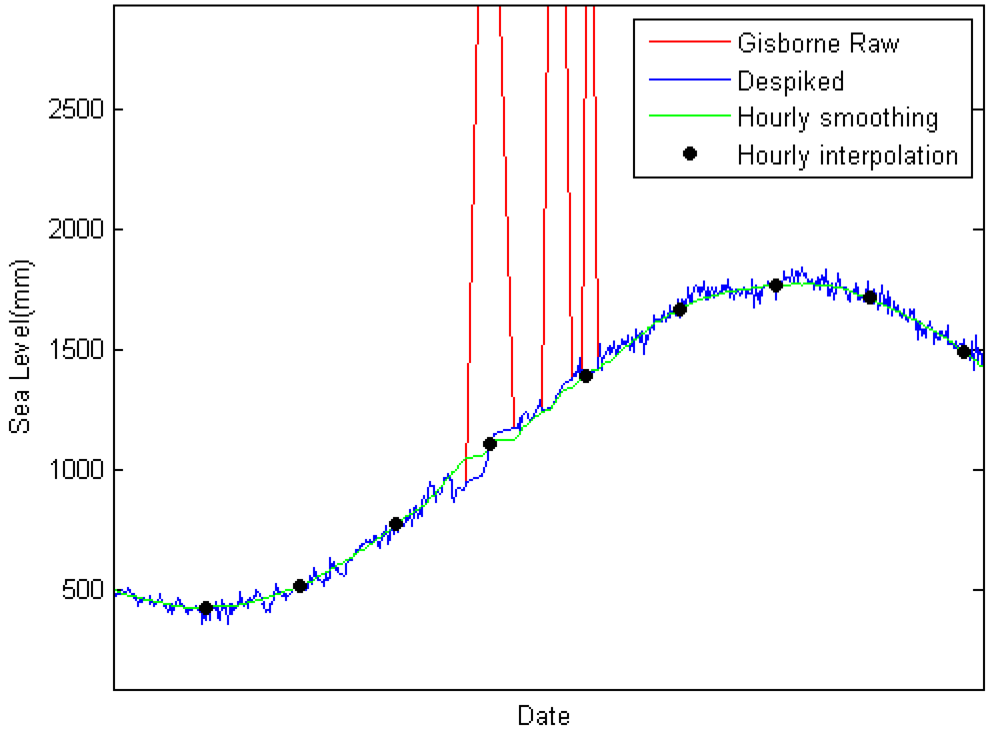

Figure B-1a: The different stages of data treatment before tidal decomposition.

Decomposition of Gisborne tide data

To decompose the tide, the unified tidal analysis function (UTide) was applied to the Port of Gisborne data to predict the tide, and the non-tidal residual was then decomposed using a wavelet filter. Methods are described below:

1. Run UTide and produce tidal harmonics for each year from September 2009 onwards. The gauge record has no apparent large datum shifts from then on (Figure B-3) enabling a sound tidal harmonic analysis to be made. Use the tidal harmonics from the best year to predict the tidal harmonics for earlier years. Calculate non-tidal residual as the difference between the measured and predicted tide.

2. Decompose the non-tidal residual into its components using a wavelet filter: high-frequency energy (unexplained tidal energy) (6-12 hours), storm-surge (24-768 hours), MSLA (>1 month), plus >4 month and >8month.

Decomposition of the non-tidal residual is used to undertake a Monte Carlo joint-probability analysis of extreme storm tides. However, it is also a valuable tool for quality assurance of tide data for a few reasons:

1. Spikes in the tidal components can indicate erroneous spikes in the original data.

2. An oscillating non-tidal residual indicates that tide data may be out of phase.

3. Jumps in the non-tidal residual for certain periods can indicate datum shifts in the measured data.

For example, analysis of the non-tidal residual revealed a spike around mid-2011 and oscillations around November 2011 to March 2012. These large oscillations in the non-tidal residual were caused by a daylight savings time-shift of 1 hour (Figure B-2). These phase shifts would affect the calculation of storm-surge, and so they were corrected before wavelet filtering was applied.

Figure B-3 compares predicted tide with measured tide for the entire record. Jumps in the non-tidal residual indicate some datum shifts which need to be corrected. The predicted tide has a pronounced slope that could be linked to the datum shifts and thus needs to be removed. Using UTide, the predicted tides were then calculated for each year from September 2009 onwards, setting the mean and slope to zero. For the period before September 2009, the tidal constituents from September 2009 to September 2010 were used to predict the pre-2009 part of the record also, with mean and slope set to zero.

Figure B-4 shows the sea-level components for Gisborne after cleaning up the data, using the methods in Table B-1. The data shows a robust tide and storm-surge record for 2004–2013, and robust MSLA and unexplained high-frequency records from 2009 onward. The robust sections of data were subsequently combined in a storm-tide analysis (see Appendix C).

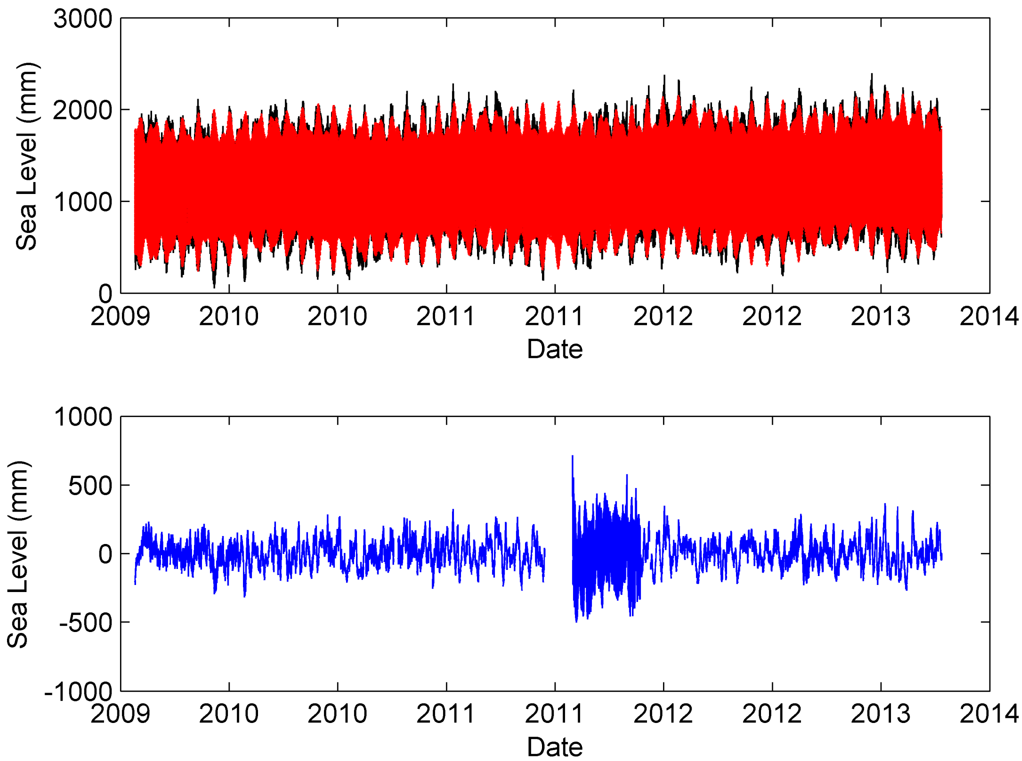

Figure B-2: Measured and predicted tide for September 2009 to September 2013. Measured tide (black), predicted (red), residual (blue).

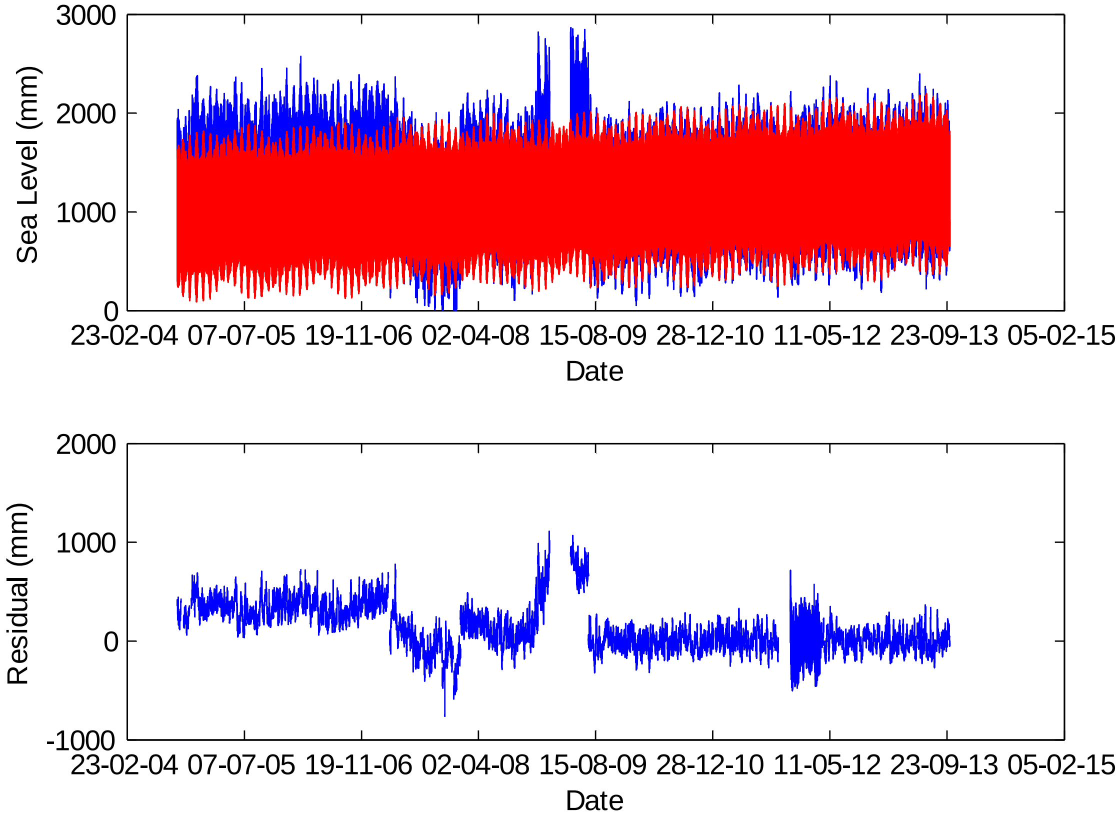

Figure B-3: Measured and predicted tide levels for the whole record, including non-tidal residual. Measured (blue top), predicted (red), residual (blue bottom).

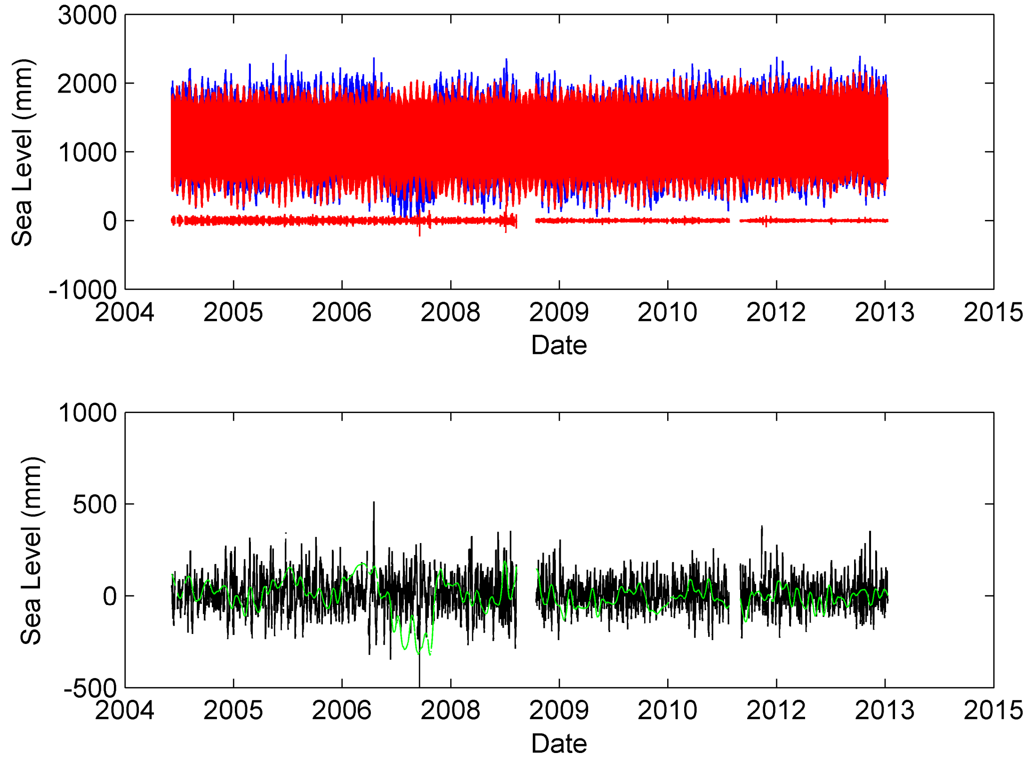

Figure B-4: Gisborne tide components after clean up. Measured tide (blue), predicted tide (large variance) and unexplained tidal energy (low variance) (red), storm surge (black), MSLA (green).

Appendix C Storm-tide modelling and analysis

Storm tide is defined as the sea-level peak reached during a storm event, from a combination of four sea level components: tide, storm-surge, MSLA and remaining high-frequency energy. The MSL for the epoch under consideration also needs to be subsequently added. In this project, the storm-tide was calculated at 11 WASP locations offshore using WASP simulations for the period 1970-2000. An assumption was made that storm-tide would not substantially change between the WASP locations offshore and 33 study output locations inshore, and that the scaling factors derived for storm-surge and MSLA close to Gisborne would account for any discrepancy. The offshore storm tides were then matched to the closest inshore locations, thus providing storm-tide data at 33 inshore locations (Figure 1-1). This section discusses how each of the sea-level components were calculated along the east coast. Apart from at Poverty Bay, there are no tide gauges to measure sea level directly.

Tide analysis

Hourly tide data were generated for all 11 WASP sites from January 1970 to December 2000. This involved generating tidal constituent (CNS) files at each site using the Utide model, and then running tifore99 using each of the CNS files. The predicted tide offshore from Poverty Bay (WASP site 195 Figure A-1) is depicted in Figure C-1.

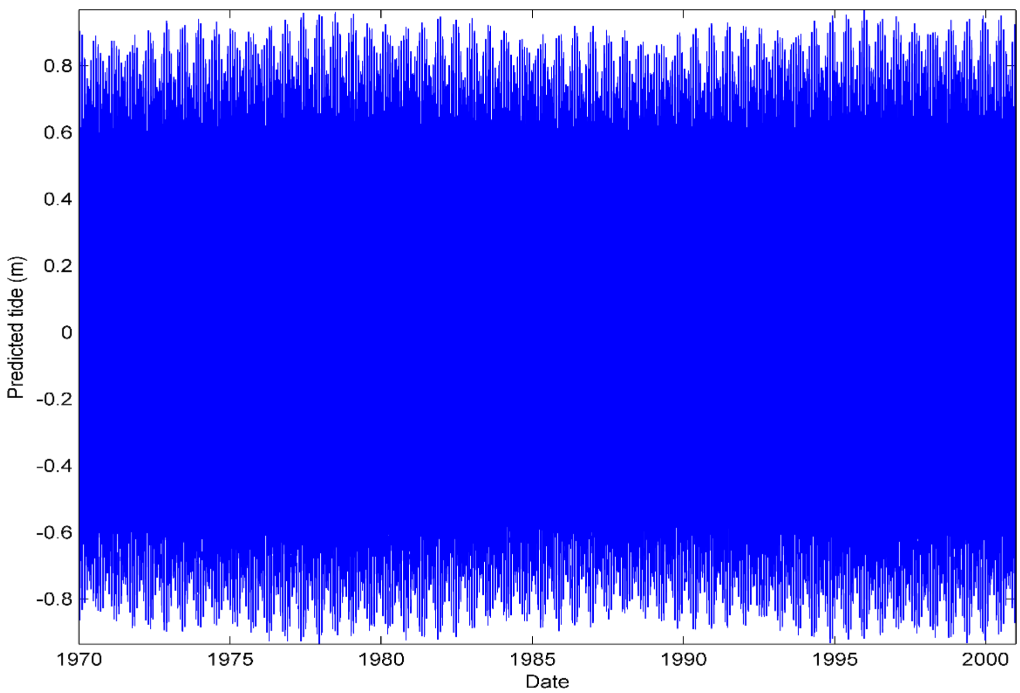

Figure C-1: Predicted tide height offshore from Poverty Bay Jan 1970 to Dec 2000. Tide data is hourly and calculated relative to MSL=0.

Storm surge analysis

Extreme storm-surge distribution

Tide can be forecast many years into the future, but our knowledge of the storm-surge distribution is restricted either to the sea-level gauge measurement period, or to a period of available model hindcasts (e.g., 1970–2000 for WASP). At the Port Gisborne gauge site, storm-surge data was restricted to 9 years from 2004–2013, however it is possible that more extreme storm surges have occurred historically, or could occur in future. To account for this, the Monte-Carlo joint-probability technique samples not only the empirical storm-surge cumulative distribution function, but also samples an extreme-value model of storm-surge. The extreme-value model models the likelihood of extreme storm surges than have been measured so far.

There are two commonly-applied extreme value models: 1. the generalised extreme-value (GEV) model fitted to block maxima (such as annual maxima) and 2. The generalised Pareto distribution (GPD) fitted to independent data peaks that exceed a given high threshold (known as peaks over threshold, or POT). The GPD is often preferred because it uses more of the available data, but the choice of threshold is subjective and can influence the result.

Figure C-2 shows the variability of the GPD scale and shape parameters with threshold. In this case there is no clear threshold where these parameters stabilise and remain constant, however the average shape parameter appears close to 0. The Gumbel distribution is one member of the GEV family of distributions, where the shape parameter equals zero.

Figure C-3 shows three extreme-value models fitted to the storm-surge data using different models and data selection techniques. As expected from Figure C-2, the GPD models show considerable variability with threshold. Since the threshold data indicated an average scale parameter of close to 0, the Gumbel distribution fitted to annual maxima was also plotted. As expected for such a short dataset (in terms of extreme-value analysis where 0.01 AEP are desired), there is considerable variability. If the dataset were ~50-years long we would expect the threshold data to exhibit stability and that all techniques would give similar answers.

The Gumbel distribution was chosen to represent storm-surge due to its simplicity, and because it is relatively conservative in that it predicts reasonably high extreme storm-surge levels. The resulting 0.01 AEP value of ~600 mm is consistent with our experience, where we have not seen a higher storm-surge measured by an open-coast sea-level gauge around New Zealand. Note that a GEV or Gumbel model fitted to annual maxima data is generally only reliable for predicting magnitudes with ARI out to 3–5 times the record length (27–45 years in this case). As a general rule, because it uses more maxima, the GPD/POT approach is generally for predicting magnitudes with ARI up to 10 times the record length.

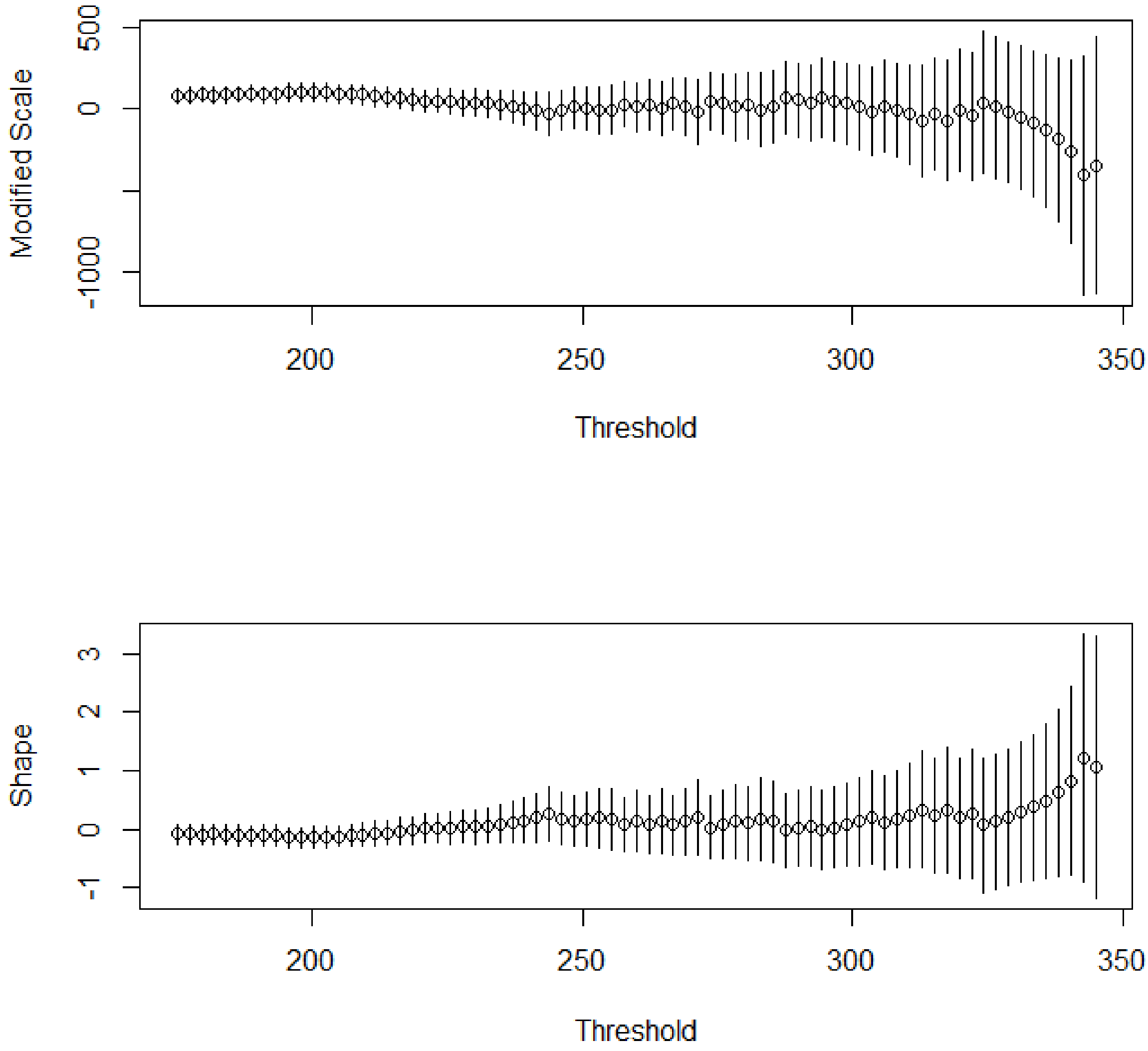

Figure C-2: Variability of the generalised Pareto distribution scale and shape parameter with truncation threshold.

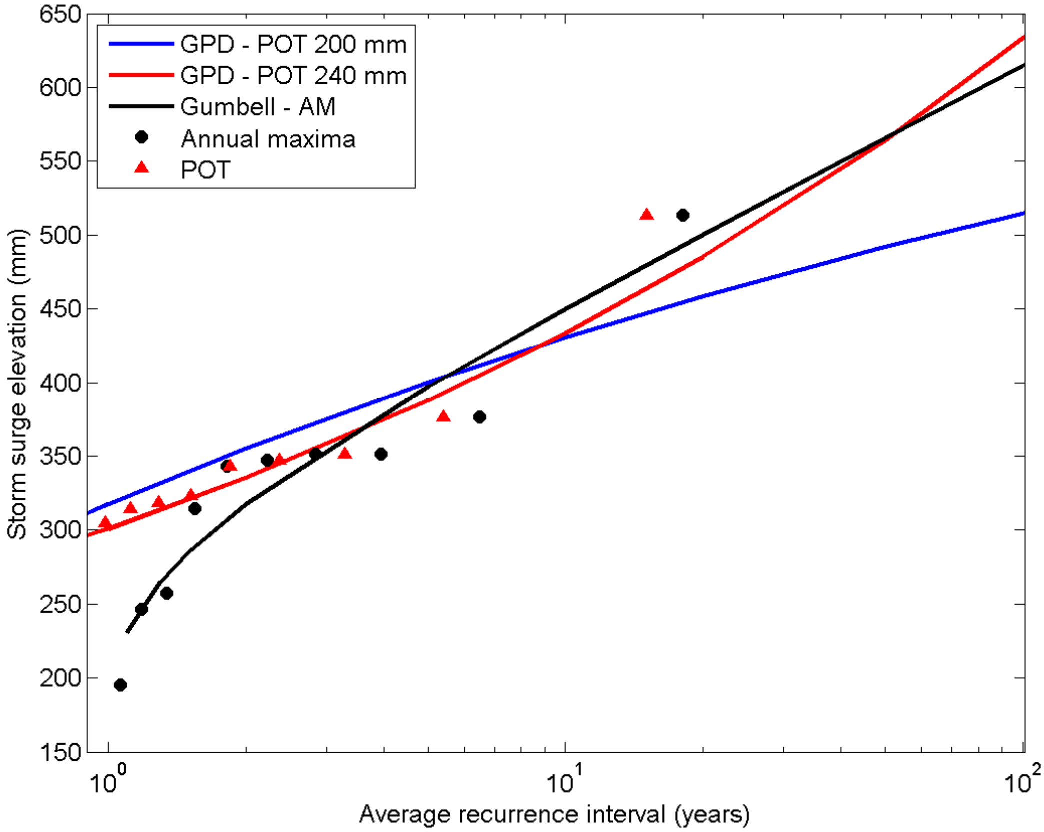

Figure C-3: Extreme-value models fitted to storm surge peaks. GPD = generalised Pareto distribution. POT = peaks-over threshold. AM = annual maxima. Gumbel = Fitted Gumbel distribution. Annual maxima and POT data are plotted in their Gringorten (1963) plotting positions. For annual maxima the Gringorten (1963) plotting positions asymptote at ARI = 1 year, meaning that the lowest 3 annual maxima plot below the POT data. The Gringorten (1963) plotting position for the largest AM in a 9-year record is 15.8-year ARI.

Calculation of storm surge

Storm-surge is the rise in water level caused by low barometric pressure and/or strong winds. Storm surge was calculated by applying a wavelet filter of detail 1–16 days to the WASP hindcast storm surge data. The POT method was then used to fit a GPD to the extreme storm surges at the Gisborne tide gauge, and the nearest offshore WASP site (Poverty Bay). The purpose of this was to derive a scaling factor which can be applied to all 11 WASP sites. Storm surges were scaled along the east coast using the following method:

1. Use peaks over threshold on the Gisborne sea level data, with a physical threshold of 0.2. This is the threshold value for the generalised Pareto location parameter. This physical threshold was exceeded approximately 10 times during the entire record.

2. Fit an empirical CDF to the less extreme storm-surges below this threshold.

3. Fit a GPD to the extreme data above this threshold. Use the GPD to extend the upper limit of the empirical CDF above the 0.2 m threshold.

4. The scaling factors were then calculated as the CDF (Gisborne Gauge) / CDF (Poverty Bay WASP site) as determined in steps 2 and 3. The CDF's have probability intervals of 0.01, so a different scaling factor is calculated at each interval (Figure C-4).

5. These scaling factors are then applied to the other offshore WASP sites.

Figure C-4 shows the resulting storm surge CDF's constructed using the POT method on the Gisborne tide gauge and closest offshore WASP site. Note that the gauge has lower storm surges than the WASP hindcasts on the less extreme end of the spectrum, but the opposite is observed on the more extreme end. This will cause the more extreme storm surges to be scaled up, and the less extreme surges scaled down at each site; this can be seen in the storm surge time-series in Figure C-5.

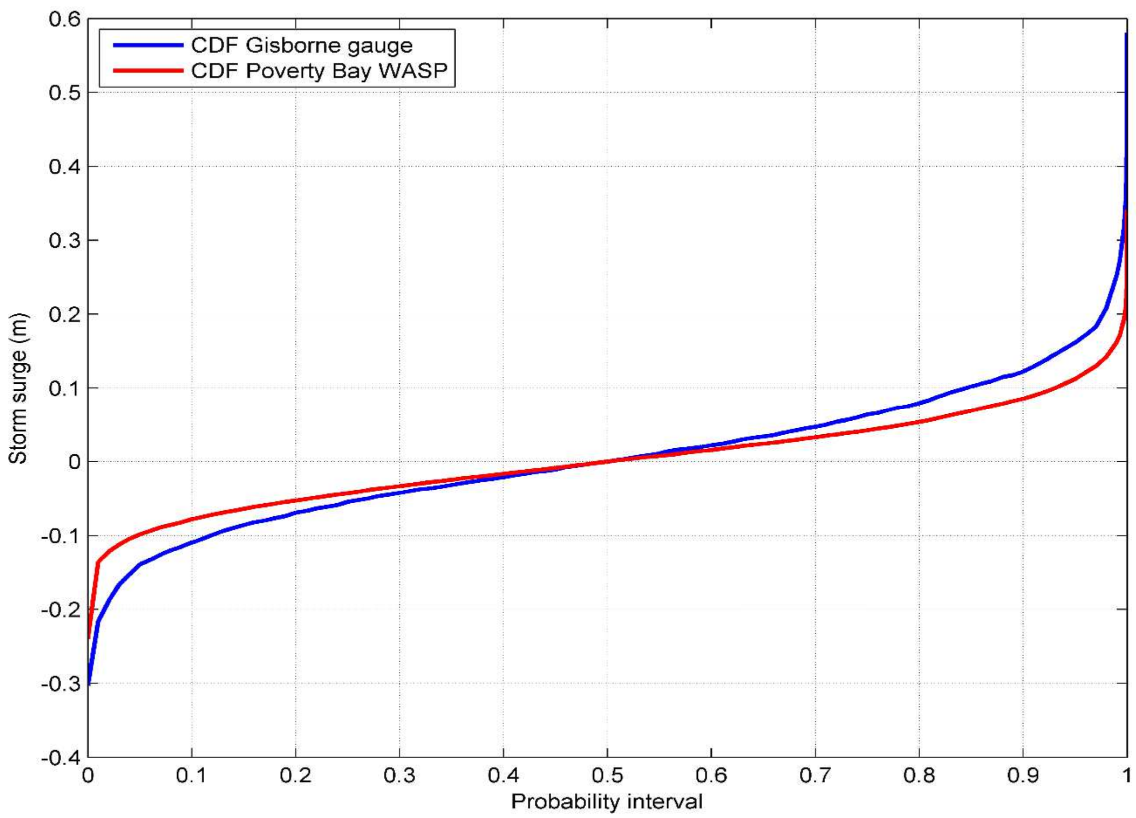

Figure C-4: Cumulative distribution of storm surges at the Gisborne tide gauge and the Poverty Bay WASP site. Probability intervals show the proportion of storm surges exceeded. The ratios of the CDF's between these two sites are used to derive the storm surge scaling factors.

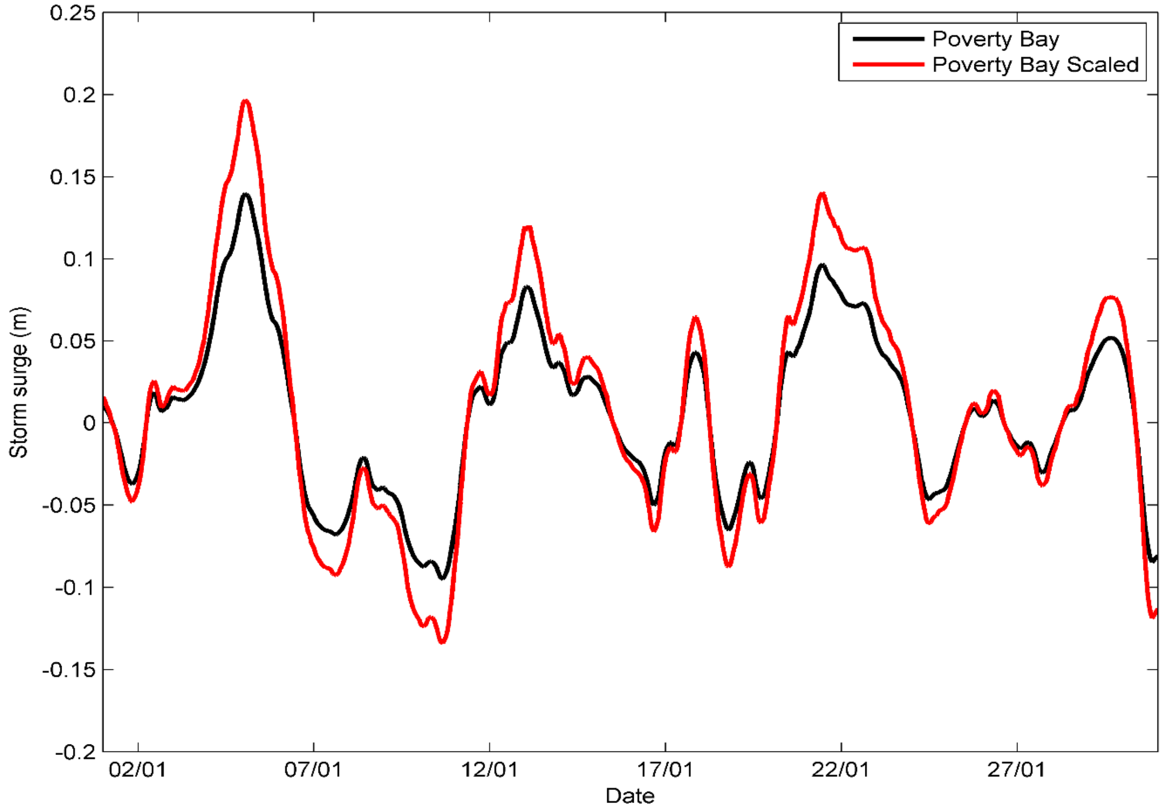

Figure C-5: Storm surge time-series at the Poverty Bay WASP site, before and after scaling factors are applied. Period covers January 1990.

Mean sea level anomaly

MSLA describes the long-term variation of sea level that is climate driven. Although the WASP models were not designed to calculate MSLA, there is some long-period energy in the WASP models resulting from weather systems used to force the models. "WASP MSLA" was calculated by filtering out the energy at >1-month period from the WASP storm surge simulations. The MSLA was determined at each WASP site using the method described below, and depicted in Figure C-6.

1. Compute the cumulative distributions of the modelled ("WASP MSLA") and measured (extracted from sea-level gauge) MSLA at Poverty Bay, and plot the two distributions against each other, then fit a line to this dataset (red line, Figure C-6). Determine the line-slope.

2. Multiply the dataset by a scaling factor so that it fits the 1:1 line. The scaling factor used was 1.5. This scaling factor was then be applied on all of the 11 offshore WASP datasets.

This method works well provided that there is a linear relationship between the modelled and measured CDF's (as shown here), if there isn't, then a single scaling factor may not be appropriate for determining the variations in MSLA along the east coast.

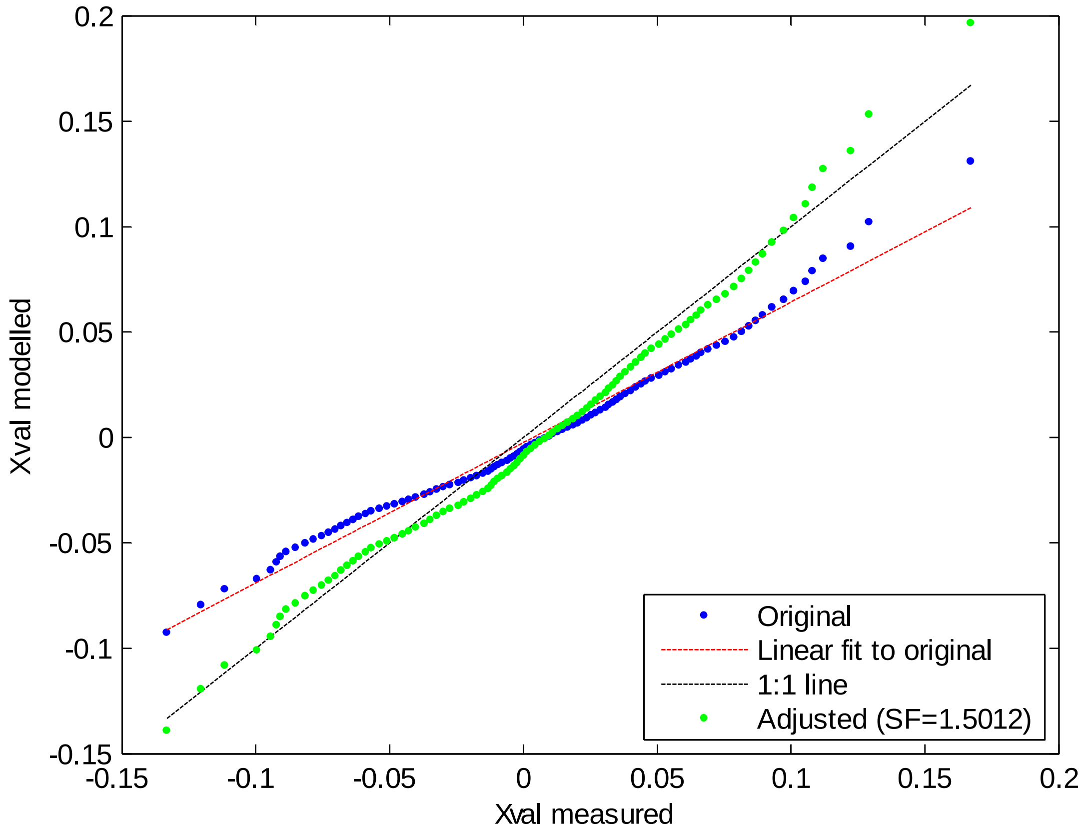

Figure C-6: Scaling of "WASP MSLA". Xval is the CDF of the MSLA extracted at 0.01 probability intervals. Original modelled ("WASP MSLA") and measured (MSLA extracted from sea-level gauge) CDF (blue dots), adjusted data (green dots) is the original multiplied by a scaling factor of 1.5, to fit the 1:1 line.

Remaining high-frequency energy

The remaining high-frequency sea-level component includes unexplained energy with period ≤12-hours which remains after filtering out the other sea level components (MSLA and storm-surge) from the non-tidal residual. The high-frequency sea-level component was calculated for the offshore WASP sites and used as a component of the storm-tide calculations there. The remaining high-frequency sea-level component at the Port of Gisborne was calculated by decomposing the non-tidal residual using a wavelet filter of 6–12-hour period. At Gisborne, the remaining high-frequency energy only makes a small contribution to total sea level, being less than 0.1 m, and it is was assumed that the remaining high-frequency sea-level component at the offshore WASP sites would be similar.

There are no tide gauges at the offshore WASP sites, so the remaining high-frequency sea-level component was calculated by fitting a normal distribution to the remaining high-frequency sea-level component at Gisborne. Then the mean and standard deviation of that distribution was used in the MCJP extreme sea-level technique. A comparison can be seen between the measured remaining high-frequency energy and the randomly sampled (with a mean close to zero, and a standard deviation of 0.01 m) in Figure C-7. Although approximated by a normal distribution most of the time, the measured time-series has weather-related periods of larger fluctuations and so the fitted normal distribution is not a perfect match to the data. Thus the measured high-frequency energy shows some time-dependence associated with sea conditions that is lacking in the random sample, and also shows higher extreme values than the randomly-generated 30-year data set, but the difference is no more than a few centimetres. Because of the small variability in high-frequency energy, and its relatively small (yet still important) influence on calculated extreme storm-tide, a randomly-generated high-frequency energy component was simulated for all of the 11 offshore sites for inclusion in storm-tide analysis.

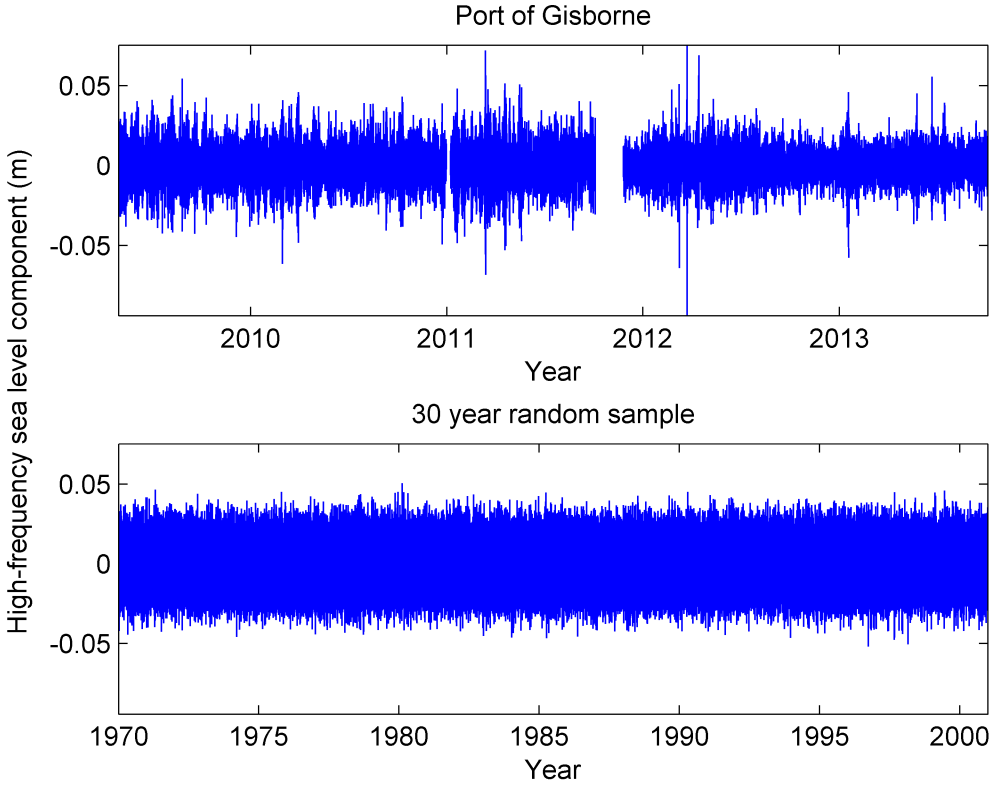

Figure C-7: Time-series of remaining high-frequency sea-level component. Top data set is extracted from the Port of Gisborne tide gauge record, using a wavelet filter. Bottom data set is from a random sample of the normal distribution fit to the gauge data.

Appendix D Wave modelling and analysis

Extreme value analysis of significant wave height

Analysing nearshore waves on the east coast of the North Island was problematic, as the only buoy record comes from Tatapouri (178.15E, -37.67S), spanning two years from 1982 to 1984. This is not long enough to reliably measure the long-term wave climate, nor calculate the extreme wave climate. Fortunately, the WASP hindcasts from 1970 to 2000 were available at 11 sites offshore from the east coast, but are not a complete solution – the hindcasts are sufficiently long to generate robust extreme wave distributions from a statistical perspective, but suffer from under-prediction of the most extreme events, as explained below. A useful workaround is explained below that arises from comparison between buoy and WASP model data, use of expert judgement, and comparison of resulting wave runup elevations with field studies (Section 2.6).

Before using the WASP wave data, they were first transformed from the offshore sites to the 33 inshore locations (Figure A-1) plus the Tatapouri wave Buoy location, using a wave-sheltering algorithm. The sheltering algorithm uses the local shoreline to delete waves from the nearest WASP site, which would approach from a direction that is locally blocked by land if that data is translocated closer to shore.

Wave sheltering

Hindcast wave statistics are extracted from grid cells of the WASP deep-water wave simulation, and interpolated to selected locations using bilinear interpolation in space. Filtering for coastal blocking is then done by:

1. At each time in the hindcast record, the peak direction θ_p and the directional spread $\Delta\theta$ are taken from the interpolated record.

2. It is assumed that a directional spreading distribution of the deep-water wave spectrum is of the form

$$D(\theta) = A\cos^{2s}\left((\theta - \theta_p)/2\right)$$

where $\Delta\theta = \sqrt{\dfrac{2}{s+1}}$.

3. It is assumed that land sheltering has the effect of removing all energy from the directional spectrum in directions in which there is land at a short fetch. This is represented by multiplying the directional distribution by a masking function $M(\theta)$.

4. Fetch from the output location to the coast is determined for each direction at small (of order 1°) direction increments.

5. If the fetch is less than the size of one grid cell, that direction is masked out, i.e., a directional masking function $M(\theta) = 0$. Otherwise $M(\theta) = 1$.

6. The “sheltered” significant wave height is obtained by scaling the deep-water value:

$$H'_{m0} = H_{m0}\sqrt{\frac{\int M(\theta)D(\theta)d\theta}{\int D(\theta)d\theta}}\ .$$

Figure D-1 and Figure D-2 show how the wave sheltering algorithm improves the match between the WASP hindcast and the wave buoy record.

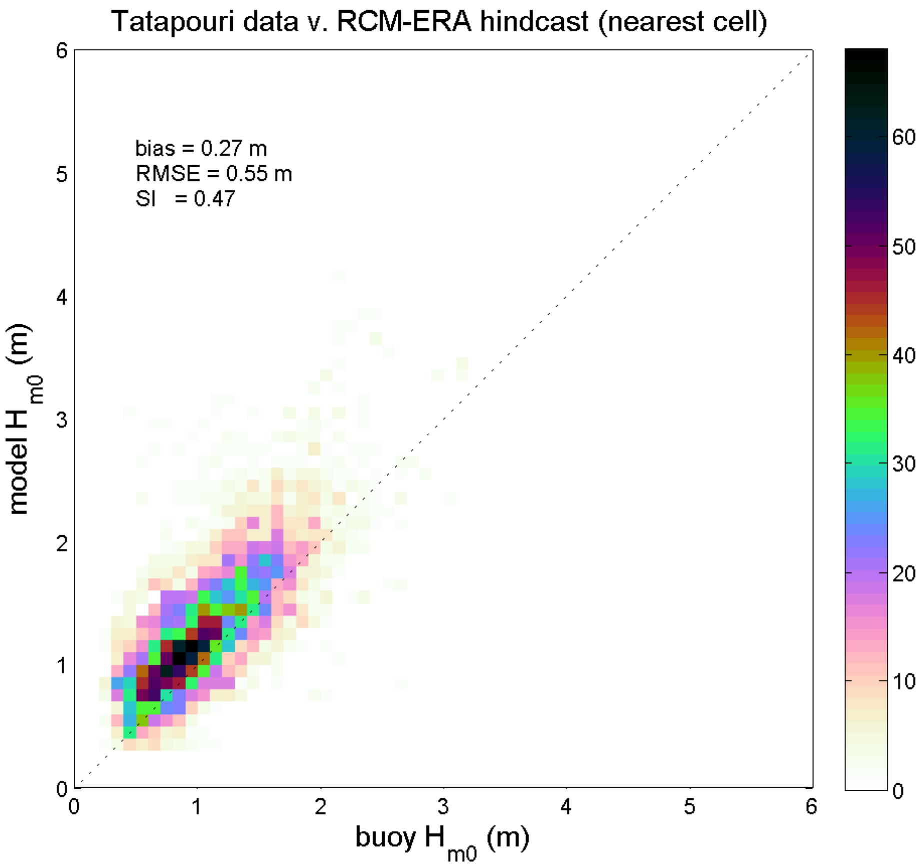

Figure D-1: Comparison of significant wave height (H_{m0}) values from the Tatapouri wave buoy measurements with the WASP wave model at the nearest WASP output location. The colour scale shows the joint occurrence distribution of measured and predicted wave heights.

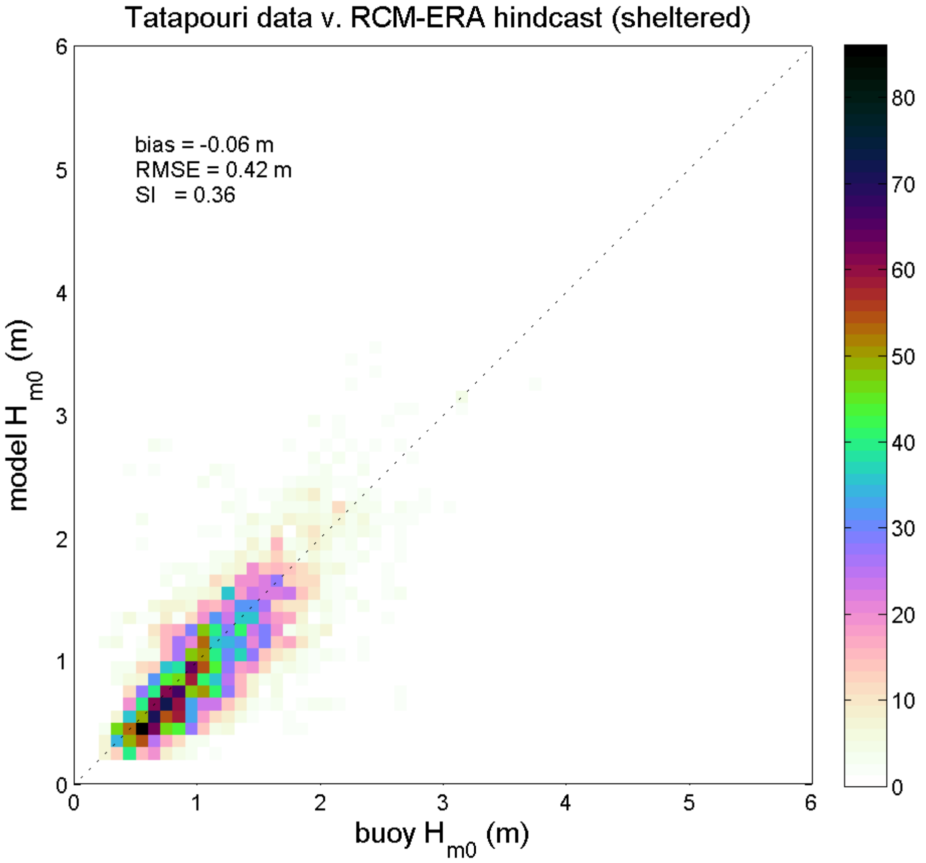

Figure D-2: Comparison of significant wave height (H_{m0}) values from the Tatapouri wave buoy measurements with the WASP wave model after applying wave-sheltering algorithm. The colour scale shows the joint occurrence distribution of measured and predicted wave heights.

Accounting for uncertainty in extreme wave height analysis

The 2.4-year long buoy record is too short for reliable extreme value analysis. This is demonstrated in Figure D-3 showing results of two different techniques used to model extreme significant wave height using the buoy record. The two techniques give vastly different results. The extreme-value model fit to the monthly maxima is what we call an "over-fitted" model, its form being too highly influenced by the many non-extreme monthly maxima in the record – so this model almost certainly under-predicts the true extreme value distribution (which we don't know but are trying to estimate). It shows high statistical confidence (tight confidence intervals) around a low extreme-value fit; in this case the statistical model is fitted to non-extreme data and so gives a false representation of the extreme distribution. The generalised Pareto model is fitted only to wave peaks above a high threshold (2 m in this case) from independent wave events. The maximum-likelihood estimate appears to match the maxima better, but the confidence intervals are huge so we have very little confidence on the constraint of the true extreme wave height distribution using this model. This lack of confidence arises from such a short data record.

Fortunately we have a 30-year wave hindcast from the WASP project, from a location offshore of Tatapouri. This is sufficiently long to achieve good extreme-value model fits from a statistical perspective. The problem is that wave hindcasts are known to give good estimates of the mean wave climate, but usually under-estimate the largest waves because the wind fields used to drive the wave models do not correctly resolve the most intense wave-producing storms. Figure D-4 presents annual maxima from the WASP wave model from the offshore location and from the Tatapouri wave buoy location after transforming the data using the wave sheltering algorithm. Extreme-value fits to these annual maxima are also shown. The extreme-value fit to the model data at the buoy location is similar to the (almost certainly) under-predicted extreme-value fit to the buoy monthly maxima.

The problem of under-prediction of extreme waves by the WASP wave hindcasts was encountered during similar studies for the Greater Wellington Regional Council (Stephens et al. 2011 (minor edits 2012)) and Bay of Plenty Regional Council (Goodhue et al. 2013). A scale factor of 1.5 was applied to extreme waves off the South-Wellington coastline, based on comparisons made with the Baring Head wave buoy. Given lack of long-term wave data to make reliable comparisons, we apply a similar scaling equation here (Equation D-1), given that the Gisborne coastline is also subjected to southerly swells. The scaling equation is weighted against occurrence probability and returns a $\times$1.5 scaling factor for ARI = 100 years (Figure D-5).

Figure D-6 shows the effect of the scaling equation applied to the extreme significant wave height distribution from the model data at the Tatapouri wave buoy location. The scaling equation acts to raise the maximum-likelihood estimate of 100-year ARI H_s from 6.1 to 9.1 m, while maintaining the 1-year ARI H_s of 4.1 m. Due to lack of long-term data records on this coast we can only guess that the scaled extreme H_s distribution is reasonable; it does approximate the (highly uncertain) GPD fit to the buoy data. Regardless of degree of fit, a 100-year ARI H_s of 9 m this close to the coast seems reasonably conservative given that this is a lee coast for ex-tropical cyclone impact and prevailing wave energy (Pickrill and Mitchell 1979). Comparisons of calculated wave runup with field studies (Section 2.6) suggest that the scaling factor has done a reasonable job of matching the true extreme wave climate.

The scaling equation was applied to the extreme-value fits made using modelled annual maxima at all 33 locations.

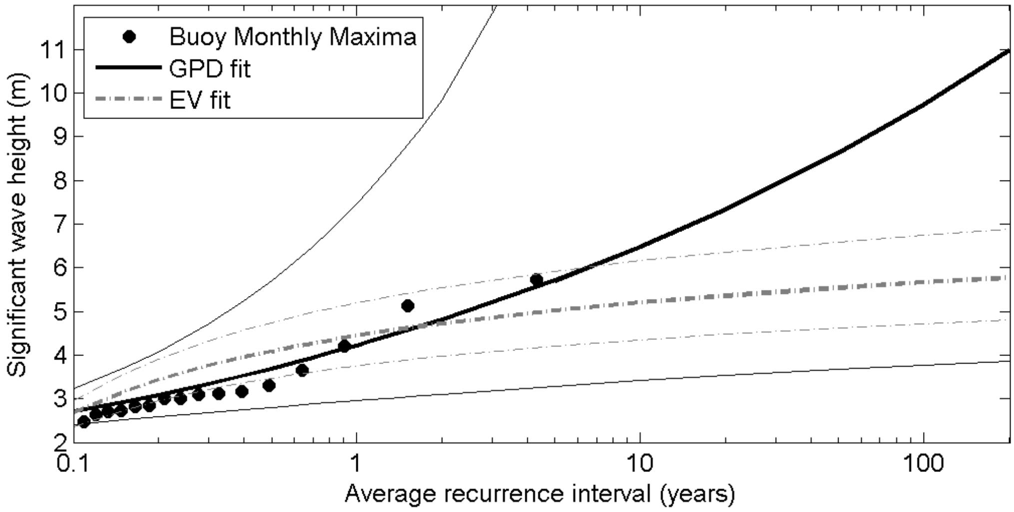

Figure D-3: Extreme value fits to Tatapouri wave buoy significant wave heights. Buoy monthly maxima are plotted in (Gringorten 1963) plotting positions. GPD = generalised Pareto distribution fit to significant wave heights from independent wave events and above 2 m height threshold. EV = extreme-value (or Gumbel, or Fisher-Tippet 1) distribution fit to monthly maxima. Thick lines represent maximum-likelihood estimate, thin lines 95% confidence intervals.

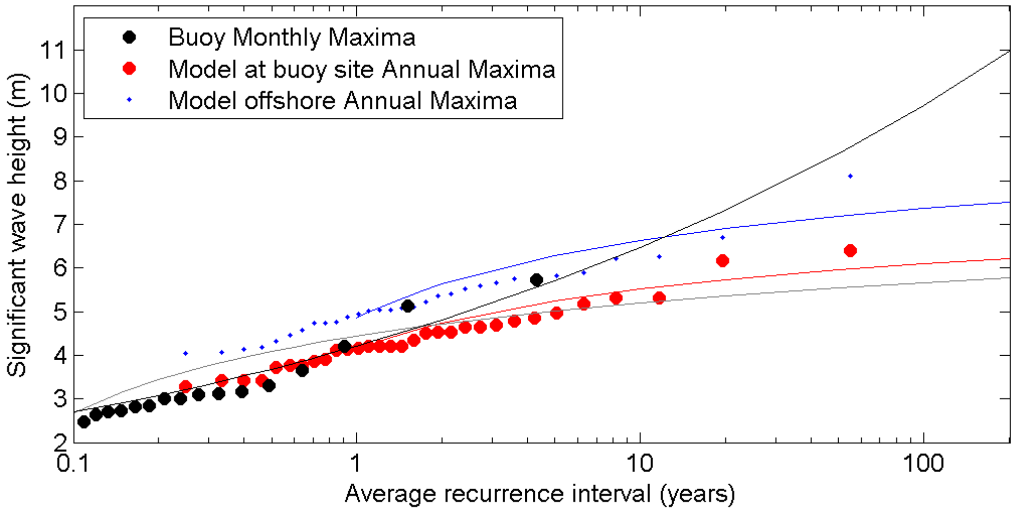

Figure D-4: Extreme value fits to Tatapouri wave buoy and WASP model significant wave heights. Buoy monthly maxima and model annual maxima are plotted in (Gringorten 1963) plotting positions. Extreme value model fits to buoy data as described in Figure D-3 caption. Extreme-value fits to model data were fitted to annual maxima. Only the maximum-likelihood estimates are plotted.

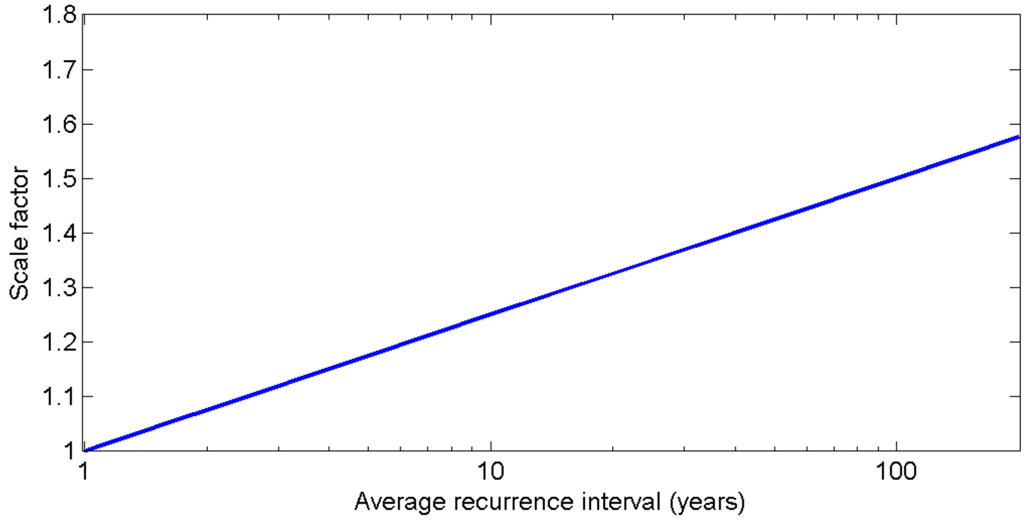

Figure D-5: Scale factor (Equation D-1) that was applied to extreme significant wave height distributions.

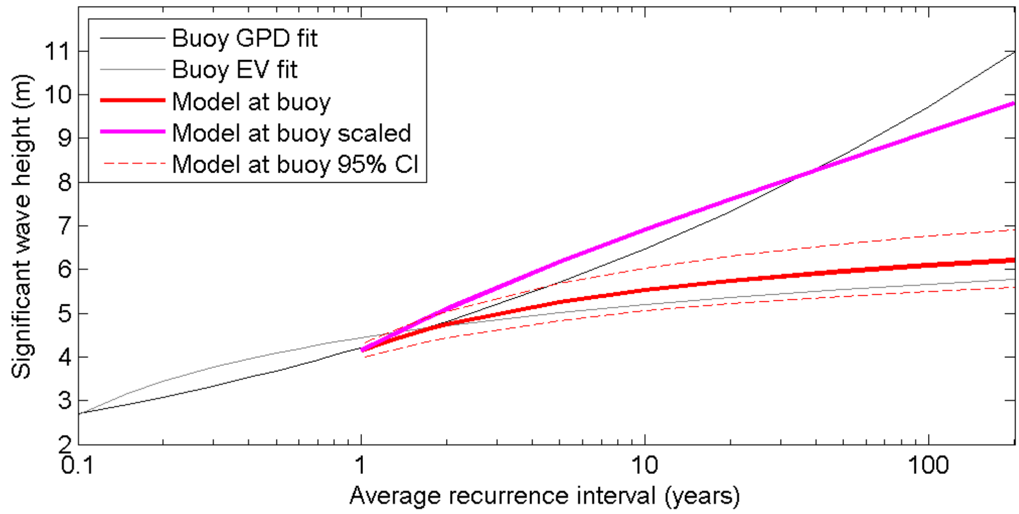

Figure D-6: Demonstration of scaling the modelled extreme significant wave height distribution. Extreme value model fits as described in Figure D-3 and Figure D-4 captions. The extreme value fit to the model data at the buoy location were scaled using Equation D-1. 95% confidence intervals for the extreme value fit to the model data are shown for comparison to those of the buoy data in Figure D-3. The confidence intervals would also scale with Equation D-1.

Equation D-1: Scale factor applied to extreme significant wave height distributions.

$$1+\frac{0.5}{\log(100)}\times\log(ARI)$$

Appendix E Joint-probability modelling

JOIN-SEA software developed by HR Wallingford was used for determining the joint probability of certain combinations of storm tide and significant wave heights occurring along the Gisborne District coastline (Hawkes et al. 2002; HR Wallingford 2000; HR Wallingford and Lancaster University 2000). After output, the marginal wave heights and storm tides are re-scaled using the data from the individual analyses outside of JOIN-SEA.

JOIN-SEA fits a generalised Pareto distribution (GPD) to the largest 5% of waves and storm-tides to model extreme values, and samples from the empirical distribution to model more frequent event magnitudes. The software fits a bivariate normal (BVN) distribution to account for any dependence between the storm-tides and waves, outputting extreme joint-probability contours as shown in Figure E-1 for example. The software also calculates the extreme-value distributions for each of significant wave height and storm-tide alone, which are plotted along the axes, or margins of the joint-probability plot, and are thus known as marginal variables. The marginal extremes calculated by the joint-probability software were adjusted using the independent extreme-value fits described in the preceding sections. In effect by adjusting the marginal extremes, the joint-probability software is being used only to predict the shape of the joint-probability curves for various wave and storm-tide combinations, while relying on more robust marginal extreme-value fits using longer datasets and/or alternative techniques (e.g., MCJP for storm-tide).

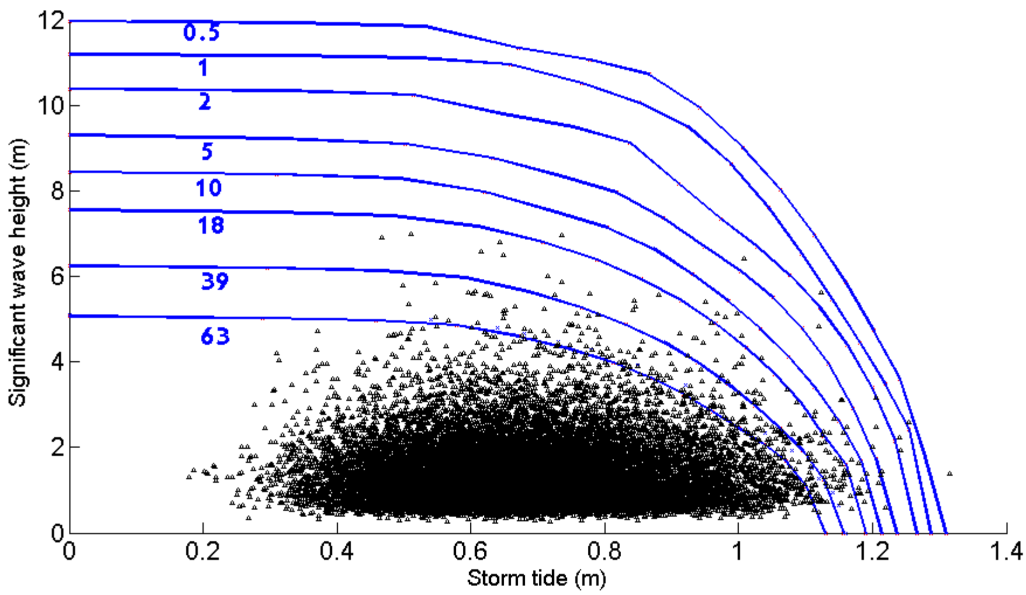

Figure E-1: Joint probability curves imposed on a scatter plot of combined storm-tide peak and wave height for 1970 to 2000 for East Cape WASP hindcast data. Blue contour lines represent the AEP in % chance of occurrence in any year for each probability curve. Significant wave height was from WASP hindcast data at East Cape, with a wave sheltering algorithm applied. Storm-tide elevation was calculated from the nearest offshore WASP data near Whakariki Island.

The following steps describe how the joint probability analysis was undertaken in this study:

1. For the period 1970 to 2000, a dataset of the high tides, and the corresponding wave heights and peak wave periods for each of the 33 nearshore sites was output. The storm-tide data for the 33 inshore sites was taken from the nearest offshore WASP site. Because there are only 11 offshore WASP sites, this meant that some of the inshore sites have the same storm-tide distribution. Storm-tide variation is small along the Gisborne District coast (< 0.1m for a 100 year average occurrence interval). Wave heights vary considerably more, with significant wave heights ranging from 2.5–6 m for a 0.01 AEP.

2. A bivariate normal distribution was fitted to the bulk of the wave height and sea level data to represent dependence between the storm-tides and waves. GPD models were fitted to the largest 5% of storm-tides and wave heights.

3. JOIN-SEA was then used to simulate 10,000 years of data based on the fitted distributions in step 2. From the simulated dataset, the ANALYSIS program determined the probabilities of joint storm-tide and significant wave height combinations. Wave height or water level values can be specified by the user. Data above these specified values is analysed in order to derive joint exceedance probability combinations, for different joint return periods. In this study, seven values of each were chosen by computing empirical CDF's of the storm-tide and wave height data, and extracting them at percentiles ranging from 25 to 95, with more emphasis on the higher percentiles.

The marginal storm-tide and significant wave height data was finally used to scale the joint-probability distributions at each site, with an example of re-scaled joint-probability distribution for East Cape is shown in Figure E-1.

Appendix F Extreme storm tide and wave height tables

Table F-1: Extreme storm-tide elevations (m) along the Gisborne coastline. Storm-tide elevations are relative to MSL = 0. Add MSL offset of 0.208 m (2004–2012) to convert to GVD-26.

AEP	0.63	0.39	0.18	0.1	0.05	0.02	0.01	0.005
ARI	**1**	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Lottin Point	1.15	1.17	1.20	1.23	1.25	1.28	1.30	1.33
Hicks Bay	1.15	1.17	1.20	1.23	1.25	1.28	1.30	1.33
Haupara Point North	1.15	1.17	1.20	1.23	1.25	1.28	1.30	1.33
Haupara Point South	1.15	1.17	1.20	1.23	1.25	1.28	1.30	1.33
Horoera	1.15	1.17	1.20	1.23	1.25	1.28	1.30	1.33
Waipapa Stream mouth	1.15	1.17	1.21	1.23	1.25	1.28	1.30	1.33
East Cape	1.13	1.16	1.19	1.21	1.24	1.27	1.29	1.31
Waiapu River mouth	1.13	1.16	1.19	1.21	1.24	1.27	1.29	1.31
Port Awanui	1.13	1.16	1.19	1.21	1.24	1.27	1.29	1.31
Koutuamoa Point	1.10	1.12	1.16	1.18	1.20	1.23	1.26	1.28
Tuparoa	1.10	1.12	1.16	1.18	1.20	1.23	1.26	1.28
Whareponga	1.10	1.12	1.16	1.18	1.20	1.23	1.26	1.28
Waipiro Bay	1.10	1.12	1.16	1.18	1.20	1.23	1.26	1.28
Tokomaru Bay 1	1.09	1.11	1.15	1.17	1.19	1.22	1.24	1.27
Tokomaru Bay 2	1.09	1.11	1.15	1.17	1.19	1.22	1.24	1.27
Tokomaru Bay 3	1.09	1.11	1.15	1.17	1.19	1.22	1.24	1.27
Anaura Bay	1.09	1.11	1.15	1.17	1.19	1.22	1.24	1.27
Kaiaua Bay	1.07	1.10	1.13	1.16	1.18	1.21	1.23	1.26
Karaka Bay	1.07	1.10	1.13	1.16	1.18	1.21	1.23	1.26
Tolaga Bay	1.07	1.09	1.13	1.15	1.18	1.21	1.23	1.25
Waihau Bay	1.07	1.09	1.13	1.15	1.18	1.21	1.23	1.25
Waiharehare Bay	1.06	1.09	1.12	1.14	1.17	1.20	1.22	1.25
Te Ikaarongamai Bay	1.06	1.09	1.12	1.14	1.17	1.20	1.22	1.25
Pariokonohi Point	1.06	1.09	1.12	1.14	1.17	1.20	1.22	1.25
Turihaua Point	1.06	1.08	1.12	1.14	1.16	1.19	1.22	1.24
Tatapouri Point	1.06	1.08	1.12	1.14	1.16	1.19	1.22	1.24
Wainui Beach	1.06	1.08	1.12	1.14	1.16	1.19	1.22	1.24
Poverty Bay at Tuamotu	1.05	1.08	1.11	1.14	1.16	1.19	1.22	1.24
Poverty Bay Kaiti	1.05	1.08	1.11	1.14	1.16	1.19	1.22	1.24
Poverty Bay Midway	1.05	1.08	1.11	1.14	1.16	1.19	1.22	1.24
Waipaoa River at Poverty Bay	1.05	1.08	1.11	1.14	1.16	1.19	1.22	1.24
PB inside Young Nick's	1.05	1.08	1.11	1.14	1.16	1.19	1.22	1.24
Orongo	1.05	1.08	1.11	1.14	1.16	1.19	1.22	1.24

Table F-2: Extreme significant wave heights (m) along the Gisborne coastline.

AEP	0.63	0.39	0.18	0.1	0.05	0.02	0.01	0.005
ARI	1	2	5	10	20	50	100	200
Lottin Point	5.63	6.75	8.03	8.91	9.75	10.82	11.62	12.40
Hicks Bay	4.40	5.61	6.95	7.85	8.71	9.79	10.59	11.37
Haupara Point North	4.93	6.10	7.41	8.31	9.16	10.23	11.03	11.81
Haupara Point South	5.14	6.27	7.54	8.42	9.25	10.31	11.09	11.86
Horoera	5.33	6.45	7.72	8.59	9.42	10.48	11.26	12.03
Waipapa Stream mouth	5.38	6.48	7.72	8.58	9.40	10.44	11.21	11.97
East Cape	5.06	6.23	7.55	8.45	9.30	10.38	11.18	11.97
Waiapu River mouth	4.61	5.70	6.92	7.75	8.54	9.54	10.28	11.00
Port Awanui	4.24	5.37	6.63	7.48	8.28	9.30	10.05	10.78
Koutuamoa Point	4.17	5.08	6.09	6.79	7.46	8.31	8.93	9.55
Tuparoa	4.50	5.48	6.59	7.35	8.07	8.99	9.67	10.35
Whareponga	4.53	5.54	6.68	7.46	8.20	9.15	9.84	10.53
Waipiro Bay	4.27	5.21	6.27	7.00	7.69	8.57	9.22	9.86
Tokomaru Bay 1	4.17	5.10	6.14	6.86	7.53	8.40	9.04	9.67
Tokomaru Bay 2	3.86	4.76	5.76	6.44	7.09	7.92	8.53	9.13
Tokomaru Bay 3	4.15	5.07	6.11	6.82	7.50	8.36	9.00	9.62
Anaura Bay	4.40	5.39	6.49	7.25	7.97	8.89	9.57	10.24
Kaiaua Bay	4.50	5.64	6.91	7.77	8.59	9.63	10.39	11.14
Karaka Bay	4.51	5.55	6.71	7.50	8.26	9.22	9.92	10.62
Tolaga Bay	4.34	5.41	6.61	7.42	8.19	9.17	9.89	10.60
Waihau Bay	4.61	5.85	7.22	8.16	9.03	10.15	10.97	11.78
Waiharehare Bay	4.60	5.66	6.85	7.66	8.43	9.41	10.14	10.85
Te Ikaarongamai Bay	4.71	5.83	7.08	7.94	8.75	9.77	10.53	11.28
Pariokonohi Point	4.35	5.39	6.54	7.33	8.08	9.03	9.73	10.42
Turihaua Point	4.19	5.19	6.31	7.07	7.79	8.71	9.38	10.05
Tatapouri Point	4.03	5.02	6.12	6.87	7.59	8.49	9.16	9.81
Wainui Beach	3.73	4.59	5.55	6.21	6.84	7.63	8.22	8.80
Poverty Bay at Tuamotu	3.11	3.90	4.78	5.38	5.95	6.66	7.19	7.71
Poverty Bay Kaiti	2.78	3.57	4.43	5.02	5.57	6.27	6.78	7.29
Poverty Bay Midway	3.08	3.88	4.76	5.36	5.92	6.64	7.17	7.69
Waipaoa River at Poverty Bay	3.28	4.06	4.92	5.51	6.08	6.79	7.31	7.83
PB inside Young Nick's	3.05	3.82	4.68	5.26	5.82	6.52	7.03	7.54
Orongo	3.51	4.32	5.23	5.85	6.44	7.19	7.75	8.29

Table F-3: Storm-tide and wave probability results for Lottin Point. Hs = significant wave height (m). Storm-tide (m) was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	5.63	2	0	6.75	5	0	8.03
1	0.29	5.61	2	0.3	6.73	5	0.31	8.01
1	0.46	5.57	2	0.48	6.7	5	0.49	7.97
1	0.59	5.48	2	0.6	6.58	5	0.62	7.8
1	0.68	5.27	2	0.7	6.33	5	0.72	7.49
1	0.76	5.01	2	0.78	5.99	5	0.8	7.09
1	0.82	4.69	2	0.84	5.62	5	0.86	6.67
1	0.88	4.34	2	0.9	5.2	5	0.92	6.14
1	0.93	3.95	2	0.95	4.66	5	0.98	5.55
1	0.97	3.55	2	1	4.07	5	1.02	4.92
1	1.01	3.11	2	1.04	3.47	5	1.07	4.27
1	1.05	2.63	2	1.08	2.91	5	1.1	3.6
1	1.08	2	2	1.11	2.4	5	1.14	2.93
1	1.12	1.55	2	1.14	1.74	5	1.17	2.14
1	1.15	0	2	1.17	0	5	1.2	0
10	0	8.91	20	0	9.75	50	0	10.82
10	0.31	8.89	20	0.32	9.73	50	0.33	10.82
10	0.5	8.84	20	0.51	9.7	50	0.52	10.82
10	0.63	8.63	20	0.64	9.51	50	0.65	10.52
10	0.73	8.36	20	0.74	9	50	0.76	9.92
10	0.81	7.91	20	0.83	8.75	50	0.85	9.43
10	0.88	7.4	20	0.9	8.19	50	0.92	8.88
10	0.94	6.76	20	0.96	7.47	50	0.98	8.24
10	1	6.05	20	1.01	6.71	50	1.04	7.54
10	1.04	5.32	20	1.06	5.93	50	1.09	6.76
10	1.09	4.57	20	1.11	5.15	50	1.13	5.9
10	1.13	3.83	20	1.15	4.37	50	1.17	4.97
10	1.16	3.09	20	1.18	3.61	50	1.21	3.96
10	1.2	2.25	20	1.22	2.86	50	1.25	2.74
10	1.23	0	20	1.25	0	50	1.28	0
100	0	11.62	200	0	12.4			
100	0.33	11.62	200	0.34	12.4			
100	0.53	11.62	200	0.54	12.4			
100	0.67	11.17	200	0.68	12.09			
100	0.77	10.79	200	0.79	11.4			
100	0.86	10.14	200	0.88	11.01			
100	0.93	9.43	200	0.95	10.64			
100	1	8.68	200	1.02	10.07			
100	1.06	7.9	200	1.08	9.31			
100	1.11	7.06	200	1.13	8.37			
100	1.15	6.14	200	1.17	7.26			
100	1.19	5.15	200	1.22	6.01			
100	1.23	4.08	200	1.26	4.63			
100	1.27	2.82	200	1.29	3.13			
100	1.3	0	200	1.33	0			

Table F-4: Storm-tide and wave probability results for Hicks Bay. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.4	2	0	5.61	5	0	6.95
1	0.29	4.38	2	0.3	5.59	5	0.31	6.93
1	0.46	4.35	2	0.48	5.56	5	0.49	6.89
1	0.59	4.28	2	0.6	5.45	5	0.62	6.75
1	0.68	4.07	2	0.7	5.17	5	0.72	6.4
1	0.76	3.83	2	0.78	4.87	5	0.8	6.06
1	0.82	3.51	2	0.84	4.49	5	0.86	5.61
1	0.88	3.19	2	0.9	4.1	5	0.92	5.13
1	0.93	2.86	2	0.95	3.6	5	0.98	4.55
1	0.97	2.5	2	1	3.06	5	1.02	3.94
1	1.01	2.05	2	1.04	2.58	5	1.07	3.33
1	1.05	1.63	2	1.08	2.13	5	1.1	2.74
1	1.08	1.26	2	1.11	1.61	5	1.14	1.99
1	1.12	0.82	2	1.14	1.06	5	1.17	1.37
1	1.15	0	2	1.17	0	5	1.2	0
10	0	7.85	20	0	8.71	50	0	9.79
10	0.31	7.84	20	0.32	8.69	50	0.33	9.77
10	0.5	7.81	20	0.51	8.66	50	0.52	9.73
10	0.63	7.6	20	0.64	8.41	50	0.65	9.44
10	0.73	7.18	20	0.74	7.95	50	0.76	9.09
10	0.81	6.86	20	0.83	7.53	50	0.85	8.49
10	0.88	6.4	20	0.9	7.09	50	0.92	8.02
10	0.94	5.81	20	0.96	6.45	50	0.98	7.33
10	1	5.11	20	1.01	5.65	50	1.04	6.52
10	1.04	4.39	20	1.06	4.83	50	1.09	5.66
10	1.09	3.69	20	1.11	4.04	50	1.13	4.79
10	1.13	3.04	20	1.15	3.32	50	1.17	3.93
10	1.16	2.4	20	1.18	2.68	50	1.21	3.09
10	1.2	1.69	20	1.22	1.75	50	1.25	2.14
10	1.23	0	20	1.25	0	50	1.28	0
100	0	10.59	200	0	11.37			
100	0.33	10.56	200	0.34	11.31			
100	0.53	10.5	200	0.54	11.19			
100	0.67	9.91	200	0.68	10.71			
100	0.77	9.42	200	0.79	10.19			
100	0.86	9.06	200	0.88	9.55			
100	0.93	8.27	200	0.95	8.76			
100	1	7.43	200	1.02	7.86			
100	1.06	6.59	200	1.08	6.92			
100	1.11	5.74	200	1.13	5.98			
100	1.15	4.91	200	1.17	5.06			
100	1.19	4.08	200	1.22	4.16			
100	1.23	3.26	200	1.26	3.3			
100	1.27	2.16	200	1.29	2.21			
100	1.3	0	200	1.33	0			

Table F-5: Storm-tide and wave probability results for Haupara Point North. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.93	2	0	6.1	5	0	7.41
1	0.29	4.92	2	0.3	6.09	5	0.31	7.39
1	0.46	4.89	2	0.48	6.06	5	0.49	7.35
1	0.59	4.81	2	0.6	5.94	5	0.62	7.2
1	0.68	4.59	2	0.7	5.7	5	0.72	6.94
1	0.76	4.33	2	0.78	5.39	5	0.8	6.55
1	0.82	3.97	2	0.84	4.97	5	0.86	6.03
1	0.88	3.65	2	0.9	4.52	5	0.92	5.57
1	0.93	3.29	2	0.95	4.02	5	0.98	5.01
1	0.97	2.89	2	1	3.5	5	1.02	4.39
1	1.01	2.47	2	1.04	2.98	5	1.07	3.73
1	1.05	2	2	1.08	2.45	5	1.1	3.04
1	1.08	1.54	2	1.11	1.93	5	1.14	2.21
1	1.12	1.08	2	1.14	1.23	5	1.17	1.57
1	1.15	0	2	1.17	0	5	1.2	0
10	0	8.31	20	0	9.16	50	0	10.23
10	0.31	8.29	20	0.32	9.14	50	0.33	10.23
10	0.5	8.25	20	0.51	9.11	50	0.52	10.22
10	0.63	8.09	20	0.64	8.96	50	0.65	10
10	0.73	7.77	20	0.74	8.61	50	0.76	9.64
10	0.81	7.3	20	0.83	8.22	50	0.85	8.99
10	0.88	6.8	20	0.9	7.62	50	0.92	8.5
10	0.94	6.19	20	0.96	6.89	50	0.98	7.87
10	1	5.49	20	1.01	6.13	50	1.04	7.15
10	1.04	4.76	20	1.06	5.34	50	1.09	6.34
10	1.09	3.99	20	1.11	4.55	50	1.13	5.43
10	1.13	3.22	20	1.15	3.76	50	1.17	4.44
10	1.16	2.33	20	1.18	2.97	50	1.21	3.36
10	1.2	1.64	20	1.22	2.05	50	1.25	1.96
10	1.23	0	20	1.25	0	50	1.28	0
100	0	11.03	200	0	11.81			
100	0.33	11.03	200	0.34	11.81			
100	0.53	11.03	200	0.54	11.81			
100	0.67	10.66	200	0.68	11.81			
100	0.77	10.39	200	0.79	11.71			
100	0.86	9.76	200	0.88	10.75			
100	0.93	8.98	200	0.95	9.88			
100	1	8.23	200	1.02	9.18			
100	1.06	7.49	200	1.08	8.48			
100	1.11	6.71	200	1.13	7.68			
100	1.15	5.86	200	1.17	6.73			
100	1.19	4.94	200	1.22	5.6			
100	1.23	3.93	200	1.26	4.3			
100	1.27	2.72	200	1.29	2.43			
100	1.3	0	200	1.33	0			

Table F-6: Storm-tide and wave probability results for Haupara Point South. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	5.14	2	0	6.27	5	0	7.54
1	0.29	5.13	2	0.3	6.25	5	0.31	7.52
1	0.46	5.1	2	0.48	6.22	5	0.49	7.48
1	0.59	5.02	2	0.6	6.12	5	0.62	7.36
1	0.68	4.79	2	0.7	5.86	5	0.72	7
1	0.76	4.51	2	0.78	5.54	5	0.8	6.68
1	0.82	4.21	2	0.84	5.15	5	0.87	6.33
1	0.88	3.87	2	0.9	4.76	5	0.92	5.87
1	0.93	3.48	2	0.95	4.25	5	0.98	5.28
1	0.97	3.04	2	1	3.68	5	1.02	4.62
1	1.01	2.6	2	1.04	3.11	5	1.07	3.93
1	1.05	2.14	2	1.08	2.58	5	1.1	3.22
1	1.09	1.69	2	1.11	1.99	5	1.14	2.44
1	1.12	1.08	2	1.14	1.42	5	1.17	1.66
1	1.15	0	2	1.17	0	5	1.2	0
10	0	8.42	20	0	9.25	50	0	10.31
10	0.31	8.4	20	0.32	9.24	50	0.33	10.28
10	0.5	8.36	20	0.51	9.21	50	0.52	10.24
10	0.63	8.2	20	0.64	9.07	50	0.66	10.07
10	0.73	7.78	20	0.74	8.75	50	0.76	9.59
10	0.81	7.38	20	0.83	8.24	50	0.85	9.11
10	0.88	7.03	20	0.9	7.78	50	0.92	8.93
10	0.94	6.51	20	0.96	7.22	50	0.98	8.46
10	1	5.84	20	1.01	6.61	50	1.04	7.72
10	1.04	5.1	20	1.06	5.91	50	1.09	6.83
10	1.09	4.34	20	1.11	5.11	50	1.13	5.83
10	1.13	3.58	20	1.15	4.21	50	1.17	4.76
10	1.16	2.83	20	1.18	3.22	50	1.21	3.65
10	1.2	1.64	20	1.22	1.9	50	1.25	2.28
10	1.23	0	20	1.25	0	50	1.28	0
100	0	11.09	200	0	11.86			
100	0.33	11.08	200	0.34	11.86			
100	0.53	11.06	200	0.54	11.86			
100	0.67	10.97	200	0.68	11.86			
100	0.77	10.84	200	0.79	11.62			
100	0.86	9.84	200	0.88	10.74			
100	0.94	9.73	200	0.95	10.57			
100	1	9.23	200	1.02	10.1			
100	1.06	8.45	200	1.08	9.36			
100	1.11	7.49	200	1.13	8.42			
100	1.15	6.42	200	1.18	7.32			
100	1.19	5.29	200	1.22	6.08			
100	1.23	4.13	200	1.26	4.73			
100	1.27	2.83	200	1.29	3.3			
100	1.3	0	200	1.33	0			

Table F-7: Storm-tide and wave probability results for Horoera. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	5.33	2	0	6.45	5	0	7.72
1	0.29	5.31	2	0.3	6.44	5	0.31	7.7
1	0.46	5.28	2	0.48	6.42	5	0.49	7.67
1	0.59	5.2	2	0.6	6.3	5	0.62	7.52
1	0.68	5	2	0.7	6.05	5	0.72	7.17
1	0.76	4.73	2	0.78	5.7	5	0.8	6.78
1	0.82	4.4	2	0.84	5.32	5	0.87	6.37
1	0.88	4.09	2	0.9	4.96	5	0.92	5.88
1	0.93	3.72	2	0.95	4.46	5	0.98	5.28
1	0.97	3.25	2	1	3.87	5	1.02	4.63
1	1.01	2.77	2	1.04	3.29	5	1.07	3.94
1	1.05	2.3	2	1.08	2.74	5	1.1	3.24
1	1.09	1.82	2	1.11	2.21	5	1.14	2.45
1	1.12	1.41	2	1.14	1.58	5	1.17	1.88
1	1.15	0	2	1.17	0	5	1.2	0
10	0	8.59	20	0	9.42	50	0	10.48
10	0.31	8.56	20	0.32	9.4	50	0.33	10.47
10	0.5	8.52	20	0.51	9.37	50	0.52	10.45
10	0.63	8.38	20	0.64	9.26	50	0.66	10.24
10	0.73	8.05	20	0.74	8.81	50	0.76	9.83
10	0.81	7.6	20	0.83	8.43	50	0.85	9.34
10	0.88	7.27	20	0.9	8.08	50	0.92	8.98
10	0.94	6.74	20	0.96	7.6	50	0.98	8.3
10	1	5.96	20	1.01	7.02	50	1.04	7.41
10	1.04	5.11	20	1.06	6.35	50	1.09	6.44
10	1.09	4.29	20	1.11	5.59	50	1.13	5.46
10	1.13	3.54	20	1.15	4.74	50	1.17	4.52
10	1.16	2.89	20	1.18	3.81	50	1.21	3.62
10	1.2	2.02	20	1.22	2.65	50	1.25	2.74
10	1.23	0	20	1.25	0	50	1.28	0
100	0	11.26	200	0	12.03			
100	0.33	11.24	200	0.34	11.97			
100	0.53	11.22	200	0.54	11.89			
100	0.67	10.88	200	0.68	11.73			
100	0.77	10.44	200	0.79	11.54			
100	0.86	10.01	200	0.88	10.64			
100	0.94	9.39	200	0.95	10.09			
100	1	8.72	200	1.02	9.45			
100	1.06	8	200	1.08	8.75			
100	1.11	7.22	200	1.13	7.94			
100	1.15	6.37	200	1.18	7.02			
100	1.19	5.44	200	1.22	5.99			
100	1.23	4.43	200	1.26	4.84			
100	1.27	3.36	200	1.29	3.59			
100	1.3	0	200	1.33	0			

Table F-8: Storm-tide and wave probability results for Waipapa Stream mouth. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	5.38	2	0	6.48	5	0	7.72
1	0.29	5.37	2	0.3	6.46	5	0.31	7.69
1	0.47	5.34	2	0.48	6.42	5	0.49	7.64
1	0.59	5.24	2	0.6	6.3	5	0.62	7.51
1	0.68	5.03	2	0.7	6.05	5	0.72	7.2
1	0.76	4.77	2	0.78	5.75	5	0.8	6.83
1	0.82	4.46	2	0.84	5.38	5	0.87	6.44
1	0.88	4.13	2	0.9	4.99	5	0.93	5.98
1	0.93	3.74	2	0.95	4.5	5	0.98	5.35
1	0.98	3.3	2	1	3.95	5	1.03	4.65
1	1.02	2.86	2	1.04	3.39	5	1.07	3.95
1	1.05	2.42	2	1.08	2.86	5	1.11	3.31
1	1.09	1.96	2	1.11	2.36	5	1.14	2.74
1	1.12	1.4	2	1.14	1.71	5	1.18	1.88
1	1.15	0	2	1.17	0	5	1.21	0
10	0	8.58	20	0	9.4	50	0	10.44
10	0.31	8.55	20	0.32	9.39	50	0.33	10.42
10	0.5	8.5	20	0.51	9.37	50	0.52	10.38
10	0.63	8.34	20	0.64	9.22	50	0.66	10.16
10	0.73	8.03	20	0.74	8.89	50	0.76	9.75
10	0.81	7.62	20	0.83	8.38	50	0.85	9.25
10	0.88	7.24	20	0.9	8	50	0.92	8.9
10	0.94	6.75	20	0.96	7.43	50	0.98	8.23
10	1	6.09	20	1.02	6.69	50	1.04	7.34
10	1.05	5.35	20	1.06	5.87	50	1.09	6.37
10	1.09	4.58	20	1.11	5.04	50	1.14	5.39
10	1.13	3.81	20	1.15	4.21	50	1.18	4.45
10	1.16	3.06	20	1.19	3.41	50	1.21	3.56
10	1.2	2.22	20	1.22	2.59	50	1.25	2.68
10	1.23	0	20	1.25	0	50	1.28	0
100	0	11.21	200	0	11.97			
100	0.33	11.21	200	0.34	11.94			
100	0.53	11.2	200	0.54	11.9			
100	0.67	11.06	200	0.68	11.71			
100	0.77	10.58	200	0.79	11.41			
100	0.86	10.1	200	0.88	11.03			
100	0.94	9.79	200	0.95	10.66			
100	1	9.23	200	1.02	10.1			
100	1.06	8.48	200	1.08	9.39			
100	1.11	7.6	200	1.13	8.51			
100	1.15	6.62	200	1.17	7.48			
100	1.2	5.57	200	1.22	6.31			
100	1.23	4.47	200	1.26	5.02			
100	1.27	3.34	200	1.29	3.62			
100	1.3	0	200	1.33	0			

Table F-9: Storm-tide and wave probability results for East Cape. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	5.06	2	0	6.23	5	0	7.55
1	0.29	5.03	2	0.3	6.2	5	0.3	7.5
1	0.46	4.97	2	0.47	6.13	5	0.48	7.42
1	0.58	4.87	2	0.59	5.96	5	0.61	7.17
1	0.67	4.59	2	0.69	5.63	5	0.71	6.81
1	0.75	4.3	2	0.77	5.28	5	0.79	6.39
1	0.81	3.98	2	0.83	4.88	5	0.86	5.94
1	0.87	3.64	2	0.89	4.47	5	0.91	5.44
1	0.92	3.25	2	0.94	3.99	5	0.97	4.89
1	0.96	2.84	2	0.98	3.48	5	1.01	4.32
1	1	2.44	2	1.02	2.96	5	1.05	3.71
1	1.04	2.07	2	1.06	2.44	5	1.09	3.06
1	1.07	1.68	2	1.1	1.92	5	1.13	2.26
1	1.1	1.07	2	1.13	1.23	5	1.16	1.6
1	1.13	0	2	1.16	0	5	1.19	0
10	0	8.45	20	0	9.3	50	0	10.38
10	0.31	8.39	20	0.32	9.22	50	0.32	10.33
10	0.49	8.29	20	0.5	9.1	50	0.51	10.25
10	0.62	7.98	20	0.63	8.76	50	0.65	9.79
10	0.72	7.52	20	0.73	8.34	50	0.75	9.5
10	0.8	7.14	20	0.82	7.96	50	0.84	9.13
10	0.87	6.65	20	0.89	7.35	50	0.91	8.17
10	0.93	6.04	20	0.95	6.69	50	0.97	7.35
10	0.98	5.42	20	1	6.11	50	1.03	6.69
10	1.03	4.78	20	1.05	5.5	50	1.08	6.02
10	1.07	4.11	20	1.09	4.79	50	1.12	5.27
10	1.11	3.41	20	1.13	3.95	50	1.16	4.4
10	1.15	2.6	20	1.17	2.91	50	1.2	3.4
10	1.18	1.67	20	1.2	1.74	50	1.23	2.15
10	1.21	0	20	1.24	0	50	1.27	0
100	0	11.18	200	0	11.97			
100	0.33	11.15	200	0.34	11.93			
100	0.52	11.1	200	0.53	11.85			
100	0.66	10.95	200	0.67	11.34			
100	0.76	10.52	200	0.78	11.07			
100	0.85	10.06	200	0.87	10.72			
100	0.92	9.49	200	0.94	9.94			
100	0.99	8.63	200	1.01	9.02			
100	1.04	7.6	200	1.06	8.01			
100	1.09	6.52	200	1.11	6.95			
100	1.14	5.46	200	1.16	5.86			
100	1.18	4.44	200	1.2	4.73			
100	1.22	3.48	200	1.24	3.6			
100	1.25	2.42	200	1.28	1.88			
100	1.29	0	200	1.31	0			

Table F-10: Storm-tide and wave probability results for Waiapu River mouth. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.61	2	0	5.7	5	0	6.92
1	0.29	4.58	2	0.3	5.66	5	0.3	6.87
1	0.46	4.52	2	0.47	5.6	5	0.48	6.8
1	0.58	4.41	2	0.59	5.43	5	0.61	6.6
1	0.67	4.16	2	0.69	5.13	5	0.71	6.2
1	0.75	3.85	2	0.77	4.75	5	0.79	5.74
1	0.81	3.54	2	0.83	4.38	5	0.86	5.31
1	0.87	3.24	2	0.89	4.04	5	0.91	4.93
1	0.92	2.93	2	0.94	3.66	5	0.97	4.44
1	0.96	2.56	2	0.98	3.27	5	1.01	3.9
1	1	2.19	2	1.02	2.85	5	1.05	3.36
1	1.04	1.81	2	1.06	2.39	5	1.09	2.82
1	1.07	1.37	2	1.1	1.72	5	1.13	2.19
1	1.1	0.9	2	1.13	1.2	5	1.16	1.45
1	1.13	0	2	1.16	0	5	1.19	0
10	0	7.75	20	0	8.54	50	0	9.54
10	0.31	7.69	20	0.32	8.46	50	0.32	9.47
10	0.49	7.61	20	0.5	8.35	50	0.51	9.34
10	0.62	7.36	20	0.63	8.05	50	0.65	8.79
10	0.72	6.91	20	0.73	7.6	50	0.75	8.18
10	0.8	6.36	20	0.82	6.98	50	0.84	7.68
10	0.87	5.88	20	0.89	6.42	50	0.91	6.91
10	0.93	5.35	20	0.95	5.89	50	0.97	6.14
10	0.98	4.77	20	1	5.45	50	1.03	5.43
10	1.03	4.17	20	1.05	4.96	50	1.08	4.75
10	1.07	3.57	20	1.09	4.36	50	1.12	4.1
10	1.11	2.99	20	1.13	3.61	50	1.16	3.47
10	1.15	2.34	20	1.17	2.41	50	1.2	2.88
10	1.18	1.42	20	1.2	1.48	50	1.23	1.75
10	1.21	0	20	1.24	0	50	1.27	0
100	0	10.28	200	0	11			
100	0.33	10.2	200	0.34	10.81			
100	0.52	10.08	200	0.53	10.53			
100	0.66	9.87	200	0.67	9.95			
100	0.76	9.24	200	0.78	9.51			
100	0.85	8.44	200	0.87	8.65			
100	0.92	7.63	200	0.94	7.71			
100	0.99	6.87	200	1.01	7			
100	1.04	6.17	200	1.06	6.41			
100	1.09	5.48	200	1.11	5.83			
100	1.14	4.78	200	1.16	5.17			
100	1.18	4.07	200	1.2	4.41			
100	1.22	3.32	200	1.24	3.53			
100	1.25	2.08	200	1.28	2.12			
100	1.29	0	200	1.31	0			

Table F-11: Storm-tide and wave probability results for Port Awanui. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.24	2	0	5.37	5	0	6.63
1	0.29	4.21	2	0.3	5.34	5	0.3	6.59
1	0.46	4.16	2	0.47	5.28	5	0.48	6.52
1	0.58	4.06	2	0.59	5.16	5	0.61	6.31
1	0.67	3.85	2	0.69	4.9	5	0.71	5.99
1	0.75	3.61	2	0.77	4.58	5	0.79	5.57
1	0.81	3.36	2	0.83	4.26	5	0.86	5.18
1	0.87	3.09	2	0.89	3.95	5	0.91	4.75
1	0.92	2.81	2	0.94	3.59	5	0.97	4.31
1	0.96	2.52	2	0.98	3.21	5	1.01	3.86
1	1	2.22	2	1.02	2.82	5	1.05	3.38
1	1.04	1.87	2	1.06	2.44	5	1.09	2.89
1	1.07	1.45	2	1.1	2.03	5	1.13	2.25
1	1.1	1.02	2	1.13	1.41	5	1.16	1.49
1	1.13	0	2	1.16	0	5	1.19	0
10	0	7.48	20	0	8.28	50	0	9.3
10	0.31	7.44	20	0.32	8.23	50	0.32	9.21
10	0.49	7.37	20	0.5	8.14	50	0.51	9.08
10	0.62	7.12	20	0.63	7.95	50	0.65	8.87
10	0.72	6.77	20	0.73	7.57	50	0.75	8.46
10	0.8	6.3	20	0.82	7.03	50	0.84	7.88
10	0.87	5.86	20	0.89	6.63	50	0.91	7.56
10	0.93	5.38	20	0.95	6.15	50	0.97	7.14
10	0.98	4.93	20	1	5.61	50	1.03	6.65
10	1.03	4.48	20	1.05	5.01	50	1.08	6.05
10	1.07	3.99	20	1.09	4.37	50	1.12	5.34
10	1.11	3.43	20	1.13	3.68	50	1.16	4.52
10	1.15	2.68	20	1.17	2.86	50	1.2	3.58
10	1.18	1.72	20	1.2	1.84	50	1.23	2.28
10	1.21	0	20	1.24	0	50	1.27	0
100	0	10.05	200	0	10.78			
100	0.33	9.91	200	0.34	10.68			
100	0.52	9.74	200	0.53	10.62			
100	0.66	9.52	200	0.67	10.57			
100	0.76	9.12	200	0.78	10.01			
100	0.85	8.64	200	0.87	9.51			
100	0.92	8.05	200	0.94	9.03			
100	0.99	7.37	200	1.01	8.47			
100	1.04	6.67	200	1.06	7.86			
100	1.09	5.95	200	1.11	7.16			
100	1.14	5.2	200	1.16	6.36			
100	1.18	4.43	200	1.2	5.46			
100	1.22	3.64	200	1.24	4.46			
100	1.25	2.65	200	1.28	3.18			
100	1.29	0	200	1.31	0			

Table F-12: Storm-tide and wave probability results for Koutuamoa Point. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.17	2	0	5.08	5	0	6.09
1	0.28	4.14	2	0.29	5.04	5	0.3	6.05
1	0.44	4.08	2	0.46	4.97	5	0.47	5.98
1	0.56	4	2	0.58	4.85	5	0.59	5.82
1	0.65	3.77	2	0.67	4.56	5	0.69	5.49
1	0.73	3.53	2	0.74	4.26	5	0.77	5.08
1	0.79	3.2	2	0.81	3.88	5	0.83	4.65
1	0.84	2.89	2	0.86	3.51	5	0.89	4.18
1	0.89	2.59	2	0.91	3.12	5	0.94	3.68
1	0.93	2.26	2	0.96	2.69	5	0.98	3.16
1	0.97	1.96	2	0.99	2.25	5	1.02	2.66
1	1.01	1.51	2	1.03	1.84	5	1.06	2.2
1	1.04	1.23	2	1.06	1.41	5	1.1	1.63
1	1.07	0.76	2	1.09	0.87	5	1.13	0.98
1	1.1	0	2	1.12	0	5	1.16	0
10	0	6.79	20	0	7.46	50	0	8.31
10	0.3	6.75	20	0.31	7.39	50	0.32	8.27
10	0.48	6.67	20	0.49	7.29	50	0.5	8.2
10	0.6	6.49	20	0.62	7.04	50	0.63	7.94
10	0.7	6.16	20	0.71	6.71	50	0.73	7.47
10	0.78	5.74	20	0.8	6.31	50	0.82	7.04
10	0.85	5.23	20	0.86	5.81	50	0.89	6.58
10	0.91	4.75	20	0.92	5.24	50	0.95	6
10	0.96	4.23	20	0.98	4.63	50	1	5.33
10	1	3.67	20	1.02	4.02	50	1.05	4.63
10	1.04	3.11	20	1.06	3.4	50	1.09	3.94
10	1.08	2.45	20	1.1	2.75	50	1.13	3.29
10	1.12	2.02	20	1.14	2.12	50	1.17	2.57
10	1.15	1.22	20	1.17	1.28	50	1.2	1.48
10	1.18	0	20	1.2	0	50	1.23	0
100	0	8.93	200	0	9.55			
100	0.32	8.87	200	0.33	9.53			
100	0.51	8.77	200	0.52	9.5			
100	0.64	8.52	200	0.65	9.36			
100	0.75	8.08	200	0.76	8.52			
100	0.83	7.43	200	0.85	8.02			
100	0.9	6.95	200	0.92	7.4			
100	0.96	6.39	200	0.98	6.74			
100	1.02	5.79	200	1.04	6.1			
100	1.07	5.15	200	1.09	5.44			
100	1.11	4.48	200	1.13	4.76			
100	1.15	3.76	200	1.17	4.04			
100	1.19	2.91	200	1.21	3.27			
100	1.22	1.88	200	1.25	2.28			
100	1.26	0	200	1.28	0			

Table F-13: Storm-tide and wave probability results for Tuparoa. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.5	2	0	5.48	5	0	6.59
1	0.28	4.46	2	0.29	5.44	5	0.3	6.53
1	0.44	4.4	2	0.46	5.36	5	0.47	6.44
1	0.56	4.3	2	0.58	5.22	5	0.59	6.26
1	0.65	4.07	2	0.67	4.94	5	0.69	5.91
1	0.73	3.78	2	0.74	4.58	5	0.77	5.48
1	0.79	3.47	2	0.81	4.17	5	0.83	4.98
1	0.84	3.13	2	0.86	3.78	5	0.89	4.56
1	0.89	2.83	2	0.91	3.38	5	0.94	4.06
1	0.93	2.47	2	0.96	2.93	5	0.98	3.51
1	0.97	2.09	2	0.99	2.49	5	1.02	2.99
1	1.01	1.73	2	1.03	2.07	5	1.06	2.53
1	1.04	1.38	2	1.06	1.7	5	1.1	2.06
1	1.07	0.91	2	1.09	1.11	5	1.13	1.31
1	1.1	0	2	1.12	0	5	1.16	0
10	0	7.35	20	0	8.07	50	0	8.99
10	0.3	7.26	20	0.31	8.04	50	0.32	8.94
10	0.48	7.13	20	0.49	7.98	50	0.5	8.83
10	0.6	6.92	20	0.62	7.63	50	0.63	8.48
10	0.7	6.53	20	0.71	7.17	50	0.73	8.04
10	0.78	6.07	20	0.8	6.6	50	0.82	7.32
10	0.85	5.44	20	0.86	6	50	0.89	6.79
10	0.91	5.03	20	0.92	5.5	50	0.95	6.31
10	0.96	4.49	20	0.98	4.89	50	1	5.84
10	1	3.91	20	1.02	4.25	50	1.05	5.31
10	1.04	3.32	20	1.06	3.62	50	1.09	4.67
10	1.08	2.74	20	1.1	3.02	50	1.13	3.9
10	1.12	2.15	20	1.14	2.36	50	1.17	2.91
10	1.15	1.29	20	1.17	1.35	50	1.2	1.65
10	1.18	0	20	1.2	0	50	1.23	0
100	0	9.67	200	0	10.35			
100	0.32	9.66	200	0.33	10.35			
100	0.51	9.63	200	0.52	10.35			
100	0.64	9.29	200	0.65	9.86			
100	0.75	8.84	200	0.76	9.35			
100	0.83	7.98	200	0.85	8.32			
100	0.9	7.29	200	0.92	7.8			
100	0.96	6.66	200	0.98	7.24			
100	1.02	6.13	200	1.04	6.67			
100	1.07	5.56	200	1.09	6.03			
100	1.11	4.89	200	1.13	5.29			
100	1.15	4.08	200	1.17	4.43			
100	1.19	3.08	200	1.21	3.46			
100	1.22	1.58	200	1.25	1.66			
100	1.26	0	200	1.28	0			

Table F-14: Storm-tide and wave probability results for Whareponga. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.53	2	0	5.54	5	0	6.68
1	0.28	4.5	2	0.29	5.5	5	0.3	6.64
1	0.44	4.44	2	0.46	5.44	5	0.47	6.56
1	0.56	4.36	2	0.58	5.32	5	0.59	6.33
1	0.65	4.11	2	0.67	5.01	5	0.69	5.97
1	0.73	3.84	2	0.74	4.67	5	0.77	5.56
1	0.79	3.52	2	0.81	4.3	5	0.83	5.14
1	0.84	3.23	2	0.86	3.93	5	0.89	4.69
1	0.89	2.91	2	0.91	3.53	5	0.94	4.18
1	0.93	2.56	2	0.96	3.07	5	0.98	3.63
1	0.97	2.19	2	0.99	2.62	5	1.02	3.07
1	1.01	1.8	2	1.03	2.2	5	1.06	2.47
1	1.04	1.36	2	1.06	1.71	5	1.1	1.9
1	1.07	1.06	2	1.09	1.2	5	1.13	1.24
1	1.1	0	2	1.12	0	5	1.16	0
10	0	7.46	20	0	8.2	50	0	9.15
10	0.3	7.41	20	0.31	8.16	50	0.32	9.13
10	0.48	7.33	20	0.49	8.07	50	0.5	9.1
10	0.6	7.08	20	0.62	7.63	50	0.63	8.79
10	0.7	6.63	20	0.71	7.16	50	0.73	8.36
10	0.78	6.15	20	0.8	6.61	50	0.82	7.48
10	0.85	5.73	20	0.86	6.18	50	0.89	6.99
10	0.91	5.28	20	0.92	5.65	50	0.95	6.34
10	0.96	4.77	20	0.98	4.99	50	1	5.57
10	1	4.22	20	1.02	4.29	50	1.05	4.77
10	1.04	3.61	20	1.06	3.61	50	1.09	4.01
10	1.08	2.94	20	1.1	2.98	50	1.13	3.31
10	1.12	2.17	20	1.14	2.32	50	1.17	2.7
10	1.15	1.4	20	1.17	1.41	50	1.2	1.48
10	1.18	0	20	1.2	0	50	1.23	0
100	0	9.84	200	0	10.53			
100	0.32	9.81	200	0.33	10.53			
100	0.51	9.75	200	0.52	10.53			
100	0.64	9.22	200	0.65	9.86			
100	0.75	8.89	200	0.76	9.65			
100	0.83	8.17	200	0.85	9.12			
100	0.9	7.53	200	0.92	8.85			
100	0.96	6.79	200	0.98	8.21			
100	1.02	6.01	200	1.04	7.22			
100	1.07	5.21	200	1.09	6.12			
100	1.11	4.4	200	1.13	5.01			
100	1.15	3.59	200	1.17	3.98			
100	1.19	2.73	200	1.21	3.04			
100	1.22	1.88	200	1.25	2.18			
100	1.26	0	200	1.28	0			

Table F-15: Storm-tide and wave probability results for Waipiro Bay. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.27	2	0	5.21	5	0	6.27
1	0.28	4.24	2	0.29	5.18	5	0.3	6.23
1	0.44	4.19	2	0.46	5.12	5	0.47	6.16
1	0.56	4.1	2	0.58	5	5	0.59	5.99
1	0.65	3.83	2	0.67	4.7	5	0.69	5.65
1	0.73	3.52	2	0.74	4.34	5	0.77	5.24
1	0.79	3.19	2	0.81	3.94	5	0.83	4.76
1	0.84	2.86	2	0.86	3.55	5	0.89	4.31
1	0.89	2.52	2	0.91	3.15	5	0.94	3.77
1	0.93	2.1	2	0.96	2.69	5	0.98	3.18
1	0.97	1.77	2	0.99	2.24	5	1.02	2.66
1	1.01	1.43	2	1.03	1.84	5	1.06	2.14
1	1.04	1.06	2	1.06	1.41	5	1.1	1.59
1	1.07	0.77	2	1.09	1.02	5	1.13	0.97
1	1.1	0	2	1.12	0	5	1.16	0
10	0	7	20	0	7.69	50	0	8.57
10	0.3	6.95	20	0.31	7.65	50	0.32	8.47
10	0.48	6.87	20	0.49	7.58	50	0.5	8.33
10	0.6	6.63	20	0.62	7.3	50	0.63	8.07
10	0.7	6.29	20	0.71	6.9	50	0.73	7.59
10	0.78	5.8	20	0.8	6.37	50	0.82	7.09
10	0.85	5.34	20	0.86	5.88	50	0.89	6.56
10	0.91	4.82	20	0.92	5.31	50	0.95	5.98
10	0.96	4.26	20	0.98	4.68	50	1	5.39
10	1	3.67	20	1.02	4.03	50	1.05	4.78
10	1.04	3.08	20	1.06	3.39	50	1.09	4.13
10	1.08	2.43	20	1.1	2.74	50	1.13	3.42
10	1.12	1.83	20	1.14	2.11	50	1.17	2.5
10	1.15	1.21	20	1.17	1.26	50	1.2	1.77
10	1.18	0	20	1.2	0	50	1.23	0
100	0	9.22	200	0	9.86			
100	0.32	9.16	200	0.33	9.73			
100	0.51	9.07	200	0.52	9.55			
100	0.64	8.82	200	0.65	9.28			
100	0.75	8.13	200	0.76	8.57			
100	0.83	7.68	200	0.85	8.02			
100	0.9	7.12	200	0.92	7.47			
100	0.96	6.53	200	0.98	6.91			
100	1.02	6.04	200	1.04	6.4			
100	1.07	5.51	200	1.09	5.84			
100	1.11	4.88	200	1.13	5.18			
100	1.15	4.1	200	1.17	4.4			
100	1.19	3.1	200	1.21	3.49			
100	1.22	1.95	200	1.25	2.21			
100	1.26	0	200	1.28	0			

Table F-16: Storm-tide and wave probability results for Tokomaru Bay 1. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.17	2	0	5.1	5	0	6.14
1	0.28	4.14	2	0.28	5.06	5	0.29	6.09
1	0.44	4.07	2	0.45	4.99	5	0.46	6.01
1	0.56	3.99	2	0.57	4.87	5	0.59	5.82
1	0.65	3.73	2	0.66	4.55	5	0.68	5.44
1	0.72	3.46	2	0.74	4.22	5	0.76	5.08
1	0.78	3.15	2	0.8	3.84	5	0.82	4.62
1	0.83	2.83	2	0.85	3.44	5	0.88	4.13
1	0.88	2.47	2	0.9	3.03	5	0.93	3.62
1	0.92	2.16	2	0.95	2.58	5	0.97	3.1
1	0.96	1.75	2	0.98	2.13	5	1.01	2.61
1	1	1.42	2	1.02	1.73	5	1.05	2.1
1	1.03	1.05	2	1.05	1.21	5	1.08	1.56
1	1.06	0.77	2	1.08	0.88	5	1.12	0.96
1	1.09	0	2	1.11	0	5	1.15	0
10	0	6.86	20	0	7.53	50	0	8.4
10	0.3	6.76	20	0.3	7.47	50	0.31	8.33
10	0.47	6.63	20	0.48	7.37	50	0.5	8.22
10	0.6	6.41	20	0.61	7.07	50	0.63	7.88
10	0.69	5.96	20	0.71	6.5	50	0.73	7.31
10	0.77	5.56	20	0.79	5.99	50	0.81	6.65
10	0.84	5.15	20	0.86	5.53	50	0.88	6.1
10	0.9	4.62	20	0.91	4.98	50	0.94	5.48
10	0.95	4.02	20	0.97	4.29	50	0.99	4.78
10	0.99	3.39	20	1.01	3.58	50	1.04	4.08
10	1.04	2.83	20	1.06	2.97	50	1.08	3.41
10	1.07	2.34	20	1.09	2.46	50	1.12	2.74
10	1.11	1.64	20	1.13	1.7	50	1.16	2.09
10	1.14	1.17	20	1.16	1.04	50	1.19	1.46
10	1.17	0	20	1.19	0	50	1.22	0
100	0	9.04	200	0	9.67			
100	0.32	9.01	200	0.32	9.49			
100	0.5	8.96	200	0.51	9.28			
100	0.64	8.61	200	0.65	9			
100	0.74	8.09	200	0.75	8.68			
100	0.82	7.46	200	0.84	8.1			
100	0.89	6.75	200	0.91	7.32			
100	0.96	5.91	200	0.97	6.41			
100	1.01	5.05	200	1.03	5.46			
100	1.06	4.25	200	1.08	4.59			
100	1.1	3.54	200	1.12	3.85			
100	1.14	2.96	200	1.16	3.26			
100	1.18	2.41	200	1.2	2.9			
100	1.21	1.45	200	1.24	1.82			
100	1.24	0	200	1.27	0			

Table F-17: Storm-tide and wave probability results for Tokomaru Bay 2. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	3.86	2	0	4.76	5	0	5.76
1	0.28	3.83	2	0.28	4.73	5	0.29	5.73
1	0.44	3.79	2	0.45	4.68	5	0.46	5.68
1	0.56	3.71	2	0.57	4.57	5	0.59	5.5
1	0.65	3.47	2	0.66	4.28	5	0.68	5.15
1	0.72	3.18	2	0.74	3.95	5	0.76	4.74
1	0.78	2.89	2	0.8	3.58	5	0.82	4.29
1	0.83	2.56	2	0.85	3.18	5	0.88	3.8
1	0.88	2.22	2	0.9	2.71	5	0.93	3.19
1	0.92	1.8	2	0.95	2.19	5	0.97	2.58
1	0.96	1.43	2	0.98	1.75	5	1.01	2.09
1	1	1.15	2	1.02	1.42	5	1.05	1.6
1	1.03	0.78	2	1.05	1.02	5	1.08	1.15
1	1.06	0.45	2	1.08	0.5	5	1.12	0.56
1	1.09	0	2	1.11	0	5	1.15	0
10	0	6.44	20	0	7.09	50	0	7.92
10	0.3	6.41	20	0.3	7.07	50	0.31	7.9
10	0.47	6.36	20	0.48	7.03	50	0.5	7.86
10	0.6	6.13	20	0.61	6.78	50	0.63	7.6
10	0.69	5.72	20	0.71	6.26	50	0.73	7.17
10	0.77	5.33	20	0.79	5.83	50	0.81	6.62
10	0.84	4.81	20	0.86	5.29	50	0.88	5.96
10	0.9	4.23	20	0.91	4.71	50	0.94	5.24
10	0.95	3.67	20	0.97	4.13	50	0.99	4.46
10	0.99	3.12	20	1.01	3.49	50	1.04	3.68
10	1.04	2.47	20	1.06	2.66	50	1.08	2.95
10	1.07	1.84	20	1.09	2.04	50	1.12	2.29
10	1.11	1.26	20	1.13	1.46	50	1.16	1.86
10	1.14	0.78	20	1.16	0.83	50	1.19	1.28
10	1.17	0	20	1.19	0	50	1.22	0
100	0	8.53	200	0	9.13			
100	0.32	8.48	200	0.32	9.04			
100	0.5	8.39	200	0.51	8.93			
100	0.64	8.23	200	0.65	8.8			
100	0.74	7.84	200	0.75	8.62			
100	0.82	7.06	200	0.84	7.73			
100	0.89	6.6	200	0.91	7.03			
100	0.96	5.9	200	0.97	6.17			
100	1.01	4.99	200	1.03	5.27			
100	1.06	4.08	200	1.08	4.41			
100	1.1	3.25	200	1.12	3.66			
100	1.14	2.54	200	1.16	3.05			
100	1.18	2.28	200	1.2	2.49			
100	1.21	1.35	200	1.24	1.4			
100	1.24	0	200	1.27	0			

Table F-18: Storm-tide and wave probability results for Tokomaru Bay 3. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.15	2	0	5.07	5	0	6.11
1	0.28	4.11	2	0.28	5.02	5	0.29	6.06
1	0.44	4.04	2	0.45	4.94	5	0.46	5.97
1	0.56	3.95	2	0.57	4.82	5	0.59	5.79
1	0.65	3.71	2	0.66	4.52	5	0.68	5.44
1	0.72	3.43	2	0.74	4.18	5	0.76	5.07
1	0.78	3.1	2	0.8	3.8	5	0.82	4.62
1	0.83	2.77	2	0.85	3.41	5	0.88	4.14
1	0.88	2.42	2	0.9	3	5	0.93	3.62
1	0.92	2.08	2	0.95	2.53	5	0.97	3.05
1	0.96	1.74	2	0.98	2.09	5	1.01	2.55
1	1	1.37	2	1.02	1.7	5	1.05	2.05
1	1.03	1.04	2	1.05	1.19	5	1.08	1.52
1	1.06	0.71	2	1.08	0.81	5	1.12	0.94
1	1.09	0	2	1.11	0	5	1.15	0
10	0	6.82	20	0	7.5	50	0	8.36
10	0.3	6.77	20	0.3	7.46	50	0.31	8.33
10	0.47	6.68	20	0.48	7.38	50	0.5	8.27
10	0.6	6.47	20	0.61	7.16	50	0.63	7.93
10	0.69	6.02	20	0.71	6.71	50	0.73	7.61
10	0.77	5.66	20	0.79	6.33	50	0.81	7.24
10	0.84	5.19	20	0.86	5.87	50	0.88	6.72
10	0.9	4.61	20	0.91	5.23	50	0.94	6.07
10	0.95	4.02	20	0.97	4.63	50	0.99	5.4
10	0.99	3.42	20	1.01	4.03	50	1.04	4.69
10	1.04	2.82	20	1.06	3.35	50	1.08	3.95
10	1.07	2.17	20	1.09	2.47	50	1.12	3.17
10	1.11	1.63	20	1.13	1.77	50	1.16	2.2
10	1.14	0.79	20	1.16	1.04	50	1.19	1.39
10	1.17	0	20	1.19	0	50	1.22	0
100	0	9	200	0	9.62			
100	0.32	8.85	200	0.32	9.49			
100	0.5	8.65	200	0.51	9.28			
100	0.64	8.34	200	0.65	8.74			
100	0.74	7.91	200	0.75	8.43			
100	0.82	7.73	200	0.84	8.13			
100	0.89	7.14	200	0.91	7.84			
100	0.96	6.47	200	0.97	7.25			
100	1.01	5.89	200	1.03	6.42			
100	1.06	5.26	200	1.08	5.48			
100	1.1	4.49	200	1.12	4.53			
100	1.14	3.55	200	1.16	3.6			
100	1.18	2.27	200	1.2	2.56			
100	1.21	1.32	200	1.24	1.37			
100	1.24	0	200	1.27	0			

Table F-19: Storm-tide and wave probability results for Anaura Bay. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.4	2	0	5.39	5	0	6.49
1	0.28	4.36	2	0.28	5.34	5	0.29	6.43
1	0.44	4.3	2	0.45	5.26	5	0.46	6.33
1	0.56	4.21	2	0.57	5.13	5	0.59	6.13
1	0.65	3.94	2	0.66	4.83	5	0.68	5.81
1	0.72	3.66	2	0.74	4.48	5	0.76	5.34
1	0.78	3.32	2	0.8	4.07	5	0.82	4.92
1	0.83	2.97	2	0.85	3.66	5	0.88	4.45
1	0.88	2.63	2	0.9	3.2	5	0.93	3.9
1	0.92	2.25	2	0.95	2.7	5	0.97	3.28
1	0.96	1.85	2	0.98	2.24	5	1.01	2.73
1	1	1.5	2	1.02	1.84	5	1.05	2.26
1	1.03	1.23	2	1.05	1.41	5	1.08	1.71
1	1.06	0.82	2	1.08	0.87	5	1.12	1.13
1	1.09	0	2	1.11	0	5	1.15	0
10	0	7.25	20	0	7.97	50	0	8.89
10	0.3	7.2	20	0.3	7.92	50	0.31	8.84
10	0.47	7.1	20	0.48	7.82	50	0.5	8.75
10	0.6	6.84	20	0.61	7.51	50	0.63	8.36
10	0.69	6.44	20	0.71	7.06	50	0.73	7.88
10	0.77	5.95	20	0.79	6.56	50	0.81	7.53
10	0.84	5.41	20	0.86	6.06	50	0.88	6.97
10	0.9	4.93	20	0.91	5.44	50	0.94	6.32
10	0.95	4.33	20	0.97	4.74	50	0.99	5.59
10	0.99	3.68	20	1.01	4.03	50	1.04	4.82
10	1.04	3.04	20	1.06	3.34	50	1.08	4.02
10	1.07	2.39	20	1.09	2.69	50	1.12	3.2
10	1.11	1.78	20	1.13	1.88	50	1.16	2.2
10	1.14	1	20	1.16	1.25	50	1.19	1.47
10	1.17	0	20	1.19	0	50	1.22	0
100	0	9.57	200	0	10.24			
100	0.32	9.53	200	0.32	10.09			
100	0.5	9.46	200	0.51	9.9			
100	0.64	9.12	200	0.65	9.57			
100	0.74	8.67	200	0.75	9.25			
100	0.82	8.16	200	0.84	8.43			
100	0.89	7.8	200	0.91	8.14			
100	0.96	7.21	200	0.97	7.61			
100	1.01	6.32	200	1.03	6.82			
100	1.06	5.33	200	1.08	5.84			
100	1.1	4.32	200	1.12	4.71			
100	1.14	3.36	200	1.16	3.46			
100	1.18	2.29	200	1.2	2.28			
100	1.21	1.71	200	1.24	1.25			
100	1.24	0	200	1.27	0			

Table F-20: Storm-tide and wave probability results for Kaiaua Bay. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.5	2	0	5.64	5	0	6.91
1	0.27	4.46	2	0.28	5.59	5	0.29	6.84
1	0.44	4.4	2	0.45	5.51	5	0.46	6.74
1	0.55	4.33	2	0.56	5.38	5	0.58	6.54
1	0.64	4.09	2	0.65	5.09	5	0.67	6.17
1	0.71	3.79	2	0.73	4.72	5	0.75	5.69
1	0.77	3.47	2	0.79	4.32	5	0.81	5.18
1	0.82	3.15	2	0.85	3.91	5	0.87	4.68
1	0.87	2.81	2	0.89	3.48	5	0.92	4.13
1	0.91	2.47	2	0.94	3.06	5	0.96	3.53
1	0.95	2.14	2	0.97	2.62	5	1	2.97
1	0.99	1.75	2	1.01	2.06	5	1.04	2.51
1	1.02	1.34	2	1.04	1.57	5	1.07	1.77
1	1.05	0.89	2	1.07	1.04	5	1.11	1.17
1	1.07	0	2	1.1	0	5	1.13	0
10	0	7.77	20	0	8.59	50	0	9.63
10	0.3	7.69	20	0.3	8.5	50	0.31	9.48
10	0.47	7.55	20	0.48	8.37	50	0.49	9.29
10	0.59	7.34	20	0.6	8.15	50	0.62	9.02
10	0.69	6.91	20	0.7	7.69	50	0.72	8.46
10	0.77	6.32	20	0.78	6.97	50	0.8	7.73
10	0.83	5.77	20	0.85	6.35	50	0.87	7.03
10	0.89	5.25	20	0.91	5.74	50	0.93	6.25
10	0.94	4.61	20	0.96	5.1	50	0.98	5.52
10	0.98	3.92	20	1	4.45	50	1.03	4.82
10	1.02	3.3	20	1.05	3.82	50	1.07	4.15
10	1.06	2.8	20	1.08	3.19	50	1.11	3.5
10	1.1	2.07	20	1.12	2.49	50	1.15	2.86
10	1.13	1.44	20	1.15	1.51	50	1.18	1.58
10	1.16	0	20	1.18	0	50	1.21	0
100	0	10.39	200	0	11.14			
100	0.32	10.21	200	0.32	10.66			
100	0.5	10.08	200	0.51	10.52			
100	0.63	9.96	200	0.64	10.45			
100	0.73	9.13	200	0.75	9.91			
100	0.82	8.59	200	0.83	9.27			
100	0.89	7.62	200	0.9	8.01			
100	0.95	6.73	200	0.97	6.99			
100	1	6.14	200	1.02	6.2			
100	1.05	5.58	200	1.07	5.49			
100	1.09	4.91	200	1.11	4.76			
100	1.13	4.05	200	1.15	3.99			
100	1.17	2.68	200	1.19	3.06			
100	1.2	1.78	200	1.22	1.86			
100	1.23	0	200	1.26	0			

Table F-21: Storm-tide and wave probability results for Karaka Bay. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.51	2	0	5.55	5	0	6.71
1	0.27	4.46	2	0.28	5.49	5	0.29	6.65
1	0.44	4.39	2	0.45	5.39	5	0.46	6.56
1	0.55	4.29	2	0.56	5.25	5	0.58	6.36
1	0.64	4.02	2	0.65	4.9	5	0.67	5.96
1	0.71	3.71	2	0.73	4.53	5	0.75	5.48
1	0.77	3.39	2	0.79	4.11	5	0.81	4.93
1	0.82	3.07	2	0.85	3.71	5	0.87	4.43
1	0.87	2.68	2	0.89	3.28	5	0.92	3.92
1	0.91	2.32	2	0.94	2.79	5	0.96	3.39
1	0.95	1.94	2	0.97	2.34	5	1	2.84
1	0.99	1.6	2	1.01	1.87	5	1.04	2.23
1	1.02	1.22	2	1.04	1.4	5	1.07	1.7
1	1.05	0.76	2	1.07	1.01	5	1.11	1.12
1	1.07	0	2	1.1	0	5	1.13	0
10	0	7.5	20	0	8.26	50	0	9.22
10	0.3	7.44	20	0.3	8.2	50	0.31	9.13
10	0.47	7.35	20	0.48	8.1	50	0.49	8.99
10	0.59	7.1	20	0.6	7.79	50	0.62	8.48
10	0.69	6.63	20	0.7	7.29	50	0.72	8.12
10	0.77	6.12	20	0.78	6.64	50	0.8	7.27
10	0.83	5.45	20	0.85	6.01	50	0.87	6.67
10	0.89	4.92	20	0.91	5.41	50	0.93	5.92
10	0.94	4.38	20	0.96	4.68	50	0.98	5.24
10	0.98	3.83	20	1	3.94	50	1.03	4.57
10	1.02	3.21	20	1.05	3.28	50	1.07	3.86
10	1.06	2.37	20	1.08	2.76	50	1.11	3.1
10	1.1	1.8	20	1.12	2.08	50	1.15	2.15
10	1.13	1.19	20	1.15	1.23	50	1.18	1.18
10	1.16	0	20	1.18	0	50	1.21	0
100	0	9.92	200	0	10.62			
100	0.32	9.9	200	0.32	10.61			
100	0.5	9.87	200	0.51	10.6			
100	0.63	9.48	200	0.64	10.26			
100	0.73	8.69	200	0.75	9.81			
100	0.82	7.88	200	0.83	8.87			
100	0.89	7.36	200	0.9	8.18			
100	0.95	6.75	200	0.97	7.29			
100	1	5.97	200	1.02	6.42			
100	1.05	5.13	200	1.07	5.55			
100	1.09	4.27	200	1.11	4.67			
100	1.13	3.42	200	1.15	3.8			
100	1.17	2.38	200	1.19	2.9			
100	1.2	1.49	200	1.22	1.63			
100	1.23	0	200	1.26	0			

Table F-22: Storm-tide and wave probability results for Tolaga Bay. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.34	2	0	5.41	5	0	6.61
1	0.27	4.28	2	0.28	5.34	5	0.29	6.54
1	0.43	4.19	2	0.44	5.23	5	0.46	6.42
1	0.55	4.09	2	0.56	5.08	5	0.58	6.23
1	0.63	3.81	2	0.65	4.7	5	0.67	5.78
1	0.71	3.48	2	0.72	4.3	5	0.75	5.24
1	0.77	3.15	2	0.79	3.91	5	0.81	4.76
1	0.82	2.79	2	0.84	3.46	5	0.87	4.19
1	0.87	2.43	2	0.89	2.99	5	0.92	3.59
1	0.91	2.01	2	0.93	2.44	5	0.96	3.03
1	0.95	1.65	2	0.97	2	5	1	2.38
1	0.98	1.25	2	1	1.59	5	1.03	1.78
1	1.01	0.89	2	1.04	1.12	5	1.07	1.34
1	1.04	0.59	2	1.07	0.67	5	1.1	0.76
1	1.07	0	2	1.09	0	5	1.13	0
10	0	7.42	20	0	8.19	50	0	9.17
10	0.29	7.34	20	0.3	8.08	50	0.31	8.96
10	0.47	7.22	20	0.48	7.91	50	0.49	8.67
10	0.59	7.01	20	0.6	7.59	50	0.62	8.25
10	0.68	6.56	20	0.7	7.09	50	0.72	7.7
10	0.76	6	20	0.78	6.65	50	0.8	7.26
10	0.83	5.32	20	0.84	5.77	50	0.87	6.32
10	0.88	4.65	20	0.9	5.14	50	0.93	5.63
10	0.93	4	20	0.95	4.42	50	0.98	4.93
10	0.98	3.37	20	1	3.7	50	1.03	4.22
10	1.02	2.7	20	1.04	3.01	50	1.07	3.46
10	1.06	2.18	20	1.08	2.25	50	1.11	2.54
10	1.09	1.44	20	1.11	1.47	50	1.14	1.56
10	1.12	0.8	20	1.15	0.84	50	1.18	1.05
10	1.15	0	20	1.18	0	50	1.21	0
100	0	9.89	200	0	10.6			
100	0.31	9.68	200	0.32	10.12			
100	0.5	9.38	200	0.51	9.81			
100	0.63	8.88	200	0.64	9.54			
100	0.73	8.1	200	0.74	8.69			
100	0.81	7.8	200	0.83	8.15			
100	0.88	6.78	200	0.9	7.08			
100	0.94	5.79	200	0.96	6.21			
100	1	5.03	200	1.02	5.52			
100	1.04	4.31	200	1.07	4.76			
100	1.09	3.55	200	1.11	3.81			
100	1.13	2.62	200	1.15	2.42			
100	1.16	1.6	200	1.19	1.64			
100	1.2	1.07	200	1.22	0.93			
100	1.23	0	200	1.25	0			

Table F-23: Storm-tide and wave probability results for Waihau Bay. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.61	2	0	5.85	5	0	7.22
1	0.27	4.57	2	0.28	5.81	5	0.29	7.17
1	0.43	4.51	2	0.44	5.73	5	0.46	7.08
1	0.55	4.44	2	0.56	5.63	5	0.58	6.93
1	0.63	4.22	2	0.65	5.33	5	0.67	6.54
1	0.71	3.97	2	0.72	4.99	5	0.75	6.11
1	0.77	3.67	2	0.79	4.64	5	0.81	5.69
1	0.82	3.36	2	0.84	4.28	5	0.87	5.2
1	0.87	3.03	2	0.89	3.82	5	0.92	4.63
1	0.91	2.68	2	0.93	3.36	5	0.96	4.01
1	0.95	2.29	2	0.97	2.88	5	1	3.37
1	0.98	1.84	2	1	2.39	5	1.03	2.76
1	1.01	1.43	2	1.04	1.71	5	1.07	2.18
1	1.04	1.02	2	1.07	1.21	5	1.1	1.4
1	1.07	0	2	1.09	0	5	1.13	0
10	0	8.16	20	0	9.03	50	0	10.15
10	0.29	8.09	20	0.3	8.95	50	0.31	10.11
10	0.47	7.99	20	0.48	8.82	50	0.49	10.03
10	0.59	7.83	20	0.6	8.6	50	0.62	9.7
10	0.68	7.38	20	0.7	8.2	50	0.72	9.23
10	0.76	6.92	20	0.78	7.68	50	0.8	8.73
10	0.83	6.44	20	0.84	7.19	50	0.87	8.11
10	0.88	5.89	20	0.9	6.45	50	0.93	7.35
10	0.93	5.3	20	0.95	5.77	50	0.98	6.53
10	0.98	4.7	20	1	5.13	50	1.03	5.68
10	1.02	4.06	20	1.04	4.48	50	1.07	4.8
10	1.06	3.35	20	1.08	3.76	50	1.11	3.89
10	1.09	2.43	20	1.11	2.9	50	1.14	2.68
10	1.12	1.5	20	1.15	1.85	50	1.18	1.63
10	1.15	0	20	1.18	0	50	1.21	0
100	0	10.97	200	0	11.78			
100	0.31	10.9	200	0.32	11.77			
100	0.5	10.79	200	0.51	11.76			
100	0.63	10.25	200	0.64	11.28			
100	0.73	9.8	200	0.74	10.59			
100	0.81	9.29	200	0.83	9.91			
100	0.88	8.59	200	0.9	9.25			
100	0.94	7.72	200	0.96	8.48			
100	1	6.83	200	1.02	7.69			
100	1.04	5.92	200	1.07	6.84			
100	1.09	4.98	200	1.11	5.9			
100	1.13	4.03	200	1.15	4.87			
100	1.16	2.92	200	1.19	3.75			
100	1.2	1.77	200	1.22	2.05			
100	1.23	0	200	1.25	0			

Table F-24: Storm-tide and wave probability results for Waiharehare Bay. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.6	2	0	5.66	5	0	6.85
1	0.27	4.56	2	0.28	5.61	5	0.29	6.8
1	0.43	4.5	2	0.44	5.54	5	0.45	6.71
1	0.54	4.42	2	0.56	5.42	5	0.57	6.53
1	0.63	4.16	2	0.65	5.09	5	0.67	6.12
1	0.7	3.85	2	0.72	4.72	5	0.74	5.68
1	0.76	3.54	2	0.78	4.35	5	0.81	5.24
1	0.81	3.2	2	0.83	3.89	5	0.86	4.72
1	0.86	2.83	2	0.88	3.42	5	0.91	4.15
1	0.9	2.43	2	0.92	2.94	5	0.95	3.6
1	0.94	2.05	2	0.96	2.48	5	0.99	3.04
1	0.97	1.72	2	1	2.04	5	1.03	2.44
1	1	1.22	2	1.03	1.56	5	1.06	1.88
1	1.03	0.9	2	1.06	1.03	5	1.09	1.33
1	1.06	0	2	1.09	0	5	1.12	0
10	0	7.66	20	0	8.43	50	0	9.41
10	0.29	7.59	20	0.3	8.37	50	0.31	9.32
10	0.46	7.48	20	0.47	8.27	50	0.49	9.19
10	0.59	7.27	20	0.6	8	50	0.61	8.93
10	0.68	6.81	20	0.69	7.44	50	0.71	8.33
10	0.76	6.3	20	0.77	6.96	50	0.79	7.78
10	0.82	5.81	20	0.84	6.36	50	0.86	7.14
10	0.88	5.16	20	0.9	5.67	50	0.92	6.33
10	0.93	4.55	20	0.95	5.03	50	0.97	5.62
10	0.97	4.02	20	0.99	4.43	50	1.02	4.93
10	1.01	3.44	20	1.03	3.79	50	1.06	4.22
10	1.05	2.66	20	1.07	3.07	50	1.1	3.45
10	1.08	2	20	1.11	2.09	50	1.14	2.51
10	1.12	1.4	20	1.14	1.46	50	1.17	1.53
10	1.14	0	20	1.17	0	50	1.2	0
100	0	10.14	200	0	10.85			
100	0.31	10.09	200	0.32	10.85			
100	0.5	10	200	0.51	10.85			
100	0.63	9.57	200	0.64	10.65			
100	0.73	8.91	200	0.74	9.68			
100	0.81	8.45	200	0.83	9.1			
100	0.88	7.83	200	0.9	8.64			
100	0.94	6.95	200	0.96	7.93			
100	0.99	6.15	200	1.01	7.01			
100	1.04	5.36	200	1.06	6.04			
100	1.08	4.57	200	1.11	5.1			
100	1.12	3.76	200	1.15	4.24			
100	1.16	2.83	200	1.18	3.49			
100	1.19	2.24	200	1.22	2.83			
100	1.22	0	200	1.25	0			

Table F-25: Storm-tide and wave probability results for Te Ikaarongamai Bay. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.71	2	0	5.83	5	0	7.08
1	0.27	4.67	2	0.28	5.78	5	0.29	7.04
1	0.43	4.61	2	0.44	5.71	5	0.45	6.96
1	0.54	4.53	2	0.56	5.61	5	0.57	6.83
1	0.63	4.31	2	0.65	5.35	5	0.67	6.5
1	0.7	4.04	2	0.72	5.01	5	0.74	6.12
1	0.76	3.75	2	0.78	4.67	5	0.81	5.71
1	0.81	3.44	2	0.83	4.27	5	0.86	5.23
1	0.86	3.1	2	0.88	3.85	5	0.91	4.69
1	0.9	2.74	2	0.92	3.42	5	0.95	4.17
1	0.94	2.33	2	0.96	2.98	5	0.99	3.63
1	0.97	1.98	2	1	2.51	5	1.03	3.01
1	1	1.59	2	1.03	1.9	5	1.06	2.25
1	1.03	1.21	2	1.06	1.4	5	1.09	1.57
1	1.06	0	2	1.09	0	5	1.12	0
10	0	7.94	20	0	8.75	50	0	9.77
10	0.29	7.88	20	0.3	8.68	50	0.31	9.74
10	0.46	7.8	20	0.47	8.58	50	0.49	9.7
10	0.59	7.66	20	0.6	8.42	50	0.61	9.64
10	0.68	7.26	20	0.69	8.05	50	0.71	9.14
10	0.76	6.84	20	0.77	7.55	50	0.79	8.69
10	0.82	6.44	20	0.84	7.06	50	0.86	8.18
10	0.88	5.88	20	0.9	6.54	50	0.92	7.69
10	0.93	5.23	20	0.95	5.85	50	0.97	6.85
10	0.97	4.53	20	0.99	5.06	50	1.02	5.88
10	1.01	3.84	20	1.03	4.27	50	1.06	4.91
10	1.05	3.19	20	1.07	3.55	50	1.1	4.03
10	1.08	2.58	20	1.11	2.92	50	1.14	3.29
10	1.12	1.56	20	1.14	1.94	50	1.17	2.5
10	1.14	0	20	1.17	0	50	1.2	0
100	0	10.53	200	0	11.28			
100	0.31	10.48	200	0.32	11.17			
100	0.5	10.4	200	0.51	11.1			
100	0.63	10.29	200	0.64	11.03			
100	0.73	9.98	200	0.74	10.67			
100	0.81	9.39	200	0.83	10.43			
100	0.88	9.04	200	0.9	9.94			
100	0.94	8.52	200	0.96	9.23			
100	0.99	7.61	200	1.01	8.33			
100	1.04	6.55	200	1.06	7.28			
100	1.08	5.45	200	1.11	6.12			
100	1.12	4.39	200	1.15	4.86			
100	1.16	3.4	200	1.18	3.48			
100	1.19	2.35	200	1.22	2.42			
100	1.22	0	200	1.25	0			

Table F-26: Storm-tide and wave probability results for Pariokonohi Point. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.35	2	0	5.39	5	0	6.54
1	0.27	4.31	2	0.28	5.34	5	0.29	6.49
1	0.43	4.24	2	0.44	5.27	5	0.45	6.4
1	0.54	4.16	2	0.56	5.16	5	0.57	6.22
1	0.63	3.91	2	0.65	4.85	5	0.67	5.87
1	0.7	3.67	2	0.72	4.52	5	0.74	5.53
1	0.76	3.39	2	0.78	4.19	5	0.81	5.1
1	0.81	3.07	2	0.83	3.82	5	0.86	4.65
1	0.86	2.74	2	0.88	3.35	5	0.91	4.16
1	0.9	2.38	2	0.92	2.9	5	0.95	3.62
1	0.94	2.01	2	0.96	2.46	5	0.99	3.06
1	0.97	1.6	2	1	2.03	5	1.03	2.46
1	1	1.21	2	1.03	1.55	5	1.06	1.89
1	1.03	0.88	2	1.06	1.02	5	1.09	1.33
1	1.06	0	2	1.09	0	5	1.12	0
10	0	7.33	20	0	8.08	50	0	9.03
10	0.29	7.28	20	0.3	8.01	50	0.31	8.96
10	0.46	7.18	20	0.47	7.9	50	0.49	8.84
10	0.59	6.93	20	0.6	7.58	50	0.61	8.58
10	0.68	6.55	20	0.69	7.18	50	0.71	8.1
10	0.76	6.15	20	0.77	6.75	50	0.79	7.67
10	0.82	5.68	20	0.84	6.18	50	0.86	6.88
10	0.88	5.18	20	0.9	5.6	50	0.92	6.37
10	0.93	4.59	20	0.95	4.99	50	0.97	5.78
10	0.97	3.94	20	0.99	4.36	50	1.02	5.14
10	1.01	3.28	20	1.03	3.74	50	1.06	4.47
10	1.05	2.63	20	1.07	3.13	50	1.1	3.74
10	1.08	2.04	20	1.11	2.44	50	1.14	2.87
10	1.12	1.23	20	1.14	1.49	50	1.17	1.84
10	1.14	0	20	1.17	0	50	1.2	0
100	0	9.73	200	0	10.42			
100	0.31	9.62	200	0.32	10.3			
100	0.5	9.44	200	0.51	10.15			
100	0.63	9.04	200	0.64	9.97			
100	0.73	8.72	200	0.74	9.49			
100	0.81	8.1	200	0.83	8.73			
100	0.88	7.34	200	0.9	7.81			
100	0.94	6.72	200	0.96	7.07			
100	0.99	6.22	200	1.01	6.51			
100	1.04	5.72	200	1.06	5.97			
100	1.08	5.13	200	1.11	5.34			
100	1.12	4.4	200	1.15	4.57			
100	1.16	3.53	200	1.18	3.64			
100	1.19	2.09	200	1.22	1.96			
100	1.22	0	200	1.25	0			

Table F-27: Storm-tide and wave probability results for Turihaua Point. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.19	2	0	5.19	5	0	6.31
1	0.27	4.15	2	0.28	5.14	5	0.29	6.25
1	0.43	4.09	2	0.44	5.05	5	0.45	6.16
1	0.54	4.01	2	0.55	4.93	5	0.57	6.02
1	0.63	3.78	2	0.64	4.64	5	0.66	5.64
1	0.7	3.53	2	0.72	4.31	5	0.74	5.27
1	0.76	3.24	2	0.78	3.99	5	0.8	4.87
1	0.81	2.95	2	0.83	3.61	5	0.86	4.42
1	0.86	2.63	2	0.88	3.24	5	0.91	3.92
1	0.9	2.32	2	0.92	2.79	5	0.95	3.42
1	0.93	1.91	2	0.96	2.33	5	0.99	2.89
1	0.97	1.57	2	0.99	1.93	5	1.02	2.3
1	1	1.21	2	1.03	1.54	5	1.06	1.88
1	1.03	0.88	2	1.05	1.02	5	1.09	1.33
1	1.06	0	2	1.08	0	5	1.12	0
10	0	7.07	20	0	7.79	50	0	8.71
10	0.29	7	20	0.3	7.7	50	0.31	8.61
10	0.46	6.9	20	0.47	7.56	50	0.48	8.46
10	0.58	6.7	20	0.6	7.35	50	0.61	8.12
10	0.68	6.36	20	0.69	7	50	0.71	7.67
10	0.75	5.86	20	0.77	6.59	50	0.79	7.31
10	0.82	5.43	20	0.84	5.97	50	0.86	6.75
10	0.88	4.9	20	0.89	5.41	50	0.92	5.98
10	0.92	4.31	20	0.94	4.81	50	0.97	5.35
10	0.97	3.71	20	0.99	4.21	50	1.02	4.74
10	1.01	3.1	20	1.03	3.6	50	1.06	4.09
10	1.05	2.45	20	1.07	2.98	50	1.1	3.34
10	1.08	2.02	20	1.1	2.14	50	1.13	2.31
10	1.11	1.32	20	1.13	1.5	50	1.16	1.47
10	1.14	0	20	1.16	0	50	1.19	0
100	0	9.38	200	0	10.05			
100	0.31	9.32	200	0.32	9.97			
100	0.49	9.2	200	0.5	9.84			
100	0.62	8.68	200	0.64	9.31			
100	0.72	8.12	200	0.74	8.58			
100	0.81	7.87	200	0.82	8.33			
100	0.87	7.33	200	0.89	7.76			
100	0.93	6.6	200	0.95	6.99			
100	0.99	5.88	200	1.01	6.12			
100	1.04	5.13	200	1.06	5.24			
100	1.08	4.33	200	1.1	4.4			
100	1.12	3.49	200	1.14	3.62			
100	1.15	2.56	200	1.18	2.85			
100	1.19	1.72	200	1.21	1.67			
100	1.22	0	200	1.24	0			

Table F-28: Storm-tide and wave probability results for Tatapouri Point. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	4.03	2	0	5.02	5	0	6.12
1	0.27	4	2	0.28	4.98	5	0.29	6.07
1	0.43	3.93	2	0.44	4.92	5	0.45	5.99
1	0.54	3.87	2	0.55	4.82	5	0.57	5.83
1	0.63	3.64	2	0.64	4.53	5	0.66	5.5
1	0.7	3.39	2	0.72	4.2	5	0.74	5.09
1	0.76	3.11	2	0.78	3.87	5	0.8	4.66
1	0.81	2.81	2	0.83	3.5	5	0.86	4.19
1	0.86	2.49	2	0.88	3.07	5	0.91	3.67
1	0.9	2.16	2	0.92	2.64	5	0.95	3.16
1	0.93	1.87	2	0.96	2.2	5	0.99	2.67
1	0.97	1.44	2	0.99	1.82	5	1.02	2.14
1	1	1.1	2	1.03	1.38	5	1.06	1.59
1	1.03	0.73	2	1.05	0.86	5	1.09	1.03
1	1.06	0	2	1.08	0	5	1.12	0
10	0	6.87	20	0	7.59	50	0	8.49
10	0.29	6.83	20	0.3	7.52	50	0.31	8.44
10	0.46	6.75	20	0.47	7.41	50	0.48	8.36
10	0.58	6.55	20	0.6	7.16	50	0.61	8.08
10	0.68	6.16	20	0.69	6.74	50	0.71	7.58
10	0.75	5.74	20	0.77	6.25	50	0.79	6.96
10	0.82	5.23	20	0.84	5.76	50	0.86	6.45
10	0.88	4.69	20	0.89	5.14	50	0.92	5.69
10	0.92	4.12	20	0.94	4.53	50	0.97	5.05
10	0.97	3.54	20	0.99	3.95	50	1.02	4.45
10	1.01	2.99	20	1.03	3.41	50	1.06	3.85
10	1.05	2.49	20	1.07	2.91	50	1.1	3.22
10	1.08	2.04	20	1.1	2.15	50	1.13	2.32
10	1.11	1.34	20	1.13	1.5	50	1.16	1.51
10	1.14	0	20	1.16	0	50	1.19	0
100	0	9.16	200	0	9.81			
100	0.31	9.14	200	0.32	9.79			
100	0.49	9.11	200	0.5	9.76			
100	0.62	8.69	200	0.64	9.29			
100	0.72	8.26	200	0.74	8.66			
100	0.81	7.45	200	0.82	7.8			
100	0.87	7.01	200	0.89	7.32			
100	0.93	6.46	200	0.95	6.73			
100	0.99	5.86	200	1.01	6.11			
100	1.04	5.22	200	1.06	5.43			
100	1.08	4.51	200	1.1	4.69			
100	1.12	3.75	200	1.14	3.9			
100	1.15	2.78	200	1.18	2.86			
100	1.19	1.96	200	1.21	1.64			
100	1.22	0	200	1.24	0			

Table F-29: Storm-tide and wave probability results for Wainui Beach. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	3.73	2	0	4.59	5	0	5.55
1	0.27	3.69	2	0.28	4.54	5	0.29	5.51
1	0.43	3.63	2	0.44	4.48	5	0.45	5.44
1	0.54	3.57	2	0.55	4.38	5	0.57	5.33
1	0.63	3.37	2	0.64	4.13	5	0.66	5.05
1	0.7	3.16	2	0.72	3.84	5	0.74	4.7
1	0.76	2.91	2	0.78	3.57	5	0.8	4.34
1	0.81	2.65	2	0.83	3.25	5	0.86	3.97
1	0.86	2.34	2	0.88	2.84	5	0.91	3.54
1	0.9	2.03	2	0.92	2.52	5	0.95	3.09
1	0.93	1.72	2	0.96	2.08	5	0.99	2.62
1	0.97	1.45	2	0.99	1.69	5	1.02	2.16
1	1	1.02	2	1.03	1.29	5	1.06	1.72
1	1.03	0.74	2	1.05	0.85	5	1.09	1.13
1	1.06	0	2	1.08	0	5	1.12	0
10	0	6.21	20	0	6.84	50	0	7.63
10	0.29	6.16	20	0.3	6.77	50	0.31	7.58
10	0.46	6.07	20	0.47	6.68	50	0.48	7.5
10	0.58	5.92	20	0.6	6.55	50	0.61	7.25
10	0.68	5.62	20	0.69	6.18	50	0.71	6.95
10	0.75	5.27	20	0.77	5.86	50	0.79	6.62
10	0.82	4.83	20	0.84	5.41	50	0.86	6.07
10	0.88	4.37	20	0.89	4.87	50	0.92	5.53
10	0.92	3.91	20	0.94	4.32	50	0.97	5.04
10	0.97	3.45	20	0.99	3.78	50	1.02	4.56
10	1.01	2.92	20	1.03	3.25	50	1.06	4
10	1.05	2.32	20	1.07	2.73	50	1.1	3.34
10	1.08	1.69	20	1.1	2.13	50	1.13	2.47
10	1.11	1.21	20	1.13	1.29	50	1.16	1.66
10	1.14	0	20	1.16	0	50	1.19	0
100	0	8.22	200	0	8.8			
100	0.31	8.16	200	0.32	8.75			
100	0.49	8.05	200	0.5	8.66			
100	0.62	7.82	200	0.64	8.47			
100	0.72	7.45	200	0.74	7.99			
100	0.81	7.07	200	0.82	7.6			
100	0.87	6.61	200	0.89	6.93			
100	0.93	6.04	200	0.95	6.17			
100	0.99	5.48	200	1.01	5.49			
100	1.04	4.9	200	1.06	4.84			
100	1.08	4.24	200	1.1	4.18			
100	1.12	3.5	200	1.14	3.49			
100	1.15	2.58	200	1.18	2.57			
100	1.19	1.67	200	1.21	1.6			
100	1.22	0	200	1.24	0			

Table F-30: Storm-tide and wave probability results for Poverty Bay at Tuamotu. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	3.11	2	0	3.9	5	0	4.78
1	0.27	3.08	2	0.28	3.86	5	0.29	4.74
1	0.43	3.04	2	0.44	3.79	5	0.45	4.67
1	0.54	2.98	2	0.55	3.71	5	0.57	4.55
1	0.63	2.82	2	0.64	3.51	5	0.66	4.28
1	0.7	2.63	2	0.71	3.26	5	0.74	4
1	0.76	2.41	2	0.78	3	5	0.8	3.7
1	0.81	2.16	2	0.83	2.72	5	0.86	3.36
1	0.85	1.95	2	0.88	2.4	5	0.9	2.95
1	0.9	1.66	2	0.92	2.08	5	0.95	2.49
1	0.93	1.38	2	0.96	1.74	5	0.99	2.09
1	0.97	1.11	2	0.99	1.3	5	1.02	1.74
1	1	0.76	2	1.02	1.01	5	1.06	1.17
1	1.03	0.43	2	1.05	0.49	5	1.09	0.76
1	1.05	0	2	1.08	0	5	1.11	0
10	0	5.38	20	0	5.95	50	0	6.66
10	0.29	5.34	20	0.3	5.9	50	0.31	6.61
10	0.46	5.27	20	0.47	5.82	50	0.48	6.52
10	0.58	5.13	20	0.59	5.67	50	0.61	6.32
10	0.68	4.82	20	0.69	5.42	50	0.71	6.14
10	0.75	4.51	20	0.77	5.07	50	0.79	5.73
10	0.82	4.16	20	0.83	4.66	50	0.86	5.32
10	0.87	3.77	20	0.89	4.22	50	0.92	4.81
10	0.92	3.32	20	0.94	3.69	50	0.97	4.33
10	0.97	2.84	20	0.99	3.16	50	1.01	3.8
10	1.01	2.35	20	1.03	2.66	50	1.06	3.06
10	1.04	1.79	20	1.07	2.12	50	1.09	2.41
10	1.08	1.28	20	1.1	1.58	50	1.13	2.07
10	1.11	0.83	20	1.13	1.07	50	1.16	1.44
10	1.14	0	20	1.16	0	50	1.19	0
100	0	7.19	200	0	7.71			
100	0.31	7.14	200	0.32	7.51			
100	0.49	7.06	200	0.5	7.41			
100	0.62	6.91	200	0.64	7.35			
100	0.72	6.67	200	0.74	7.22			
100	0.8	6.24	200	0.82	6.55			
100	0.87	5.73	200	0.89	6.19			
100	0.93	5.11	200	0.95	5.73			
100	0.99	4.53	200	1.01	5.14			
100	1.03	3.9	200	1.05	4.43			
100	1.08	3.04	200	1.1	3.51			
100	1.12	2.71	200	1.14	2.78			
100	1.15	2.24	200	1.18	2.3			
100	1.19	0.67	200	1.21	0.7			
100	1.22	0	200	1.24	0			

Table F-31: Storm-tide and wave probability results for Poverty Bay Kaiti. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	2.78	2	0	3.57	5	0	4.43
1	0.27	2.75	2	0.28	3.52	5	0.29	4.39
1	0.43	2.71	2	0.44	3.46	5	0.45	4.33
1	0.54	2.66	2	0.55	3.38	5	0.57	4.23
1	0.63	2.51	2	0.64	3.19	5	0.66	3.99
1	0.7	2.35	2	0.71	2.99	5	0.74	3.71
1	0.76	2.16	2	0.78	2.76	5	0.8	3.47
1	0.81	1.97	2	0.83	2.5	5	0.86	3.16
1	0.85	1.72	2	0.88	2.21	5	0.9	2.82
1	0.9	1.47	2	0.92	1.87	5	0.95	2.36
1	0.93	1.23	2	0.96	1.48	5	0.99	1.95
1	0.97	0.95	2	0.99	1.23	5	1.02	1.55
1	1	0.67	2	1.02	0.87	5	1.06	1.2
1	1.03	0.34	2	1.05	0.38	5	1.09	0.79
1	1.05	0	2	1.08	0	5	1.11	0
10	0	5.02	20	0	5.57	50	0	6.27
10	0.29	4.98	20	0.3	5.53	50	0.31	6.21
10	0.46	4.92	20	0.47	5.46	50	0.48	6.12
10	0.58	4.78	20	0.59	5.26	50	0.61	5.88
10	0.68	4.53	20	0.69	5.03	50	0.71	5.63
10	0.75	4.21	20	0.77	4.7	50	0.79	5.25
10	0.82	3.92	20	0.83	4.34	50	0.86	4.99
10	0.87	3.59	20	0.89	4.02	50	0.92	4.63
10	0.92	3.19	20	0.94	3.59	50	0.97	4.16
10	0.97	2.68	20	0.99	3.1	50	1.01	3.63
10	1.01	2.25	20	1.03	2.57	50	1.06	3.01
10	1.04	1.7	20	1.07	1.96	50	1.09	2.47
10	1.08	1.33	20	1.1	1.41	50	1.13	1.69
10	1.11	0.64	20	1.13	0.69	50	1.16	0.97
10	1.14	0	20	1.16	0	50	1.19	0
100	0	6.78	200	0	7.29			
100	0.31	6.74	200	0.32	7.16			
100	0.49	6.66	200	0.5	6.99			
100	0.62	6.37	200	0.64	6.72			
100	0.72	6.14	200	0.74	6.42			
100	0.8	5.68	200	0.82	6.09			
100	0.87	5.46	200	0.89	5.8			
100	0.93	5.09	200	0.95	5.37			
100	0.99	4.56	200	1.01	4.78			
100	1.03	3.97	200	1.05	4.17			
100	1.08	3.36	200	1.1	3.63			
100	1.12	2.76	200	1.14	3.13			
100	1.15	1.84	200	1.18	1.91			
100	1.19	1.02	200	1.21	1.02			
100	1.22	0	200	1.24	0			

Table F-32: Storm-tide and wave probability results for Poverty Bay Midway. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	3.08	2	0	3.88	5	0	4.76
1	0.27	3.05	2	0.28	3.83	5	0.29	4.71
1	0.43	2.99	2	0.44	3.76	5	0.45	4.63
1	0.54	2.93	2	0.55	3.68	5	0.57	4.52
1	0.63	2.76	2	0.64	3.46	5	0.66	4.22
1	0.7	2.57	2	0.71	3.19	5	0.74	3.93
1	0.76	2.37	2	0.78	2.96	5	0.8	3.63
1	0.81	2.15	2	0.83	2.7	5	0.86	3.34
1	0.85	1.93	2	0.88	2.42	5	0.9	3
1	0.9	1.67	2	0.92	2.08	5	0.95	2.6
1	0.93	1.38	2	0.96	1.73	5	0.99	2.13
1	0.97	1.11	2	0.99	1.41	5	1.02	1.71
1	1	0.75	2	1.02	1.02	5	1.06	1.35
1	1.03	0.43	2	1.05	0.66	5	1.09	0.92
1	1.05	0	2	1.08	0	5	1.11	0
10	0	5.36	20	0	5.92	50	0	6.64
10	0.29	5.31	20	0.3	5.87	50	0.31	6.57
10	0.46	5.23	20	0.47	5.79	50	0.48	6.48
10	0.58	5.08	20	0.59	5.64	50	0.61	6.35
10	0.68	4.74	20	0.69	5.29	50	0.71	5.89
10	0.75	4.42	20	0.77	4.94	50	0.79	5.59
10	0.82	4.09	20	0.83	4.61	50	0.86	5.21
10	0.87	3.76	20	0.89	4.17	50	0.92	4.77
10	0.92	3.38	20	0.94	3.78	50	0.97	4.38
10	0.97	2.88	20	0.99	3.35	50	1.01	3.91
10	1.01	2.36	20	1.03	2.62	50	1.06	3.13
10	1.04	1.95	20	1.07	2.22	50	1.09	2.48
10	1.08	1.46	20	1.1	1.59	50	1.13	1.97
10	1.11	0.82	20	1.13	1.05	50	1.16	0.97
10	1.14	0	20	1.16	0	50	1.19	0
100	0	7.17	200	0	7.69			
100	0.31	7.14	200	0.32	7.54			
100	0.49	7.1	200	0.5	7.42			
100	0.62	7.01	200	0.64	7.32			
100	0.72	6.52	200	0.74	6.94			
100	0.8	6.13	200	0.82	6.46			
100	0.87	5.77	200	0.89	6.06			
100	0.93	5.33	200	0.95	5.62			
100	0.99	4.88	200	1.01	5.16			
100	1.03	4.34	200	1.05	4.61			
100	1.08	3.65	200	1.1	3.95			
100	1.12	2.75	200	1.14	2.93			
100	1.15	2.2	200	1.18	2.29			
100	1.19	1.27	200	1.21	1.52			
100	1.22	0	200	1.24	0			

Table F-33: Storm-tide and wave probability results for Waipaoa River at Poverty Bay. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	3.28	2	0	4.06	5	0	4.92
1	0.27	3.25	2	0.28	4.02	5	0.29	4.88
1	0.43	3.2	2	0.44	3.96	5	0.45	4.81
1	0.54	3.14	2	0.55	3.88	5	0.57	4.68
1	0.63	2.94	2	0.64	3.63	5	0.66	4.41
1	0.7	2.72	2	0.71	3.37	5	0.74	4.09
1	0.76	2.47	2	0.78	3.07	5	0.8	3.77
1	0.81	2.21	2	0.83	2.74	5	0.86	3.4
1	0.85	1.91	2	0.88	2.36	5	0.9	2.92
1	0.9	1.57	2	0.92	1.95	5	0.95	2.44
1	0.93	1.24	2	0.96	1.54	5	0.99	1.97
1	0.97	1.02	2	0.99	1.2	5	1.02	1.58
1	1	0.72	2	1.02	0.91	5	1.06	1.15
1	1.03	0.45	2	1.05	0.52	5	1.09	0.56
1	1.05	0	2	1.08	0	5	1.11	0
10	0	5.51	20	0	6.08	50	0	6.79
10	0.29	5.48	20	0.3	6.02	50	0.31	6.71
10	0.46	5.43	20	0.47	5.94	50	0.48	6.59
10	0.58	5.26	20	0.59	5.78	50	0.61	6.41
10	0.68	4.93	20	0.69	5.4	50	0.71	6.07
10	0.75	4.56	20	0.77	5.02	50	0.79	5.54
10	0.82	4.21	20	0.83	4.65	50	0.86	5.18
10	0.87	3.8	20	0.89	4.2	50	0.92	4.74
10	0.92	3.28	20	0.94	3.59	50	0.97	4.2
10	0.97	2.69	20	0.99	3.02	50	1.01	3.59
10	1.01	2.14	20	1.03	2.54	50	1.06	2.86
10	1.04	1.73	20	1.07	1.93	50	1.09	2.28
10	1.08	1.24	20	1.1	1.33	50	1.13	1.64
10	1.11	0.61	20	1.13	0.65	50	1.16	0.61
10	1.14	0	20	1.16	0	50	1.19	0
100	0	7.31	200	0	7.83			
100	0.31	7.23	200	0.32	7.76			
100	0.49	7.1	200	0.5	7.64			
100	0.62	6.85	200	0.64	7.21			
100	0.72	6.3	200	0.74	6.57			
100	0.8	5.89	200	0.82	6.08			
100	0.87	5.56	200	0.89	5.84			
100	0.93	5.13	200	0.95	5.53			
100	0.99	4.34	200	1.01	5.08			
100	1.03	3.57	200	1.05	4.42			
100	1.08	3.07	200	1.1	3.52			
100	1.12	2.25	200	1.14	2.28			
100	1.15	1.47	200	1.18	1.52			
100	1.19	0.72	200	1.21	0.74			
100	1.22	0	200	1.24	0			

Table F-34: Storm-tide and wave probability results for Poverty Bay inside Young Nick's. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	3.05	2	0	3.82	5	0	4.68
1	0.27	3.03	2	0.28	3.79	5	0.29	4.64
1	0.43	2.98	2	0.44	3.74	5	0.45	4.58
1	0.54	2.93	2	0.55	3.66	5	0.57	4.44
1	0.63	2.73	2	0.64	3.42	5	0.66	4.14
1	0.7	2.5	2	0.71	3.14	5	0.74	3.83
1	0.76	2.24	2	0.78	2.83	5	0.8	3.47
1	0.81	1.96	2	0.83	2.48	5	0.86	3.05
1	0.85	1.72	2	0.88	2.11	5	0.9	2.63
1	0.9	1.39	2	0.92	1.73	5	0.95	2.24
1	0.93	1.07	2	0.96	1.37	5	0.99	1.7
1	0.97	0.79	2	0.99	1.05	5	1.02	1.27
1	1	0.48	2	1.02	0.68	5	1.06	0.9
1	1.03	0.22	2	1.05	0.33	5	1.09	0.47
1	1.05	0	2	1.08	0	5	1.11	0
10	0	5.26	20	0	5.82	50	0	6.52
10	0.29	5.22	20	0.3	5.78	50	0.31	6.47
10	0.46	5.15	20	0.47	5.71	50	0.48	6.39
10	0.58	4.94	20	0.59	5.52	50	0.61	6.06
10	0.68	4.68	20	0.69	5.16	50	0.71	5.73
10	0.75	4.27	20	0.77	4.73	50	0.79	5.18
10	0.82	3.9	20	0.83	4.27	50	0.86	4.71
10	0.87	3.42	20	0.89	3.79	50	0.92	4.23
10	0.92	2.88	20	0.94	3.26	50	0.97	3.59
10	0.97	2.4	20	0.99	2.77	50	1.01	3.03
10	1.01	1.85	20	1.03	2.26	50	1.06	2.48
10	1.04	1.36	20	1.07	1.65	50	1.09	1.76
10	1.08	0.97	20	1.1	1.12	50	1.13	1.2
10	1.11	0.5	20	1.13	0.48	50	1.16	0.51
10	1.14	0	20	1.16	0	50	1.19	0
100	0	7.03	200	0	7.54			
100	0.31	6.95	200	0.32	7.52			
100	0.49	6.82	200	0.5	7.48			
100	0.62	6.59	200	0.64	7.22			
100	0.72	6.22	200	0.74	6.92			
100	0.8	5.58	200	0.82	6.27			
100	0.87	5.07	200	0.89	5.77			
100	0.93	4.48	200	0.95	5.25			
100	0.99	3.74	200	1.01	4.5			
100	1.03	3.19	200	1.05	3.75			
100	1.08	2.77	200	1.1	3.08			
100	1.12	1.84	200	1.14	2.53			
100	1.15	1.24	200	1.18	1.58			
100	1.19	0.54	200	1.21	0.67			
100	1.22	0	200	1.24	0			

Table F-35: Storm-tide and wave probability results for Orongo. Hs = significant wave height (m). Storm-tide was calculated relative to a mean sea level of zero, so MSL offset needs to be applied to this table to convert to GVD-26.

ARI	Storm-tide	H_s	ARI	Storm-tide	H_s	ARI	Storm-tide	H_s
1	0	3.51	2	0	4.32	5	0	5.23
1	0.27	3.48	2	0.28	4.28	5	0.29	5.19
1	0.43	3.42	2	0.44	4.22	5	0.45	5.13
1	0.54	3.36	2	0.55	4.13	5	0.57	5.01
1	0.63	3.15	2	0.64	3.87	5	0.66	4.72
1	0.7	2.95	2	0.71	3.61	5	0.74	4.39
1	0.76	2.71	2	0.78	3.31	5	0.8	4.03
1	0.81	2.46	2	0.83	3	5	0.86	3.66
1	0.85	2.18	2	0.88	2.61	5	0.9	3.25
1	0.9	1.91	2	0.92	2.35	5	0.95	2.79
1	0.93	1.65	2	0.96	1.97	5	0.99	2.47
1	0.97	1.32	2	0.99	1.59	5	1.02	2.06
1	1	1	2	1.02	1.29	5	1.06	1.57
1	1.03	0.7	2	1.05	0.85	5	1.09	1.14
1	1.05	0	2	1.08	0	5	1.11	0
10	0	5.85	20	0	6.44	50	0	7.19
10	0.29	5.79	20	0.3	6.38	50	0.31	7.15
10	0.46	5.7	20	0.47	6.27	50	0.48	7.07
10	0.58	5.55	20	0.59	6.07	50	0.61	6.86
10	0.68	5.31	20	0.69	5.8	50	0.71	6.54
10	0.75	4.91	20	0.77	5.38	50	0.79	6.07
10	0.82	4.5	20	0.83	4.92	50	0.86	5.53
10	0.87	4.06	20	0.89	4.46	50	0.92	4.87
10	0.92	3.58	20	0.94	3.93	50	0.97	4.37
10	0.97	3.11	20	0.99	3.4	50	1.01	3.9
10	1.01	2.67	20	1.03	2.93	50	1.06	3.4
10	1.04	2.2	20	1.07	2.47	50	1.09	2.82
10	1.08	1.81	20	1.1	2	50	1.13	2.29
10	1.11	1.23	20	1.13	1.4	50	1.16	1.62
10	1.14	0	20	1.16	0	50	1.19	0
100	0	7.75	200	0	8.29			
100	0.31	7.68	200	0.32	8.26			
100	0.49	7.57	200	0.5	8.19			
100	0.62	7.29	200	0.64	7.73			
100	0.72	7.01	200	0.74	7.32			
100	0.8	6.52	200	0.82	6.84			
100	0.87	5.9	200	0.89	6.26			
100	0.93	5.23	200	0.95	5.71			
100	0.99	4.72	200	1.01	5.19			
100	1.03	4.26	200	1.05	4.66			
100	1.08	3.78	200	1.1	4.1			
100	1.12	3.28	200	1.14	3.49			
100	1.15	2.44	200	1.18	2.69			
100	1.19	1.91	200	1.21	2.02			
100	1.22	0	200	1.24	0			