REPORT

Review of Coastal Hazard at North Byron Bay using a Probabilistic Approach

Presentation of Results

Client: North Byron Bay Resort Pty Ltd

Reference: PA1998-GWB-PM-RP-0003

Status: Final/P01.01

Date: 29 November 2019

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1 Introduction

1.1 Background

Planners North are developing a Planning Proposal on behalf of North Byron Bay Resort Pty Ltd for submission to Byron Shire Council in relation to land at North Byron Beach identified as: Lots 1 & 2 DP1215893; Lots 12 & 13 DP243218; and Lot 449 DP812102. The location of the subject land is shown in **Figure 1-1**.

Figure 1-1 Location of land subject to the Planning Proposal

An issue in finalising the Planning Proposal is the extent to which the identified land is subject to coastal hazard. Two assessments of coastal hazard undertaken to date that include coverage of the subject land are:

- the 1978 Byron Bay – Hastings Point Erosion Study prepared by the then NSW Department of Public Works (Department of Public Works, 1978). The findings of this study formed the basis of the hazard lines prepared in 1986 and included in Chapter 1 Part J of the Byron Development Control Plan 2010 (BDCP10); and
- the 2013 Byron Shire Coastline Hazards Assessment Update prepared by BMT WBM Pty Ltd for Byron Shire Council (BMT WBM, 2013). The findings of this study have not as yet been included in any updated coastal hazard planning controls for Byron Shire.

Since completion of the BMT WBM (2013) study, additional dates of vertical aerial photography were also available for interpretation to assess shoreline change, covering the period 2013 to 2019.

A meeting was held at Byron Shire Council (Mullumbimby) on 1 August 2019 to discuss preparation of a further update on the coastal hazard at the subject land, attended by officers of Byron Shire Council, the Department of Industry, Planning and Environment (DPIE) and the former Office of Environment and Heritage (OEH, now part of DPIE).

It was agreed at the meeting that the further update of coastal hazard should adopt a probabilistic approach whereby uncertainty can be better assessed, as noted in the *NSW Coastal Management Manual Part B: Stage 2 – Determine risks, vulnerabilities and opportunities* (State of New South Wales and Office of Environment and Heritage, 2019).

Royal HaskoningDHV (RHDHV) have applied a probabilistic approach for determination of coastal hazard at a number of sites in New South Wales. It was agreed that in the first instance RHDHV would prepare a short report outlining the proposed methodology for the probabilistic assessment and the proposed values for key parameters to input into probabilistic analysis, for review and agreement by parties at the meeting.

A report was subsequently prepared for review, dated 3 October 2019. Comments on this report were supplied to RHDHV by DPIE (Mr Ben Fitzgibbon) on 25 October 2019 and comprised a number of marked-up comments within the report and a number of comments included in the cover email.

The comments from DPIE were summarised by RHDHV in a Comments Register together with a response to each comment. The Comments Register was supplied to Planners North on 12 November 2019 for distribution to DPIE and Byron Shire Council.

A copy of the RHDHV report dated 3 October 2019 is included in this report in full as Attachment 1. It includes two Appendices:

- Appendix A – Technical Note Outlining Probabilistic Methodology; and
- Appendix B – a copy of a letter from RHDHV to Planners North dated 1 February 2019, which in particular sets out a review of the two previous assessments of coastal hazard undertaken at the site; namely Department of Public Works (1978) and BMT WBM (2013).

A copy of the Comments Register is included in Attachment 2.

This report presents the results of the probabilistic assessment of the coastal hazard at North Byron Bay. The report will inform the Planning Proposal being developed by Planners North.

The report assumes the reader is familiar with the RHDHV report dated 3 October 2019 (Attachment 1) and the Comments Register (Attachment 2), which should be read as background to this current report, and has a reasonable knowledge of Byron Bay and the terminology used in the assessment of coastal hazards.

1.2 Structure of the Report

The report is structured in the following way:

- Section 2 summarises the adopted values for the key parameters in the probabilistic analysis;
- Section 3 provides some notes on interpretation of the coastal hazard information; and
- Section 4 presents the results of the probabilistic analysis in graphical form. The information can also be made available in electronic form where required.

2 Summary of Adopted Values for Key Parameters

2.1 General

The key parameters for input to the probabilistic analysis are:

- underlying recession;
- recession due to sea level rise (includes projected amount of sea level rise and Bruun slope factor); and
- storm demand.

The adopted values are summarised in the following Sections 2.2, 2.3 and 2.4, together with brief discussion where relevant.

The pre-storm profile adopted in the analysis, as discussed in RHDHV (October 2019), is March 2019[1].

The planning periods adopted were as follows, in accordance with recommendations in the NSW Coastal Management Manual:

- immediate;
- 20 years (2040);
- 50 years (2070); and
- 100 years (2120).

The DPIE comments on the RHDHV October 2019 report made reference to the influence on coastal hazard of potential sequestration of sand into Belongil Creek under rising sea level (refer to Comments Register in Attachment 2). This particular matter is discussed below in Section 2.5.

2.2 Underlying Recession

A triangular distribution was adopted with the following bounding parameters:

- peak/modal value (best estimate): 0.5m/yr;
- minimum: 0.4m/yr (-20%); and
- maximum: 0.6m/yr (+20%).

It is noted that the above values are based largely on BMT WBM (2013). The following further points are made:

- the values apply to so-called ‘Scenario 1’ in BMT WBM (2013) which assumes the retention and maintenance of all existing coastal protection works and interim beach access stabilisation works along the Byron Bay Embayment. This is a conservative assumption for future underlying recession at North Byron Bay; and
- the peak/modal value (best estimate) set out BMT WBM (2013) actually reduced from 0.5m/yr to 0.45m/yr after 2050, ie. after a period of 30 years. This has not been considered in the current

[1] As noted in RHDHV (October 2019), the 2019 profile is less accreted than the 2018 profile, by some 50-60m^3/m above 0m AHD, hence adoption of the 2019 profile is likely to introduce some conservatism when combined with the adopted storm demand.

probabilistic analysis, thereby introducing some conservatism for the position of the coastal hazard beyond 2050.

2.3 Recession Due to Sea Level Rise

2.3.1 Projected Sea Level Rise

General

Three approaches have been taken:

- Approach 1 - adoption of the current Byron Shire Council sea level rise policy which is based on the DECCW Sea Level Rise Policy Statement 2009, but with adjustment of the sea level rise trajectory to account for the estimated actual sea level rise over the period 1990-2020 plus extension of the trajectory to 2120, refer **Figure 3-5** of RHDHV (October 2019)[2] in Attachment 1; and

- Approach 2 - adoption of selected sea level rise trajectories set out in IPCC (2013), as indicated below, increased by 10% to account for local variation in sea level rise along the east coast of Australia relative to the global mean plus extension of the trajectories to 2120, refer **Figure 3-6** of RHDHV (October 2019) in Attachment 1:
  - peak/modal trajectory: RCP 6.0 (high),
  - minimum trajectory: RCP 2.6 (low);
  - maximum trajectory: RCP 8.5 (high); and

- Approach 3 - adoption of sea level rise projections included in Kinsela et al (2017) which are also based on IPCC (2013).

In all cases the projections are ‘normalised’ to a zero sea level rise value at the start of the planning period of 2020.

The first approach based on the current Byron Shire Council sea level rise policy requires little further explanation.

It is useful, however, to briefly discuss the second and third approaches.

Approach 2 - based on IPCC (2013) – Figure 3-6 of RHDHV (October 2019)

In this approach the ‘low’ and ‘high’ descriptors above are considered by RHDHV to correspond to the 5th and 95th percentile values of sea level rise in IPCC (2013) which define the *likely* range within which sea level rise is predicted to lie for the particular scenario, eg. RCP 2.6, RCP 4.5, RCP 6.0, etc.

DPIE made several comments in relation to the proposed RHDHV approach based on IPCC (2013):

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[2] Council’s current sea level rise policy can be found at: http://www.byron.nsw.gov.au/Services/Environment/Climate-change/Adaption/Climate-Change-Strategic-Planning-Policy.
Benchmarks for future sea level rise are 0.4m at 2050 and 0.9m at 2100 relative to 1990. The Policy notes at Section 3.10 that Climate Change Parameters will be reviewed and/or updated upon receipt of more current scientific analysis.

- increasing the IPCC global estimates by 10% does not represent a formal position by the NSW Government;
- the values proposed are considered to cover only the 17th to 83rd percentile range (not the 5th to 95th percentile range); and
- consideration should be given to the 0th to 100th percentile ranges.

Application of an increase of 10% to the global values is considered a reasonable approach based on the information in IPCC (2013) and introduces some conservatism. It is an approach adopted in coastal management studies undertaken within the Local Government Areas of Eurobodalla Shire Council, Shoalhaven City Council and Sutherland Shire Council.

While RHDHV is prepared to be corrected, our reading of IPCC (2013) is that, firstly, the values adopted are for the 'likely' range of sea level rise which correspond to the 5th and 95th percentile values (not 17th and 83rd percentile values) and that, secondly, the IPCC have not quantified 0th to 100th percentile values. IPCC (2013) notes that ….. 'we are not able to assess a *very likely* range ….. because there is no assessment available of the *very likely* range for global mean SAT[3] change, and because we cannot robustly quantify the ice-sheet dynamical change which would give rise to larger values' (IPCC, 2013; p.1186).

The values adopted by RHDHV based on IPCC (2013) are considered reasonable, particularly when it is noted that:

- the peak/modal trajectory adopts the 'high' (95th percentile) projection for RCP 6.0 and not the mean (50th percentile)[4]; and
- projections have been increased by 10% relative to the global mean, as noted earlier.

Having said the above, for completeness, a third approach was considered in which projected sea level rise values at 2050 and 2100 are taken directly from Kinsela et al (2017).

Approach 3 - based on IPCC (2013) – Kinsela et al (2017)

Kinsela et al (2017) considered the *likely* range in IPCC (2013) to correspond to the 17th and 83rd percentiles (not the 5th and 95th percentiles). They then estimated the 0th and 100th percentile values for sea level rise at 2050 and 2100, by linear extrapolation, and adopted these values for probabilistic modelling. Consideration was given to the three emission pathways; RCP 2.6, RCP 4.5 and RCP 8.5.

It is not clear if the global sea level rise values were increased by 10% to account for local variation in sea level rise along the east coast of Australia.

Kinsela et al (2017) adopted a triangular distribution to describe the probability distribution for sea level rise at 2050 and at 2050 with the following bounding parameters[5]:

- at year 2050:
  - peak/modal value (best estimate): 0.22m,
  - minimum: 0.10m,

[3] SAT is surface air temperature.
[4] This corresponds to an increase of approximately 0.2m in the projected sea level rise at 2100 taken to be the peak/modal (best estimate) trajectory.
[5] These parameters are estimated in this report from Figure 7 in Kinsela et al (2017).

- maximum: 0.40m,

- at year 2100:
  - peak/modal value (best estimate): 0.66m,
  - minimum: 0.15m,
  - maximum: 1.2m.

RHDHV has fitted a curve (trajectory) to the above values by adding a set of values at 2010 using the same approach as that in Kinsela et al (2017). The trajectory has also been extended to 2120.

Summary

For illustration purposes the sea level rise trajectories for the three separate approaches have been plotted on the same graph as shown in **Figure 2-1**.

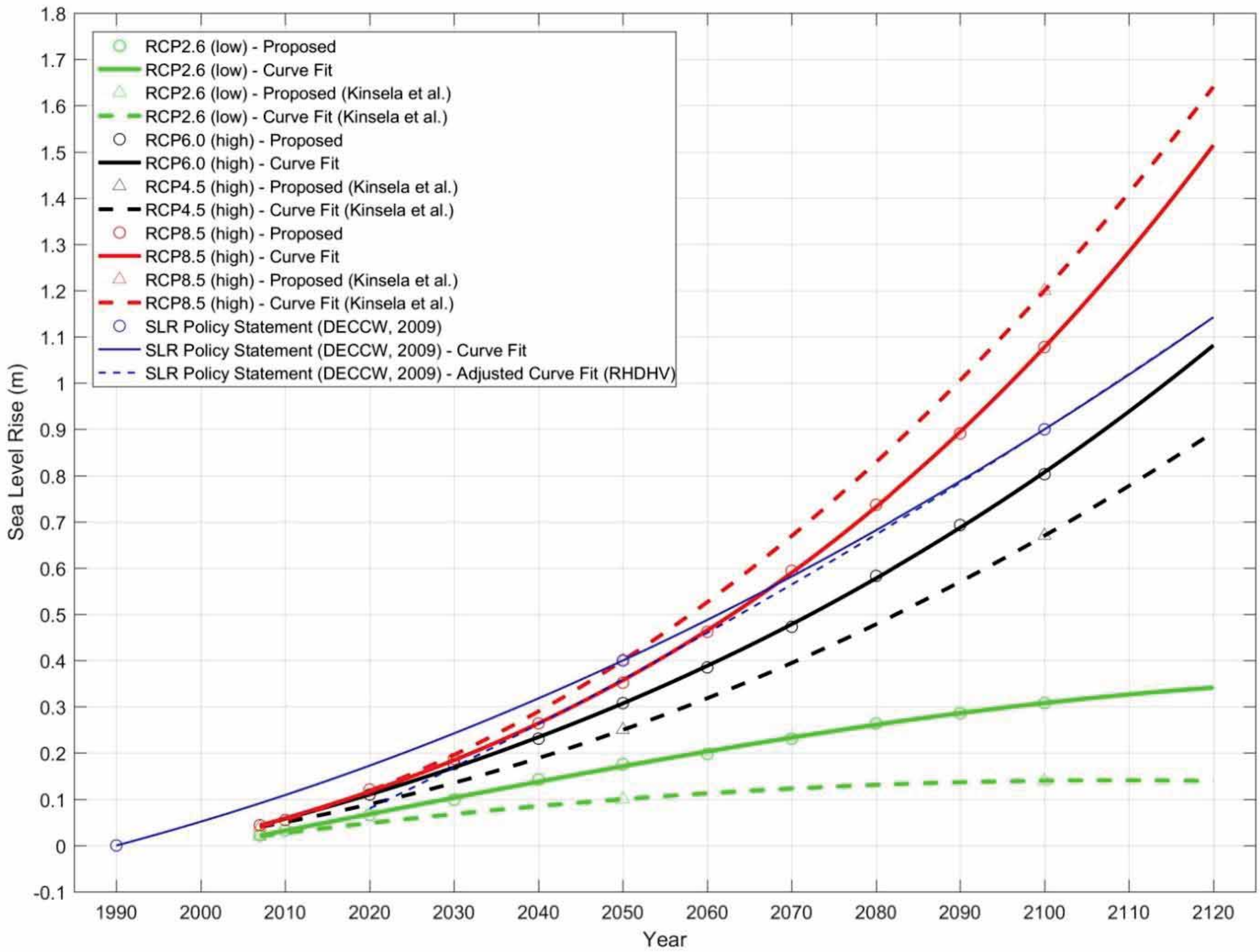

Figure 2-1 Sea level rise projections based on DECCW (2009), IPCC (2013) – RHDHV, and IPCC (2013) – Kinsela et al (2017)

2.3.2 Bruun slope factor

A triangular distribution was adopted with the following bounding parameters, which are based on a dune crest level of typically 8m AHD:

- peak/modal value (best estimate); 40:1;
- minimum: 32:1 (-20%); and
- maximum: 54:1 (+35%).

2.4 Storm Demand

Storm demand was based on the relationship developed by Gordon (1987), being a linear relationship between storm demand and the logarithm of ARI (read as AEP), for high demand (rip head) areas, adjusted such that the 100 year ARI event is set at 250m^3/m (increased from 220m^3/m), and extended to cover both more frequent events (1 year ARI) and rarer events (1000 year ARI), refer **Figure 3-7** of RHDHV (October 2019).

It is noted that the distribution adopted for storm demand is <u>not</u> a triangular distribution. It is similar to the gamma distribution described by Kinsela et al (2017) and referred to by DPIE (refer to Comments Register in Attachment 2).

2.5 Influence of Potential Sequestration of Sand into Belongil Creek under Rising Sea Level

DPIE raised the influence on coastal hazard of potential sequestration of sand into Belongil Creek under rising sea level based on the work of Kinsela et al (2017).

Kinsela et al (2017) considered that, under rising sea level, vertical growth (aggradation) of flood tide delta deposits in tidal inlets and estuaries could occur with sand sequestered from the adjacent beach and shoreface. This sand would represent a permanent loss to the beach and contribute to beach recession. The sand loss was noted to be a product of the sea level rise (S) over the particular planning period and the surface area of the submerged active flood tide delta deposits (A_D). The potential sand loss would be distributed along the length (l) of sandy shoreline within the sediment compartment.

Based on the above, the volumetric loss to the estuarine flood tide delta (V_E) per metre length of the compartment would be:

$$V_E = \frac{A_D \; x \; S}{l}$$

It was noted that the likely rates of flood tide delta response to sea level rise are uncertain and may be site specific. The implication is that the flood tide delta response to sea level rise may be slower (not instantaneous).

It is useful to put some dimensions to V_E to assess how significant the influence on coastal hazard of potential sequestration of sand into Belongil Creek under rising sea level could be.

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Belongil Creek is a small estuarine system and the area of the submerged active flood tide delta deposit (A_D) would be unlikely to exceed 40,000m^2. Taking a sea level rise value (S) of say 0.8m, corresponding to 80 years into the future at 2100, the product of A_D and S would be a sand loss of 32,000m^3 over 80 years.

Assuming the above sand loss is distributed over the active beach profile along a beach length of say 5km, the average shoreline recession would be less than 0.01m/yr. This may be compared to the best estimate of the underlying recession of 0.5m/yr (some 50 times higher).

Accordingly, the contribution to coastal hazard of the potential sequestration of sand into Belongil Creek under rising sea level is not considered significant. This contribution would be absorbed by the conservatisms in the probabilistic analysis introduced by:

- selection of the 2019 beach profile rather than the 2018 beach profile as the pre-storm profile, while maintaining a 100 year ARI storm demand at 250m^3/m (refer Footnote 1);
- adoption of a constant underlying recession of 0.5m/yr rather than reducing it to 0.45m/yr after 2050 (refer Section 2.2); and
- adoption of the ‘high’ (95th percentile) projection for RCP 6.0 and not the mean (50th percentile) projection as the peak/modal trajectory in the RHDHV approach (refer Section 2.3.1).

On the basis of the above, it is not considered necessary to make separate allowance for influence on coastal hazard of the potential sequestration of sand into Belongil Creek under rising sea level.

3 Notes on Interpretation of Coastal Hazard Information

3.1 General

There are several factors which should be taken into account in the interpretation of the coastal hazard lines presented in Section 4, namely:

- delineation of the hazard line;
- planning period versus design life of building structures; and
- probability of exceedance level for the hazard line.

These factors are discussed in the following sections.

3.2 Delineation of the Hazard Line

The means of delineation of the hazard line at a particular point in time, eg. the Zone of Wave Impact (ZWI), Zone of Slope Adjustment (ZSA) or Zone of Reduced Foundation Capacity (ZRFC), affects the position of the hazard line 'on the ground'.

The hazard lines presented in Section 4 correspond to the landward edge of the ZSA, so as to be consistent with the approaches in Department of Public Works (1978) and BMT WBM (2013).

3.3 Planning Period versus Design Life of Building Structures

The hazard lines are presented for four different planning periods:

- immediate;
- 20 years (2040);
- 50 years (2070); and
- 100 years (2120).

Consideration of design life is important in the siting and design of building structures. Horton and Britton et al (2014) have considered, based on a range of factors, that a design life of 60 years was reasonable for residential structures in a developed area.

3.4 Probability of Exceedance Level for the Hazard Line

The hazard lines have been determined probabilistically, hence an exceedance level can be assigned to the hazard lines as drawn. Two exceedance levels have been considered:

- 1% exceedance, meaning that there is a 1% chance the hazard line as drawn could be further landward for the given planning period (or, put another way, there is 99% certainty the hazard line is not further landward); and

- 5% exceedance, meaning there is a 5% chance the hazard line as drawn could be further landward for the given planning period (again, put another way, there is 95% certainty the hazard line is not further landward).

4 Results of the Probabilistic Analysis

The results of the probabilistic analysis are presented in a series of Figures from **Figure 4-1** to **Figure 4-12**. The results proposed for adoption in the Planning Proposal are those shown in **Figures 4-11** and **4-12**:

- **Figures 4-1, 4-2, 4-3** and **4-4**:
  showing the Immediate, 20 years (2040), 50 years (2070) and 100 years (2120) coastal hazard (position of ZSA) respectively, at the 1% exceedance level, including each of the three approaches to consideration of projected sea level rise[6];

Figure 4-1 Immediate coastal hazard (ZSA), 1% exceedance level

[6] *In all Figures the various approaches are referred to as follows:*
- *Approach 1 – 'SLR based on DECCW (2009) – RHDHV (2019)'*
- *Approach 2 – 'SLR based on IPCC (2013) – RHDHV (2019)'*
- *Approach 3 – 'SLR based on IPCC (2013) – Kinsela et al (2017)'*

Where SLR means sea level rise.

Figure 4-2 Year 20 (2040) coastal hazard (ZSA), 1% exceedance level

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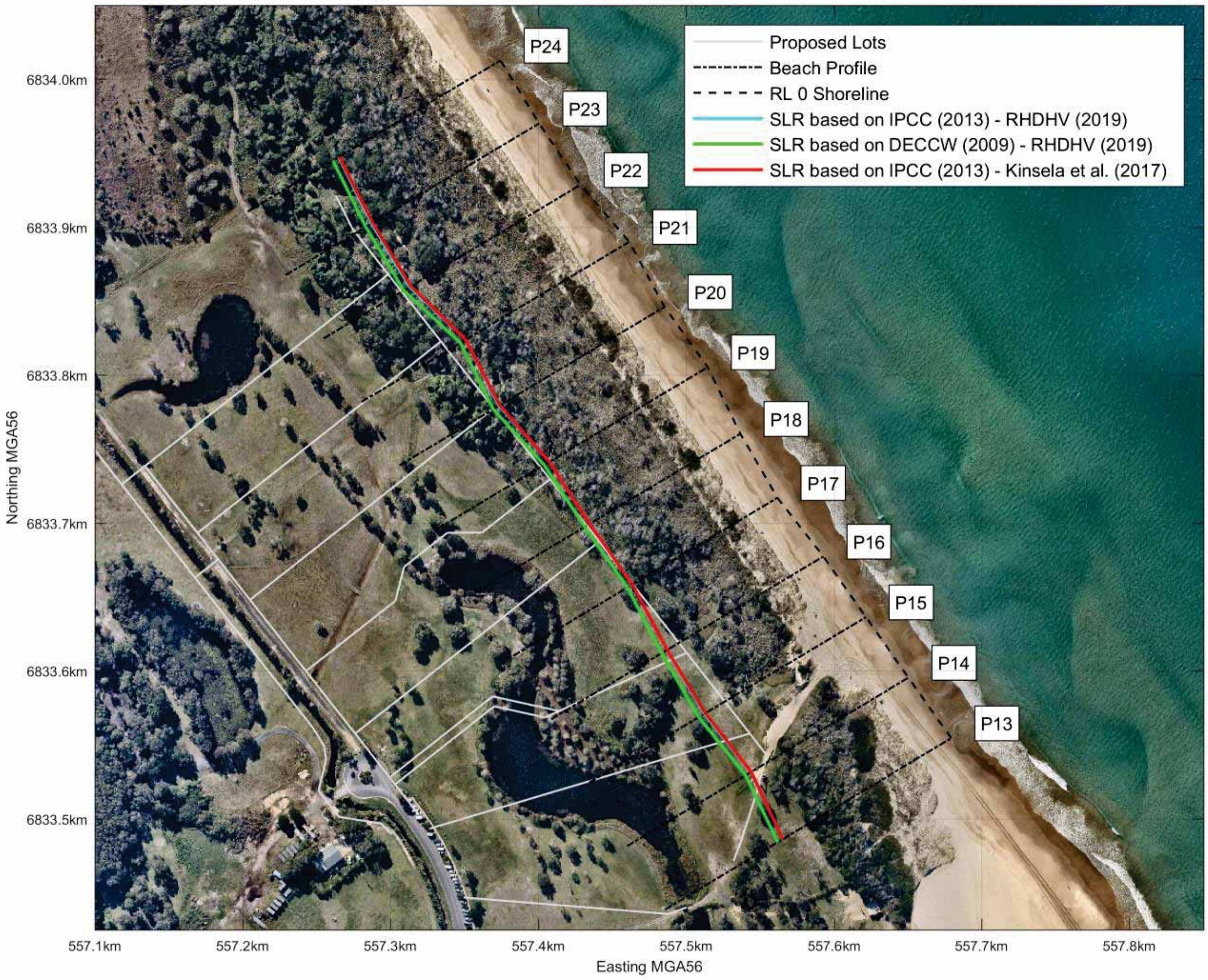

Figure 4-3 Year 50 (2070) coastal hazard (ZSA), 1% exceedance level

Figure 4-4 Year 100 (2120) coastal hazard (ZSA), 1% exceedance level

- **Figures 4-5, 4-6, 4-7** and **4-8**:
  as above for **Figures 4-1** to **4-4** but at the 5% exceedance level;

Figure 4-5 Immediate coastal hazard (ZSA), 5% exceedance level

Figure 4-6 Year 20 (2040) coastal hazard (ZSA), 5% exceedance level

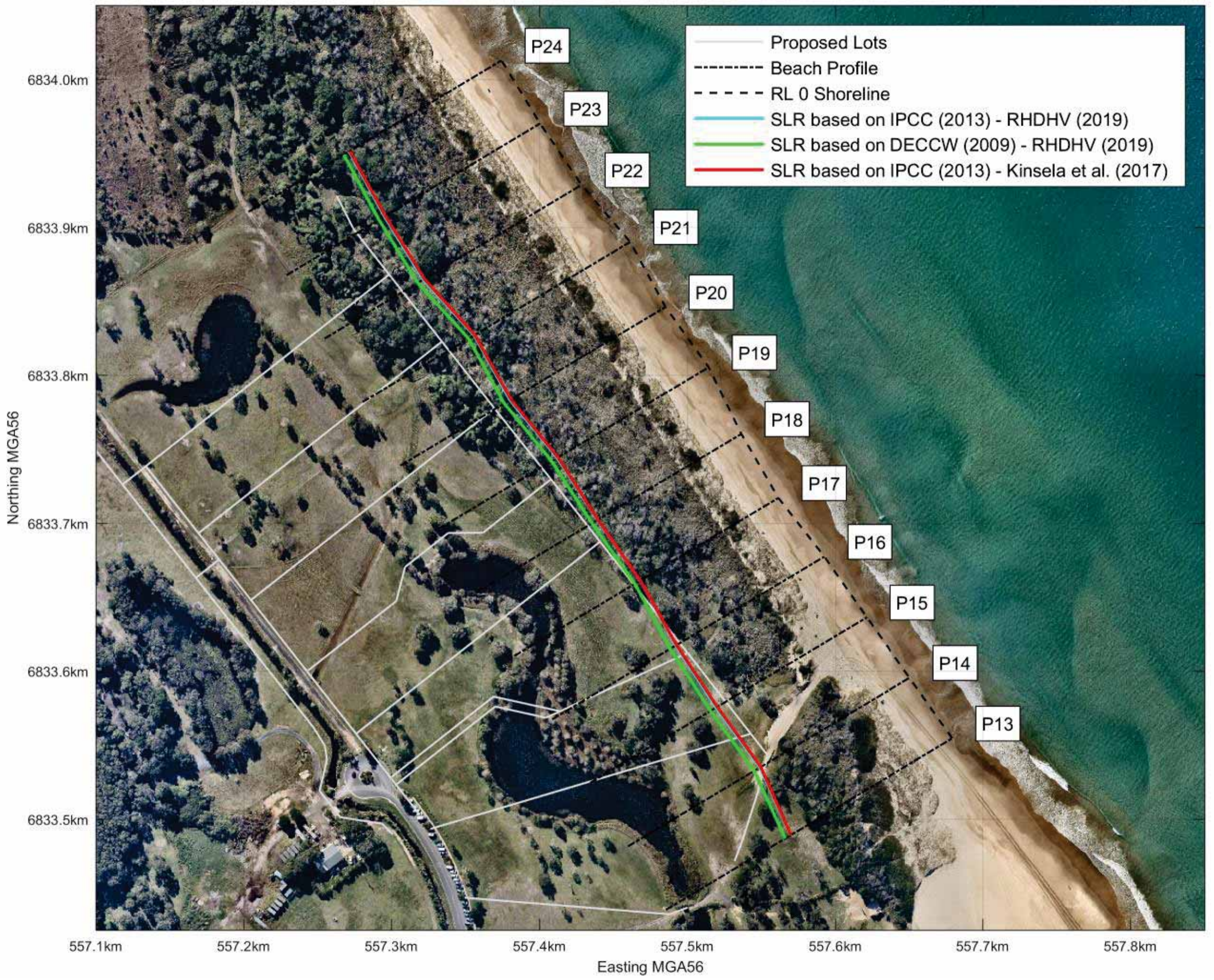

Figure 4-7 Year 50 (2070) coastal hazard (ZSA), 5% exceedance level

Figure 4-8 Year 100 (2120) coastal hazard (ZSA), 5% exceedance level

The following comment can be made at this point on the basis of the results shown in **Figures 4-1** to **4-8**:

- the coastal hazard at 20 years (2040), 50 years (2070) and 100 years (2120) are in a similar position irrespective of whether Approach 1, Approach 2 or Approach 3 is adopted for projected sea level rise, at both the 1% and 5% exceedance levels.

This is useful in that the coastal hazard is relatively insensitive to any decision on projected sea level within the realms of Approach 1, Approach 2 and Approach 3.

- **Figure 4-9**:
  showing the coastal hazard (position of ZSA) at 2050 at the 1% and 5% exceedance levels for comparison to the 2050 hazard line in BMT WBM (2013)[7]. To avoid clutter, a single hazard line at 2050 for the 1% and 5% exceedance levels is drawn, corresponding to Approach 2 for projected sea level rise;

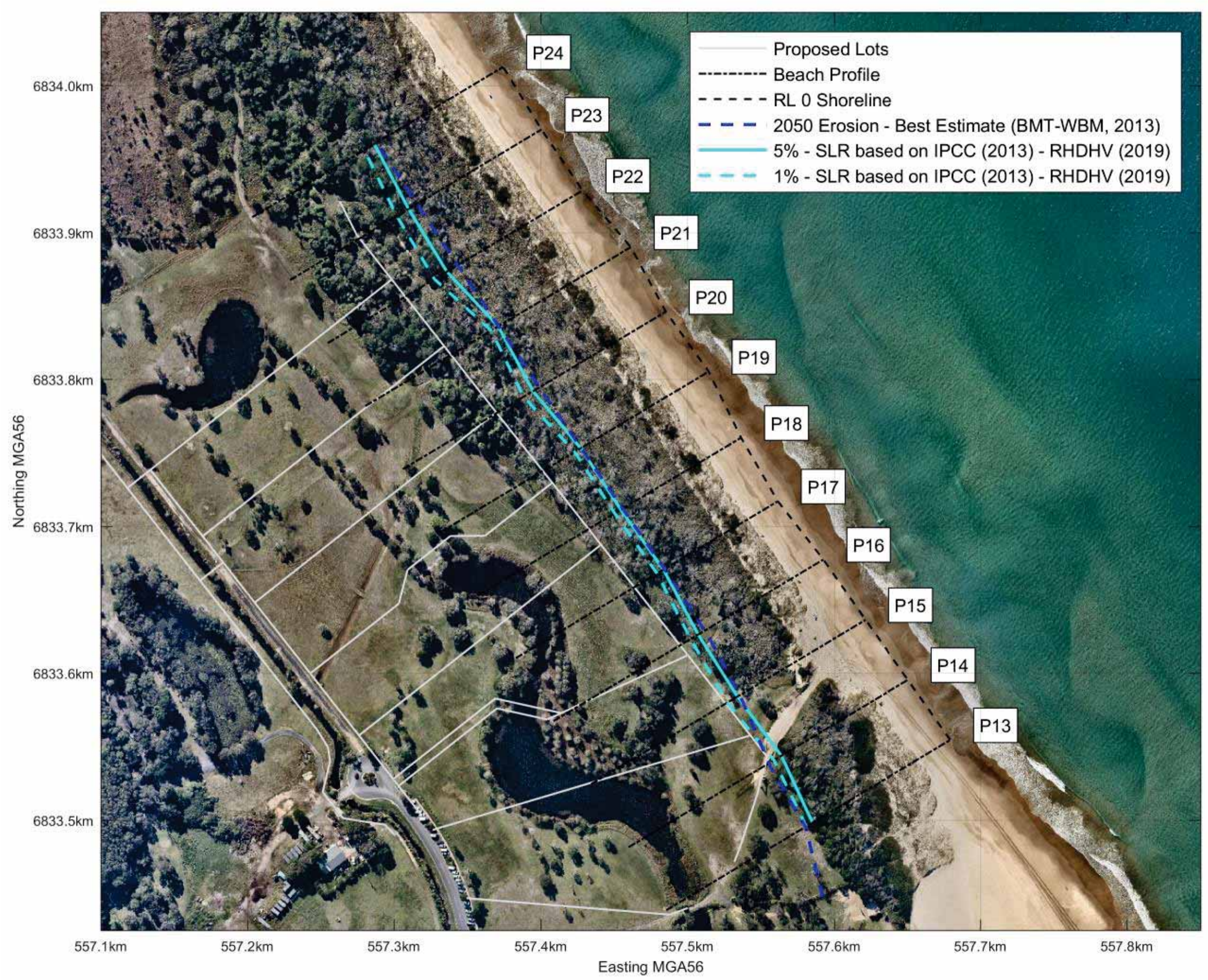

Figure 4-9 Year 30 (2050) coastal hazard (ZSA) comparison

[7] *The 2050 and 2100 hazard lines in BMT WBM (2013), for Scenario 1 (refer Section 2.2), were kindly supplied in electronic, georeferenced form, by Byron Shire Council.*

- **Figure 4-10**:
  showing the coastal hazard (position of ZSA) at 2100 at the 1% and 5% exceedance levels for comparison to the 2100 hazard line in BMT WBM (2013)[7]. Again, a single hazard line at 2100 for the 1% and 5% exceedance levels is drawn, corresponding to Approach 2 for projected sea level rise.

Figure 4-10 Year 80 (2100) coastal hazard (ZSA) comparison

The following comments can be made on the basis of the results shown in **Figures 4-9** and **4-10**:

- the coastal hazard at 2050, based on the probabilistic analysis, is generally slightly more landward (conservative) than the best estimate in BMT WBM (2013); and
- the coastal hazard at 2100, based on the probabilistic analysis, is similar to the best estimate in BMT WBM (2013).

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- Figure 4-11:
  Proposed for adoption in the Planning Proposal, being the coastal hazard (position of ZSA) at 50 years (2070) at the 1% and 5% exceedance levels, using Approach 1 for projected sea level rise. While the coastal hazard is similar irrespective of whether Approach 1, Approach 2 or Approach 3 is adopted for projected sea level rise, as noted earlier, Approach 1 is most aligned with Council's current sea level rise policy and has been selected for this reason. Both the 1% and 5% exceedance levels results are shown to inform the decision making.

Figure 4-11 Year 50 (2070) coastal hazard (ZSA) at the 1% and 5% exceedance levels

- **Figure 4-12**:
  Proposed for adoption in the Planning Proposal, as above for **Figure 4-11** but at 100 years (2120).

Figure 4-12 Year 100 (2120) coastal hazard (ZSA) at the 1% and 5% exceedance levels

5 References

BMT WBM (2013), '*Byron Shire Coastline Hazards Assessment Update*', prepared for Byron Shire Council, Final Report, R.B19093.001.03.docx, September 2013

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Gordon, AD (1987), '*Beach Fluctuations and Shoreline Change – NSW', Preprints of Papers, 8th Australasian Conference on Coastal and Ocean Engineering, Launceston*, 30 November to 4 December, Institution of Engineers Australia National Conference Publication No 87/17, pp. 103-167

Horton, Peter; Britton, Greg; Gordon, Angus; Walker, Bruce; Moratti, Mark; and Cameron, Daylan (2014), '*Drawing a Line in the Sand – Defining Beachfront Setbacks based on Acceptable Risk'*, 23rd NSW Coastal Conference.

Intergovernmental Panel on Climate Change (2013), '*Climate Change 2013, The Physical Science Basis, Working Group/Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change'*, [Stocker, TF; Qin, D; Plattner, G-K; Tignor, M; Allen, SK; Boschung, J; Nauels, A; Xia, Y; Bex, V and PM Midgley (editors)], Cambridge University Press, Cambridge, United Kingdom and New York, New York, USA

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Attachment 1 – RHDHV Report (3 October 2019)

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Figure 1-1 Location of land subject to the Planning Proposal

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A meeting was held at Byron Shire Council (Mullumbimby) on 1 August 2019 to discuss preparation of a further update on the coastal hazard at the subject land, attended by officers of Byron Shire Council, the Department of Industry, Planning and Environment (DPIE) and the former Office of Environment and Heritage (OEH, now part of DPIE).

It was agreed at the meeting that the further update of coastal hazard should adopt a probabilistic approach whereby uncertainty can be better assessed, as noted in the *NSW Coastal Management Manual Part B: Stage 2 – Determine risks, vulnerabilities and opportunities* (State of New South Wales and Office of Environment and Heritage, 2019).

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1.2 Structure of the Report

The report is structured in the following way:

- Section 2 summarises the key steps in the proposed probabilistic methodology. It includes reference to a more detailed technical note outlining the methodology included in **Appendix A**; and
- Section 3 summarises the proposed values for key parameters to be adopted in the probabilistic analysis. It includes reference to a more detailed discussion by RHDHV of parameter values previously considered in Department of Public Works (1978) and BMT WBM (2013), set out in a letter from RHDHV to Ms Kate Singleton of Planners North dated 1 February 2019, included in **Appendix B.**

The report assumes the reader has a reasonable knowledge of Byron Bay and the terminology used in the assessment of coastal hazards.

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2 Methodology for Probabilistic Assessment of Coastal Hazard

Traditionally, coastal hazard assessments in NSW have been undertaken using a deterministic approach. In this approach, each parameter that is an input to calculation of the hazard, eg. design storm demand, sea level rise (SLR) projection, etc. is assigned a single value. The single value is typically a conservative estimate for the parameter.

In the probabilistic approach, each input parameter is allowed to vary randomly according to an appropriate probability distribution function. The randomly sampled parameters are then repeatedly combined in a process known as Monte Carlo simulation. All outputs of the Monte Carlo simulation are collected to develop a probability curve for the shoreline position at the end of a particular adopted planning period.

In the probabilistic approach applied by RHDHV, the Monte Carlo simulation involves one million values of a parameter for each year of the planning period.

The three key input parameters to the probabilistic analysis are:

- shoreline recession due to net sediment loss (sediment budget differential), sometimes referred to as ‘underlying recession’;
- sea level rise and the recession in response to sea level rise; and
- event based erosion due to storm activity – referred to as ‘storm demand’.

The methodology for the probabilistic approach is set out in a technical note in Appendix A. Some general points are noted below:

- where an input parameter can vary randomly but has a distribution that is not fully known, a triangular distribution is typically assigned for the parameter. The triangular distribution is defined by a minimal value, a maximum value, and a peak/modal value (most likely or best estimate value). The peak/modal value does not need to be equidistant between the minimum and maximum values hence a skewness can be assigned to the probability distribution. The triangular distribution is depicted in **Figure 2-1**;
- recession due to sea level rise is estimated based on application of the Bruun rule, which requires an estimate of the magnitude of sea level rise and the inverse of the average beach slope extending to the depth of closure. For the Monte Carlo simulations, both of these parameters (sea level rise and inverse beach slope) are defined by separate triangular probability distributions;
- in the case of sea level rise, the minimum, maximum and modal values in successive years over a given planning period are set so that they follow a specified trajectory, eg. an International Panel for Climate Change (IPCC) concentration pathway, hence random sea level rise <u>trajectories</u> are generated in the Monte Carlo simulations in the case of sea level rise;
- the total long-term recession at each year is calculated by simply summing the separate Monte Carlo results for underlying recession and for recession due to sea level rise for that year;
- in the case of storm demand, annual exceedance probabilities (AEP values) of storm demand are randomly sampled in each year of the planning period and then converted to a volume using empirical relationships. So-called ‘high demand’ (rip head) values for storm demand are adopted;
- storm demand volume is then converted to a setback distance using the methodology outlined in Nielsen (1992), allowing separate determination of Zone of Wave Impact (ZWI), Zone of Slope Adjustment (ZSA) and Zone of Reduced Foundation Capacity (ZRFC);

- the total setback for each zone (ZWI, ZSA, ZRFC) is calculated by adding the storm demand setback to the combined long-term recession, randomly, on a year by year basis;
- calculations are performed for each beach profile along a section of shoreline of interest (profiles generally established by a photogrammetric analysis); and
- it is assumed that the beach has recovered from the storm-driven erosion that occurs in a year at the beginning of the subsequent year[1].

A flow chart showing the methodology for the probabilistic assessment of coastal hazard is provided in **Figure 2-2**.

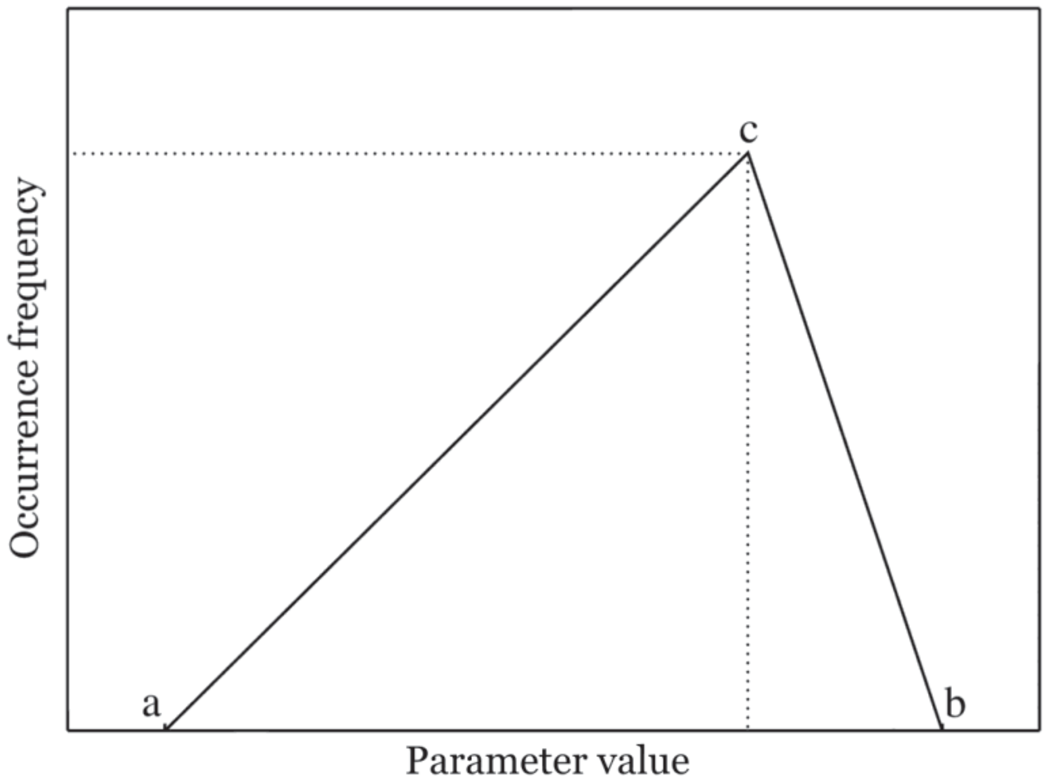

Figure 2-1 The probability density function of a triangular distribution

[1] This assumption is made to reduce computational effort, as the actual storm demand is a function of beach state. It would otherwise be necessary to continually track the beach state, including a recovery algorithm, and continually adjust the storm demand in response to beach state, particularly the larger values of storm demand (by reducing these values). Beaches in an eroded state have lower storm demands due to dissipation of wave energy on offshore bars formed during previous erosion events.

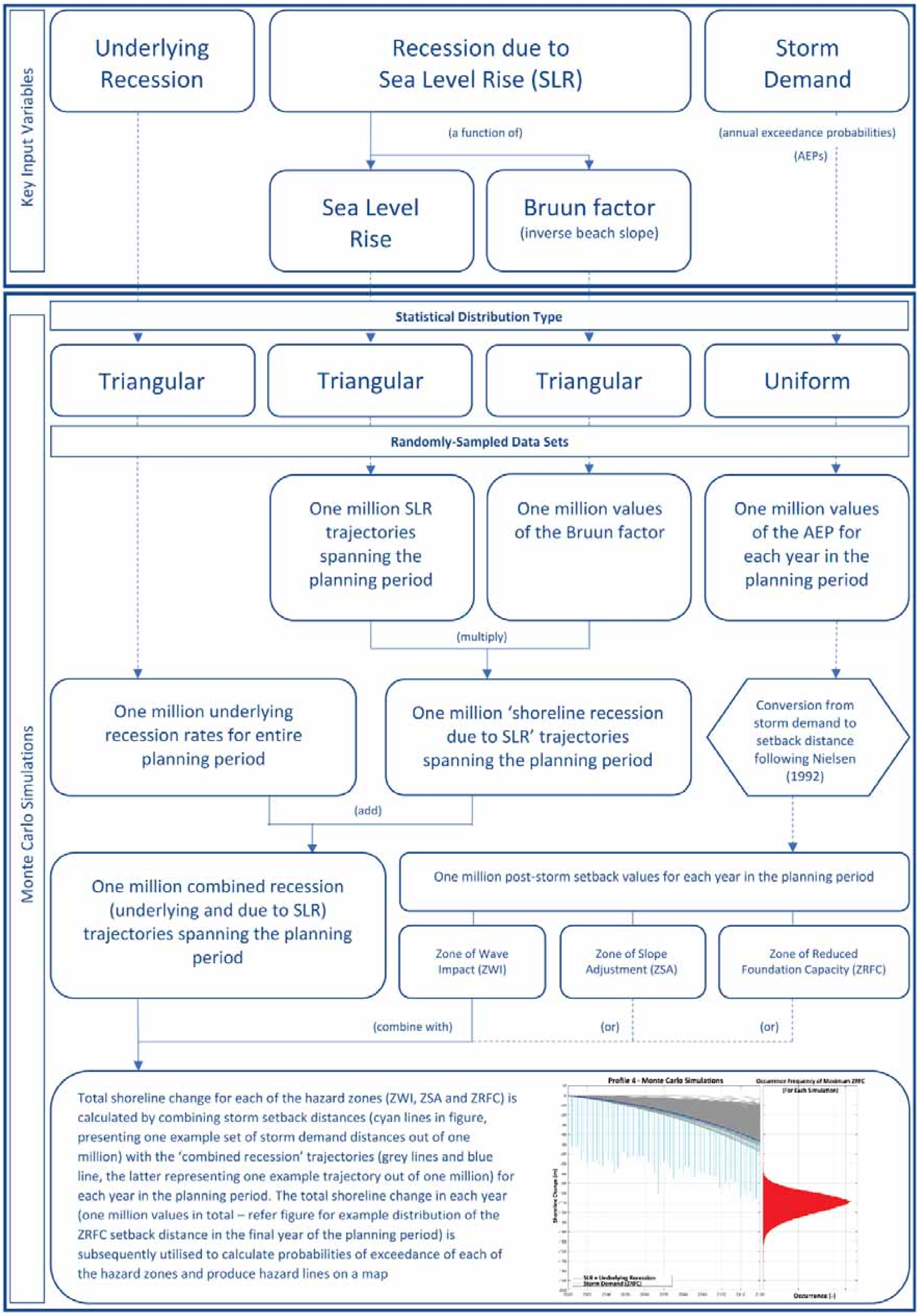

Figure 2-2 Flow chart for the probabilistic assessment of coastal hazard

3 Proposed Values for Key Parameters

3.1 General

The following sections set out the proposed values for the key parameters to adopt in the probabilistic analysis. Consideration of the proposed values has been based on the following information:

- the 1998 Byron Bay – Hastings Point Erosion Study (Department of Public Works, 1978);
- the 2013 Byron Shire Coastline Hazards Assessment Update (BMT WBM, 2013);
- additional photogrammetric data available since completion of the BMT WBM (2013) study, covering the period 2013 to 2019[2]; and
- experience of the writer.

As noted in **Section 1.2**, a more detailed discussion of parameter values previously considered in Department of Public Works (1978) and in BMT WBM (2013) is set out in a RHDHV letter to Planners North dated 1 February 2019, included in **Appendix B**. The reader is referred to **Appendix B** for more detail. Only a summary of the parameter values from these previous studies is provided in this section.

It is also necessary to select the pre-storm profile upon which to apply the shoreline recession and storm demand, and to select the planning period(s).

3.2 Pre-Storm Profile

Selection of the pre-storm profile upon which to apply the shoreline recession and storm demand is important as this influences the ultimate position of the future coastal hazard.

In selecting the pre-storm profile the aim should be to adopt a relatively accreted beach profile, typically referred to by the writer as an 'average beach full' profile, as the high storm demands selected in hazard assessments can only be realised in practice if accreted profiles exist (as noted in Footnote 1, in the situation of eroded profiles there are large quantities of sand in offshore bars which dissipate wave energy giving lower storm demands). The selected pre-storm profile should also, ideally, be a 'real' profile (not synthesized) and be contemporary, i.e. recent.

Figure 3-1 and **Figure 3-2** show beach profiles available from the NSW Beach Profile Database at Profile 18 and Profile 21 respectively for the years 2012, 2013, 2016, 2018 and 2019. The locations of the profiles are shown in **Figure 3-3**. The trends evident in **Figure 3-1** and **Figure 3-2** are representative of all the beach profiles 15 to 24 over the period 2012-2019.

Firstly, it is evident that the 2016 beach profile is not suitable for adoption due to the surface 'noise' in the profile[3]. Selection of a suitable pre-storm profile is between the dates of 2018 and 2019. The 2019 profile is less accreted than the 2018 profile, by some 50-60 m^3/m above 0m AHD, hence its adoption would be more conservative. This conservatism could be considered in selection of the storm demand values to adopt in the probabilistic assessment.

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[2] Specifically, this comprises photogrammetric data available from the NSW Beach Profile Database for Block C at Byron Bay, Profiles 15 to 24 north of the influence of Belongil Creek entrance area, for years 2013, 2016, 2018 and 2019. For completeness, profiles from 2012 are also considered.
[3] The 2016 profile was derived by LiDAR and it is apparent the laser has reflected off vegetation.

Adoption of the 2019 profile is proposed.

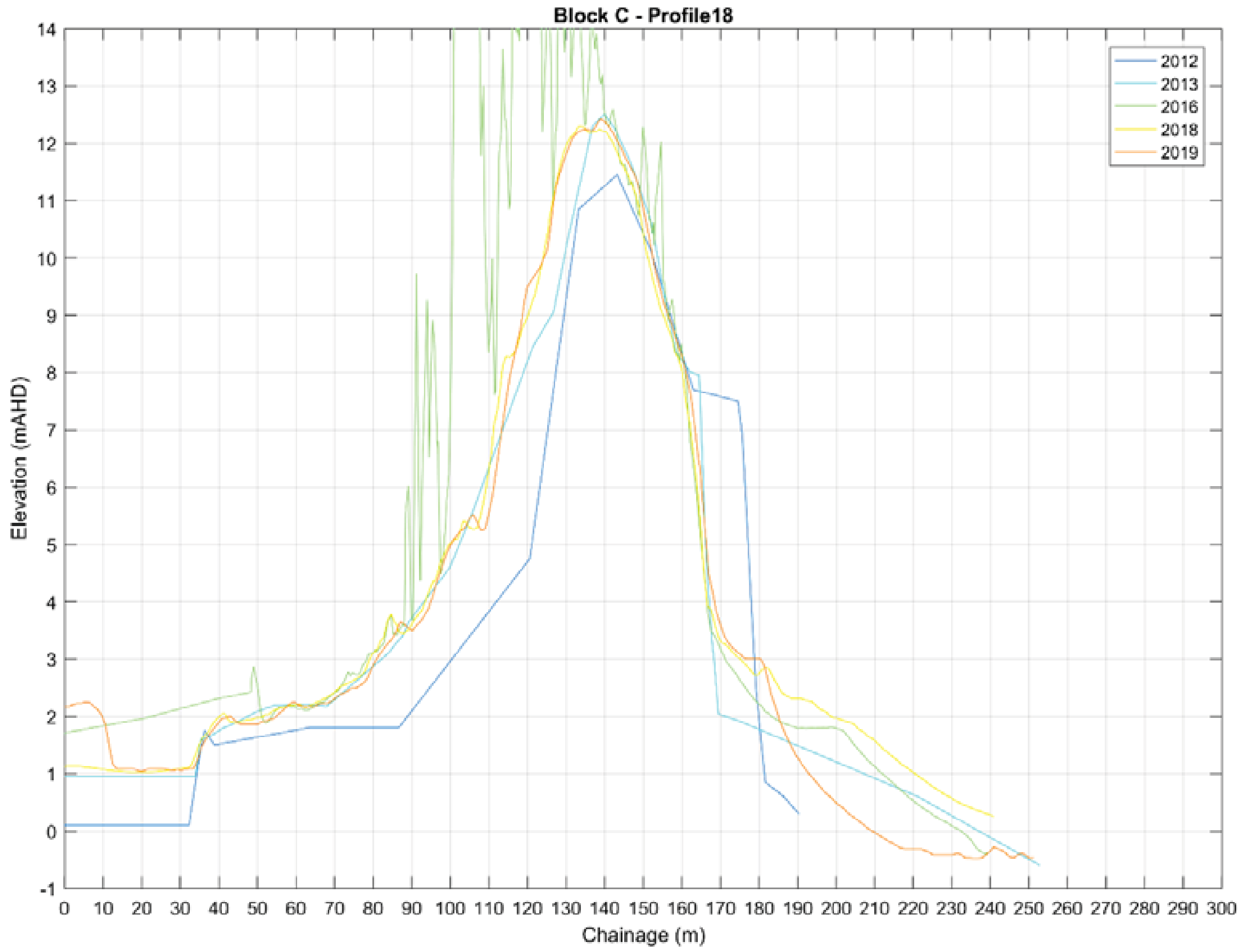

Figure 3-1 Beach profiles at Profile 18 for the period 2012-2019

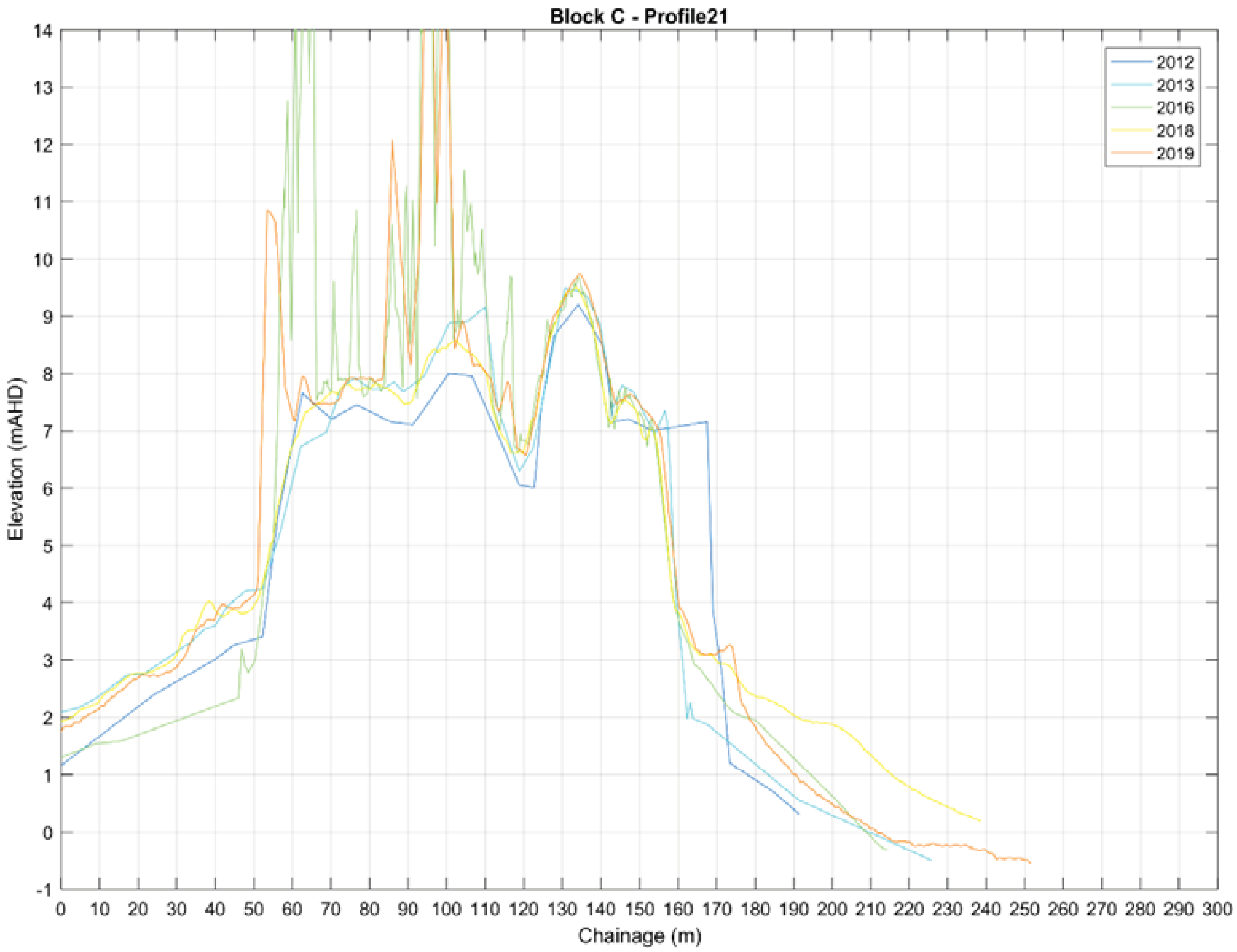

Figure 3-2 Beach profiles at Profile 21 for the period 2012-2019

Figure 3-3 Profile locations in Block C, Byron Bay adjacent to subject site

3.3 Planning Period

In discussions with officers of Council and DPIE at Mullumbimby on 1 August 2019 it was agreed that planning periods of 50 years and 100 years should be adopted for assessment of coastal hazard. As such, it is proposed the coastal hazard is determined at years 2070 and 2120. It is also possible to determine the hazard at any intermediate date. In terms of the actual development of the land, the accepted typical life of building structures also needs to be considered.

3.4 Underlying Recession

Department of Public Works (1978)

- average annual recession rates over the period 1947 to 1977 were assessed as approximately 1m/yr;
- 50-year and 100-year hazard lines appeared to be based on an adopted average annual recession rate of 2m/yr; and
- the above values can be shown to be unduly conservative.

BMT WBM (2013) (Scenario 1[4])

[4] *BMT WBM (2013) determined hazard lines for two erosion hazard scenarios:*

- *Scenario 1: Retention and permanent maintenance of all existing coastal protection works and interim beach access stabilisation works along the Bryon Bay Embayment; and*

- 0.5 m/yr for the period 2010 to 2050;
- 0.45 m/yr for the period 2050 to 2100.

The above values were considered by BMT WBM to be ‘best estimates’. In recognition of the uncertainty inherent in modelling future shoreline behaviour and/or factors that are difficult to quantify, maximum and minimum values were also determined by applying factors of +20% and -20% respectively to the ‘best estimate’ values.

Beach profiles 2012-2019

Beach profiles 15 to 24 over the period 2012-2019 show the following characteristics:

- significant landward translation of the face of the frontal dune between 2012 and 2013, up to approximately 13 m at the 5 mAHD level. This is presumably related to the ocean storm event in February 2013 where the offshore significant wave height recorded at the Byron Bay Waverider buoy exceeded 5 m for more than 24 hrs;
- there was little change to the position of the face of the frontal dune from 2013 to 2019; and
- total sand volume above 0 m AHD showed little net change over the period 2012-2019; losses in the upper face of the frontal dune were generally compensated by gain (recovery) in the lower beach berm between 0 m AHD and approximately 3 m AHD.

Based on the beach behaviour observed over the seven-year period 2012-2019 it is not considered necessary to revise the underlying recession rate determined by BMT WBM based on their analysis of the 65-year period 1947-2012 and their predictive modelling.

Proposed values

The following three values are proposed for the underlying recession rate, according to the triangular distribution:

- peak/modal value (best estimate): 0.5 m/yr;
- minimum: 0.4 m/yr (-20%); and
- maximum: 0.6 m/yr (+20%).

3.5 Recession due to Sea Level Rise

Department of Public Works (1978)

Sea level rise was not considered in the 1978 study.

BMT WBM (2013)

- magnitude of sea level rise was adopted as per Council policy which is based on DECCW (2009), namely; 0.4 m at 2050 and 0.9 m at 2100, both relative to 1990. These two values became 0.34m

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- *Scenario 2: Retention of only the Jonson Street protection works and removal of all other coastal erosion protection works and interim beach access protection works along the Byron Bay Embayment.*

Future shoreline recession in the subject area would be greater under Scenario 1 than Scenario 2. It is also considered more likely that Scenario 1 would prevail into the foreseeable future. For this reason it has been assumed Scenario 1 would apply, which is conservative for the subject area.

and 0.84m at 2050 and 2100 respectively when applied to the base year of 2010 adopted in BMT WBM (2013), based on advice from OEH at the time that the estimated sea level rise from 1990 to 2010 could be taken as 0.06m. This situation is depicted in **Figure 3-4**;

- best estimate Bruun slope factor was 45:1; lower and upper limits for the slope factor to allow for uncertainty were 36:1 (-20%) and 60:1 (+35%)[5];
- an EVO-MOD model approach was also used to estimate shoreline recession due to sea level rise and gave 'somewhat higher' recession than the Bruun Rule approach; and
- final allowances for shoreline recession due to sea level rise, relative to the 2010 beach profile, were 19 m at 2050 and 50 m at 2100.

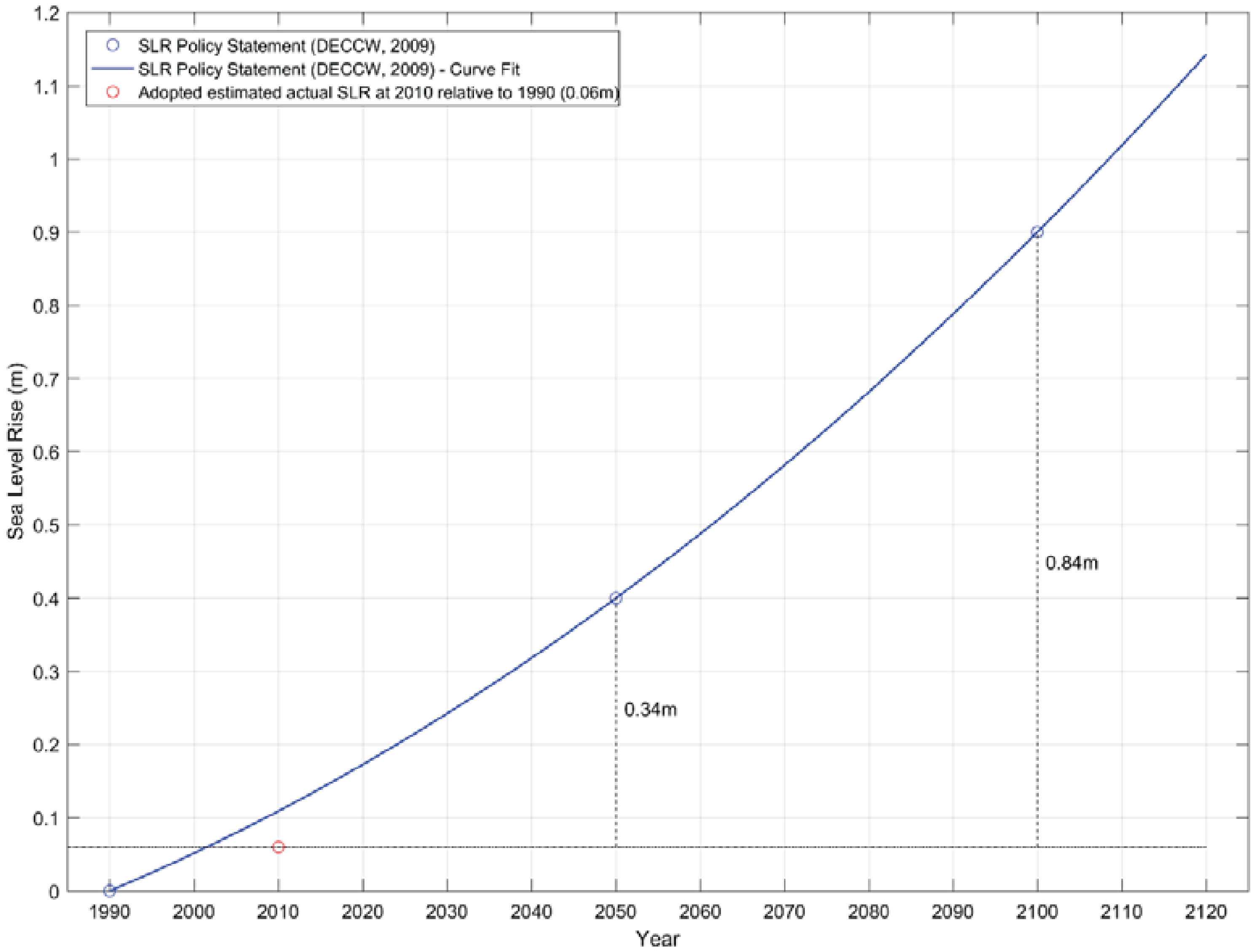

Figure 3-4 Sea level rise projections adopted by BMT WBM (2013)

<u>Beach Profiles 2012-2019</u>

The short period of additional beach profile dates 2012-2019 and short-term variability do not provide additional insight to sea level rise.

<u>Proposed Values</u>

It is understood from discussions with Mr Ben Fitzgibbon of DPIE that Council may continue to adopt a sea level rise policy based on DECCW (2009). If this is the case, it is considered that recognition needs to be given to the estimated actual sea level rise over the period 1990-2020. In addition to sea level rise projections based on DECCW (2009), it is considered that account should also be taken of the latest

[5] These slope factors were based on a dune crest level of 5 m AHD, which were considered appropriate for the typical exposed coastline parts of northern NSW and south-east Queensland. It was noted that the slope factor would be 'somewhat less' for higher dunes, for example a slope factor of 45:1 would become about 35:1 for 10 m dunes and 40:1 for 8 m dunes. Dunes in the subject area have a crest level in the range 6 m AHD to greater than 10 m AHD hence adoption of 45:1, with limits of 36:1 and 60:1 would introduce some conservatism.

global mean sea level rise projections provided in IPCC (2013). These two approaches are discussed further below.

In terms of sea level rise projections based on DECCW (2009), **Figure 3-5** shows the following:

- the original projection, namely 0.4m at 2050 and 0.9m at 2100 relative to 1990; and
- a curve of best fit projection accounting for an estimated actual sea level rise over the period 1990-2020 of 0.08m and retaining the projections of 0.4m at 2050 and 0.9m at 2100[6].

It is evident from **Figure 3-5** that a best fit sea level rise trajectory would be somewhat less than 0.4m at 2050, relative to 1990, compared to the original projection, as might be expected based on the estimates of actual sea level rise over the period 1990- 2020. A best fit trajectory could however still pass through 0.9m at 2100, relative to 1990.

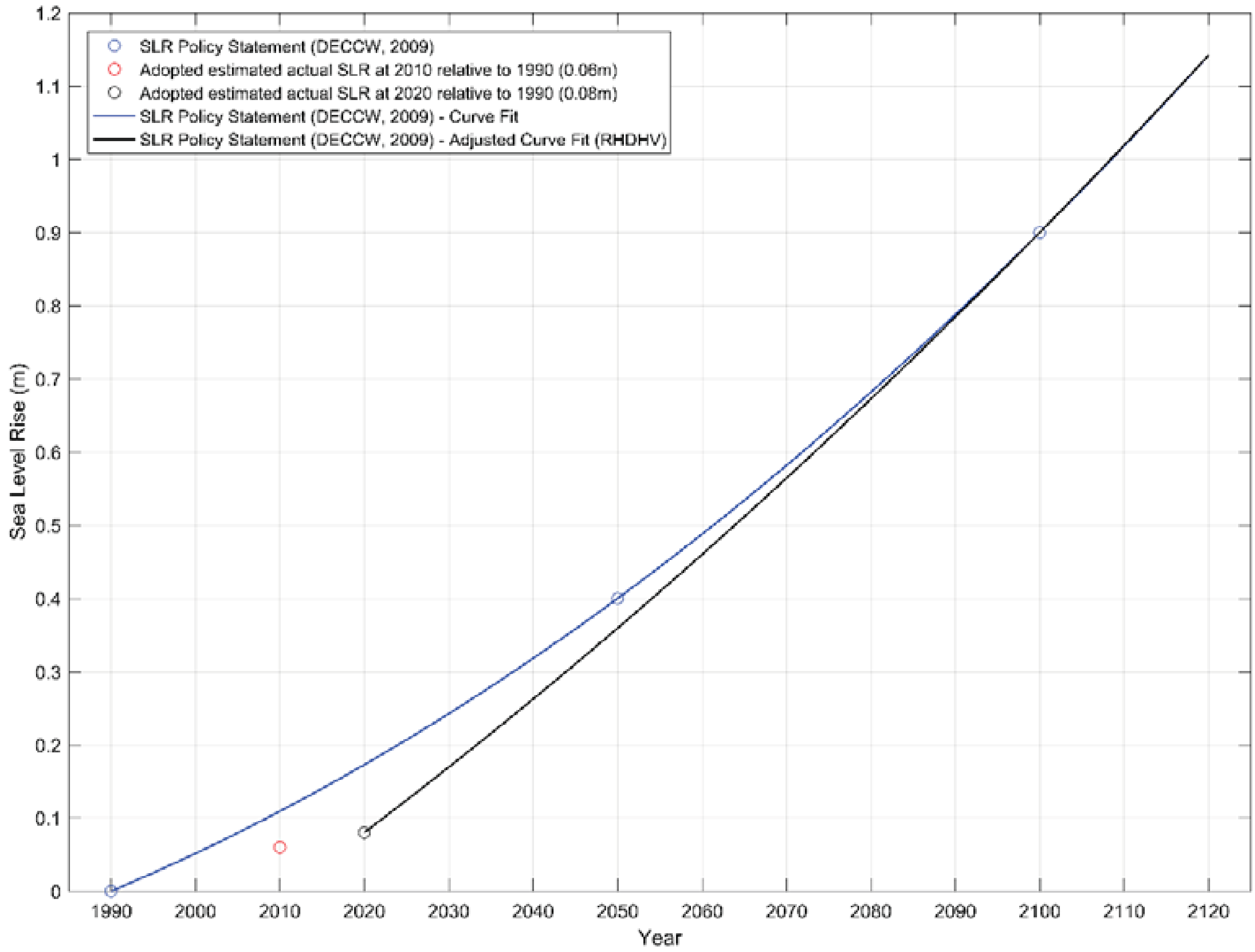

Figure 3-5 Original sea level rise projection in DECCW (2009) and curve of best fit projection accounting for estimated actual sea level rise over the period 1990-2020, relative to 1990

IPCC (2013) provides global mean sea level projections for four representative concentration pathways (RCP) scenarios; namely RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5. For each scenario a median sea level rise value is provided along with a likely range, corresponding to the 5% and 95% percentile values, for future years up to 2100. Global plots of percentage deviation from the global sea level rise are also provided and indicate that the local variation along the east coast of Australia is up to 10% higher than the global trend.

[6]The estimated actual sea level rise of 0.08m is based on the value of 0.06m advised to BMT WBM by OEH and reported in BMT WBM (2013) and an estimate of 0.02m for the period 2010-2020 based on an average relative mean sea level rise determined from the Fort Denison tide gauge record over the decade 2007-2016 of 1.81mm ± 0.3mm/yr reported by Watson (2018).

IPCC (2013) global sea level rise projections, with adjustment of plus 10% to account for local variation in sea level rise relative to the global mean, have been adopted, for example, by Eurobodalla Shire Council, Shoalhaven City Council and Sutherland Shire Council.

In a probabilistic assessment of coastal hazard recently (2018) carried out by RHDHV for a large parcel of coastal land in Sutherland Shire the following range of sea level rise trajectories were adopted, endorsed by the Council and the then OEH (all IPCC values increased by 10%):

- peak/ modal trajectory: RCP 6.0 (high);
- minimum trajectory: RCP 2.6 (low); and
- maximum trajectory: RCP 8.5 (high).

Adoption of the ‘high’ value within RCP 6.0 as the peak/modal trajectory is potentially conservative but was preferred by Council and OEH. The adoption of RCP 2.6 (low) and RCP 8.5 (high) for the minimum and maximum trajectories respectively represented a wide range of sea level rise projections but was agreed as reasonable given IPCC (2013) noted that all RCPs are considered plausible.

Figure 3-6 is a compilation of five different sea level rise projections or trajectories, comprising the two trajectories in **Figure 3-5** and the three trajectories referred to above. All trajectories are plotted relative to 1990 for comparison purposes but note that the sea level rise projections in IPCC (2013) are stated as relative to the relatively wide period of 1986-2005. From **Figure 3-6** it is evident that:

- the peak/modal trajectory of RCP 6.0 (high) from IPCC (2013), increased by 10%, is lower than the original projection in DECCW (2009) and the adjusted curve of best fit based on DECCW (2009) accounting for the estimated actual sea level rise over the period 1990-2020, thus indicating that IPCC sea level rise projections have lowered, at least for the period up to 2120; and
- the trajectory of RCP 8.5 (high) does exceed the original projections in DECCW (2009) and the adjusted curve of best fit based on DECCW (2009) after about 2060-2070, so that the probabilistic approach will randomly sample higher sea level rise values then in DECCW (2009) in the latter period of the simulations.

Due to the variability in sea level rise projections, it is proposed that the simulations consider both the adjusted curve of best fit based on DECCW (2009) as well as the projections based on the more recent IPCC (2013) scenarios. In each case the projections would be ‘normalised’ to a zero sea level rise value at the start of the planning period of 2020.

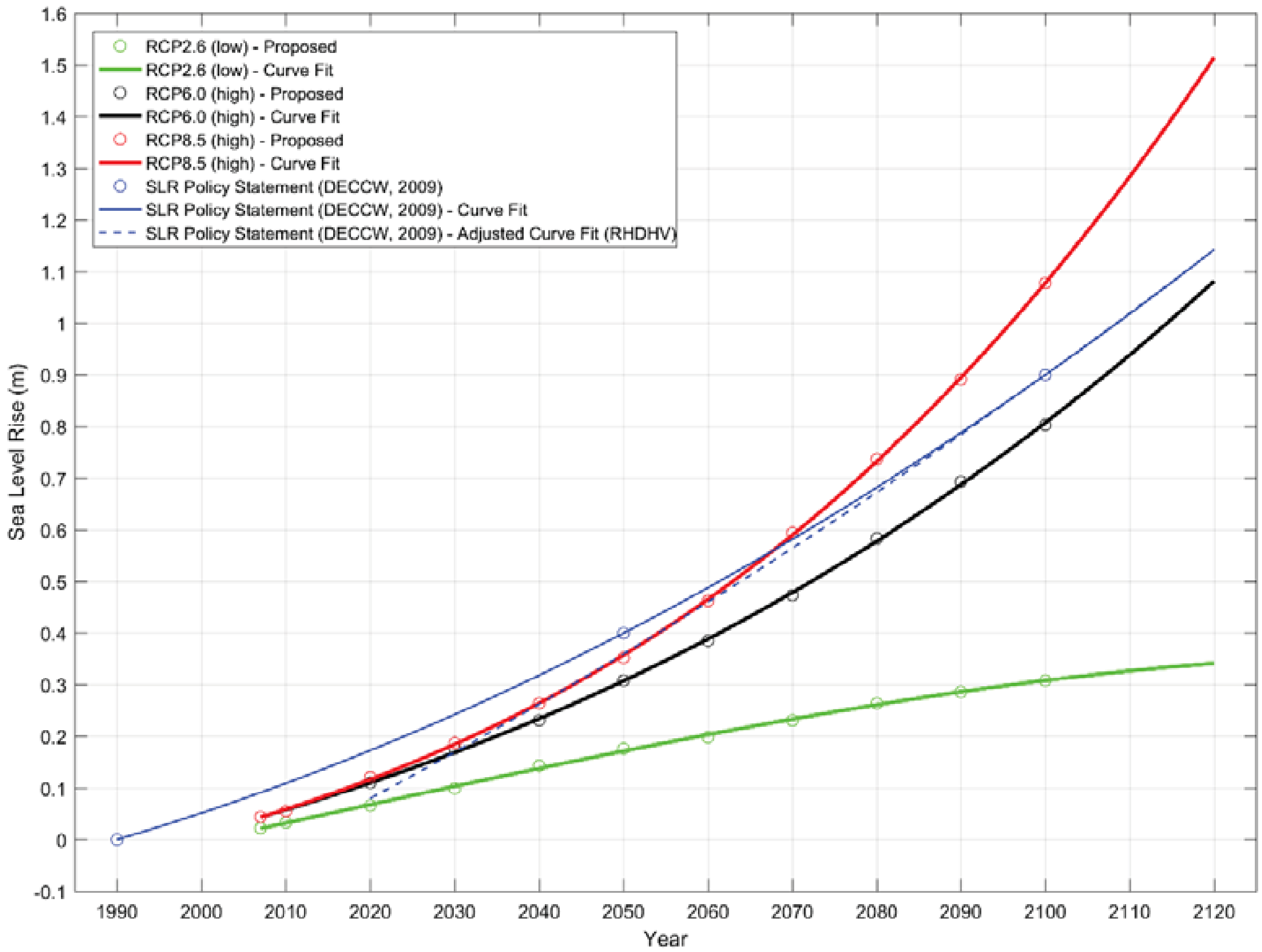

Figure 3-6 Sea level rise projections based on DECCW (2009) and IPCC (2013)

3.6 Storm Demand

<u>Department of Public Works (1978)</u>

- interpretation of storm demand was limited by the short period of record available and the location of the particular beach profile examined (located within the zone of influence of Belongil Creek); and
- no specific value in the form of m^3/m above 0m AHD was nominated.

<u>BMT WBM (2013)</u>

- a storm demand of $250m^3/m$ was adopted for the North Byron area; and
- an average recurrence interval (ARI) for this storm demand was not nominated but based on Gordon (1987) and the experience of the writer it would be approximately equal to the 100year ARI 'high' demand value at a rip head.

<u>Beach Profiles (2012-2019)</u>

Based on the beach behaviour observed over the seven year period 2012-2019 it is not considered necessary to revise the assessment of storm demand undertaken by BMT WBM.

<u>Proposed Values</u>

Based on measurements at NSW beaches, Gordon (1987) derived relationships between storm demand and average recurrence interval, in both 'high demand' (at rip heads) and 'low demand' (away from rip heads) areas. It was estimated by Gordon (1987) that the storm demand above 0m AHD was about 220m^3/m for the 100year ARI event, for exposed NSW beaches at rip heads, and that the relationship between storm demand and the logarithm of ARI could be considered linear.

It is proposed that the relationship developed by Gordon (1987) be adopted for estimation of storm demand values with the following adjustments:

- the storm demand for the 100year ARI event (high demand, rip head) is set at 250m^3/m, increased from 220m^3/m, as assessed in the analysis contained in BMT WBM (2013);
- the ARI values are re-expressed as annual exceedance probability (AEP) to facilitate the probabilistic methodology; and
- the range of ARI (AEP) is extended to cover both more frequent events (1year ARI) and rarer events (1000year ARI) than those considered in Gordon (1987). The extrapolation is based on a linear relationship between storm demand and the logarithm of ARI up to the 1000year ARI event, which is likely to be conservative (a downward concave 'tail' to the relationship is expected to be the most physically realistic).

The proposed relationship between storm demand and ARI/AEP, together with the original relationship in Gordon (1987), is shown in **Figure 3-7**.

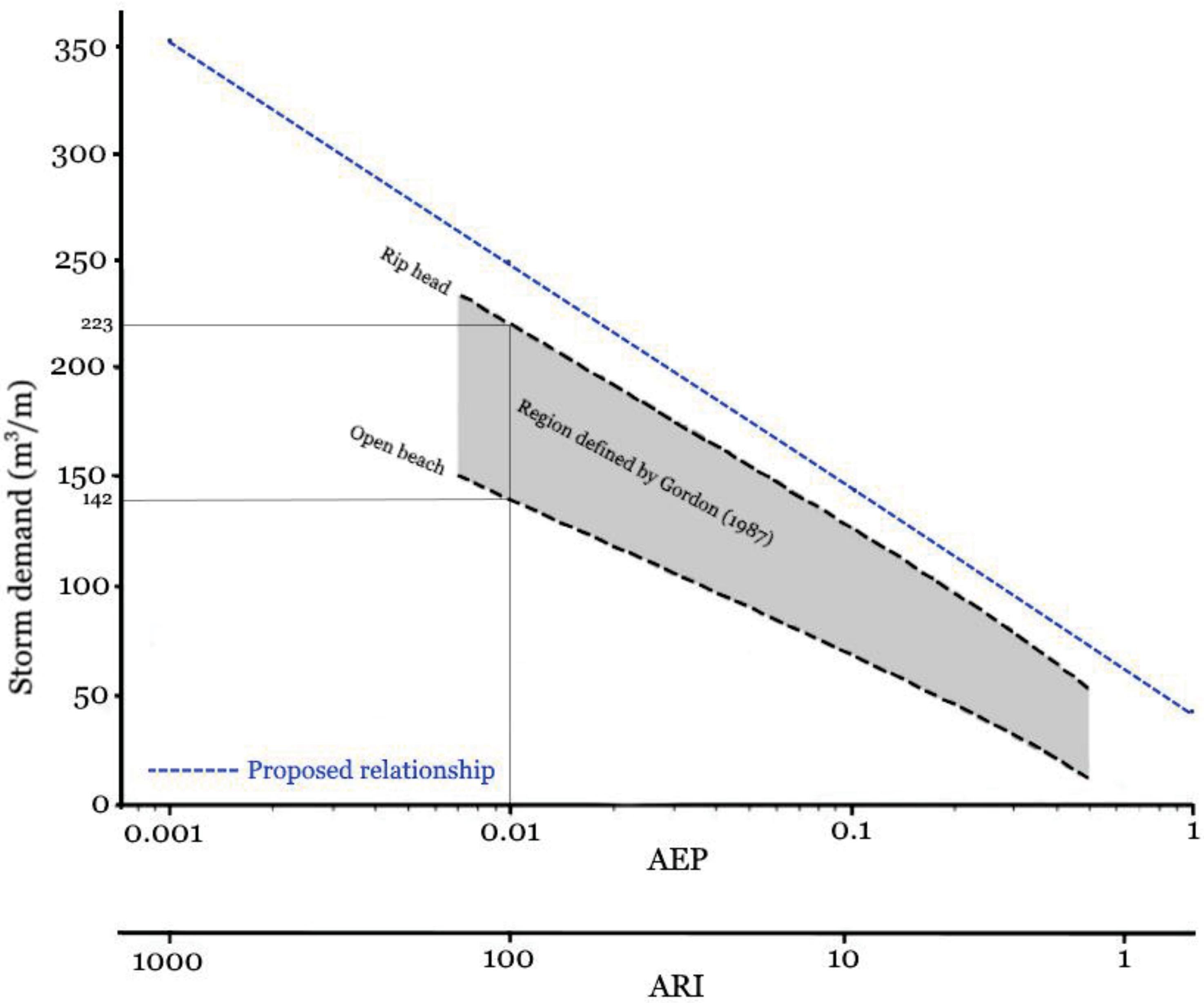

Figure 3-7 Relationship between storm demand and ARI/AEP

4 References

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Watson, P. J. (2018) How Well Do AR5 Sea Surface-Height Model Projections Match Observational Rates of Sea-Level Rise at the Regional Scale?, Journal of Marine Science and Engineering, Volume 6 Issue 1, published 1 February 2018.

Appendix A – Technical Note Outlining Probabilistic Methodology

Note / Memo

HaskoningDHV Nederland B.V.
Maritime & Aviation

Subject: **Probabilistic Coastal Hazard Assessment - Technical Note**
October, 2019

1 Introduction

Traditionally, coastal hazard assessments (CHAs) have been undertaken under a deterministic approach, whereby each input parameter is assigned a single value (e.g. 'design' storm demand, sea level rise (SLR) projection, etc.) with generally conservative estimates applied. A probabilistic approach allows each input parameter to vary randomly according to appropriate probability distribution functions. The randomly sampled parameters are repeatedly combined in a process known as Monte Carlo simulation. All outputs from the Monte Carlo simulation are collated to develop a probability curve for the shoreline position at the end of a planning period.

This technical note outlines in detail the methodology followed in the probabilistic approach incorporating a Monte Carlo analysis.

2 Probabilistic Input Parameters

The key input parameters in a probabilistic CHA typically comprise:

1. Shoreline movement due to sediment budget differentials – 'Underlying/Long-Term Recession';
2. Sea level rise and the shoreline recession in response to sea level rise – 'SLR Recession; and
3. Event-based erosion due to storm activity – 'Storm Demand'.

These key parameters and their assumed distributions are discussed below.

2.1 Long-Term Shoreline Recession

Underlying or long-term shoreline recession rates are typically estimated by analysis of a photogrammetry dataset for a particular beach spanning a sufficiently long time period. Rates of shoreline movement (for each beach profile) of an appropriate elevation contour position(s) are derived by linear regression. Alternatively, or in addition, rates of shoreline movement may be determined by assessment of volumetric change (for each beach profile) above 0m AHD derived by linear regression. Underlying shoreline recession rates typically vary spatially (i.e. within a beach compartment) and temporally (i.e. depending on the analysis period considered). In all cases the interpretation of underlying recession needs to be developed in the framework of a strong coastal processes understanding.

A triangular probability distribution, as a rough approximation of a random variable with unknown distribution, is used to generate a set of random long-term recession values (refer **Figure 1**). The triangular distribution is defined by a minimum (a), maximum (b) and peak/modal (most likely) value (c).

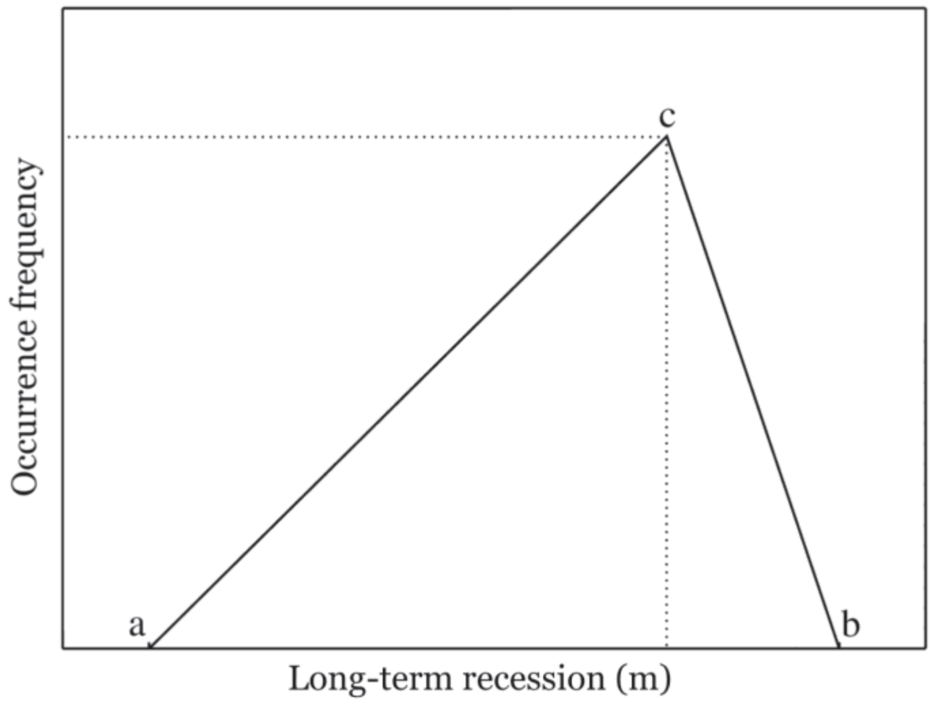

Figure 1 Triangular distribution - example probability density function

2.2 Shoreline Recession due to Sea Level Rise

SLR may result in shoreline recession due to re-adjustment of the beach profile to the new coastal water levels. Bruun (1962; 1983) proposed a methodology to estimate shoreline recession due to SLR, the so-called *Bruun Rule*. The Bruun Rule is based on the concept that SLR will lead to erosion of the upper shoreface, followed by re-establishment of the original equilibrium profile. This profile is re-established by shifting it landward and upward. The Bruun Rule is illustrated in **Figure 2**, where:

R is horizontal recession

B is width of the active beach profile (cross-shore distance from the initial dune height to the depth of closure
S is Sea Level Rise
h is active dune/berm height
d_c is depth of closure

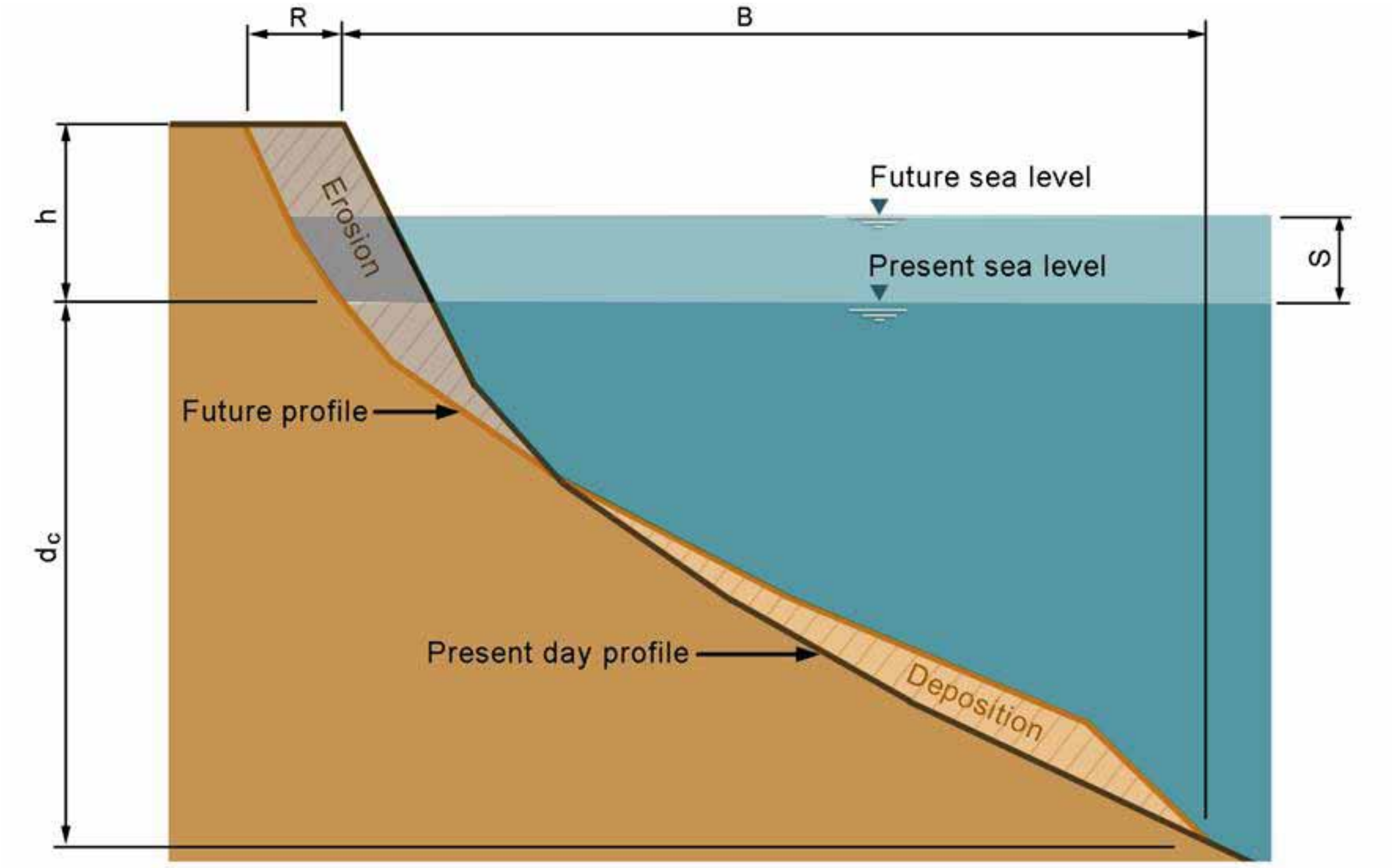

Figure 2 Illustration of the Bruun Rule

A recession rate can be estimated using the Bruun Rule equation, which divides sea level rise by the average slope of the active beach profile extending to the depth of closure (the outer limit for the nearshore littoral drift and exchange zone of littoral material between the shore and the offshore bottom area. Bruun, 1962):

$$R = \frac{S}{(h + d_c)/B}$$

The inverse beach slope is also referred to as the 'Bruun factor':

$$Bf = \frac{1}{(h + d_c)/B} = \frac{B}{h + d_c}$$

Shoreline recession due to SLR is therefore a function of both SLR and the Bruun factor:

$$R = S * Bf$$

Similar to long-term recession (refer **Section 2.1**), there is uncertainty around the distribution of both of these parameters, i.e. the values for SLR and for the Bruun factor. As such, for the Monte Carlo simulations, both of these parameters are defined by separate triangular probability distributions and minimum, maximum and peak/modal SLR and Bruun factor values are required.

2.3 Combined Long-Term Recession and Recession due to Sea Level Rise

Random values for SLR and the Bruun factor and long-term recession, are simulated using triangular distributions (refer **Section 2.1** and **Section 2.2**). The values for these variables are then combined in a Monte Carlo process to give a total shoreline movement (recession) along the beach for the given planning period (refer **Figure 3**).

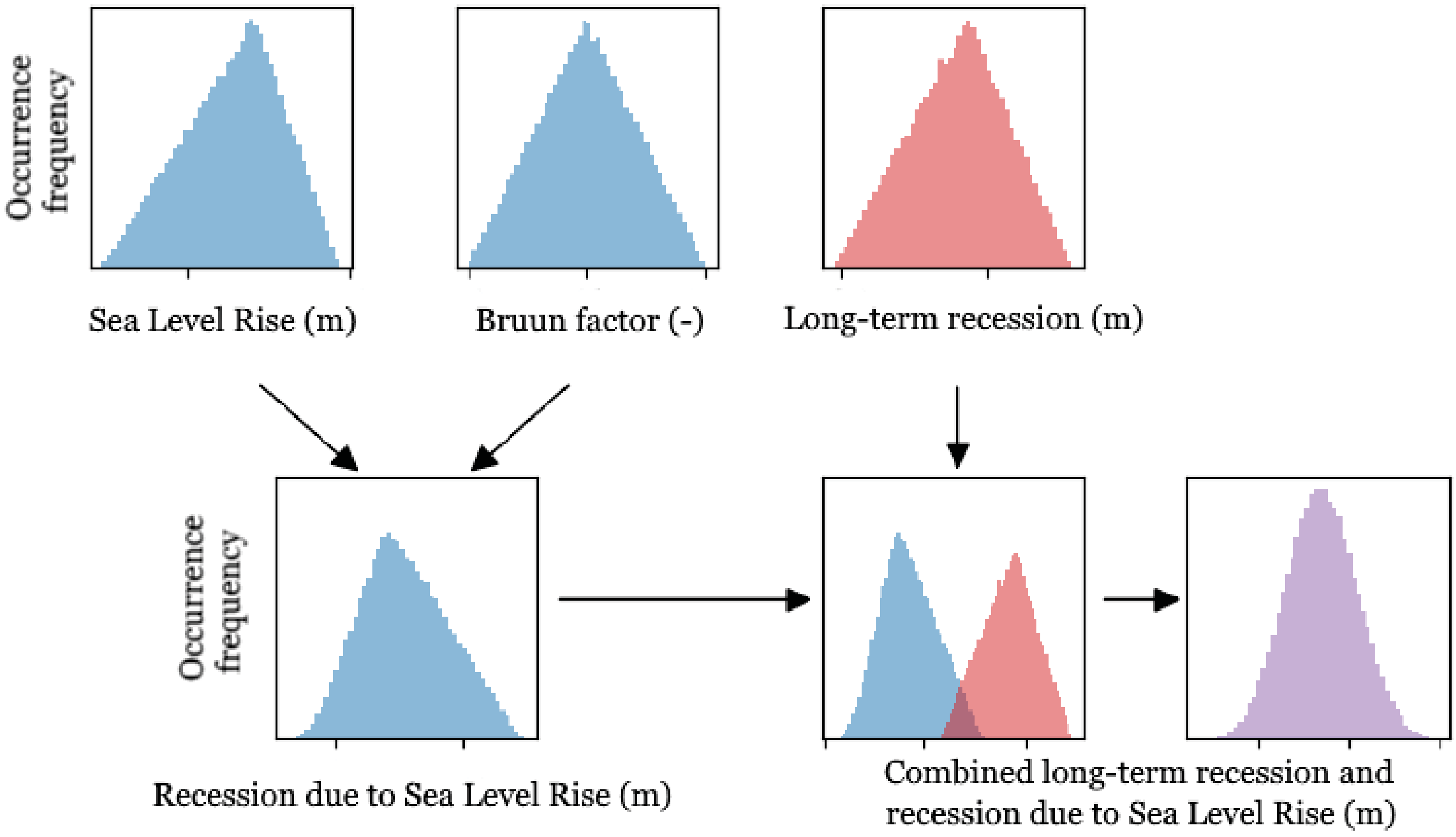

Figure 3 Methodology for combining random values to estimate shoreline movement (based on: WRL, 2017)

2.4 Storm Demand

Storm demand represents the volume of sand removed from a beach in a severe storm or a series of closely spaced storms. It is typically measured above a level of 0m AHD and expressed as cubic metres for metre run of beach (m^3/m).

Storm demand modelling using SBEACH is typically undertaken to determine storm erosion resulting under certain (average recurrence interval - ARI) storm conditions. Analysis of historical beach profiles is also used to estimate storm demand for particular ARIs. In addition, there are generally accepted values for storm demand for open coast beaches in NSW contained in the literature.

Storm demand probabilities for each year of the planning period in the Monte Carlo simulations are determined by random selection from a uniform distribution of annual exceedance probability (AEP) /ARI values (refer **Figure 4**).

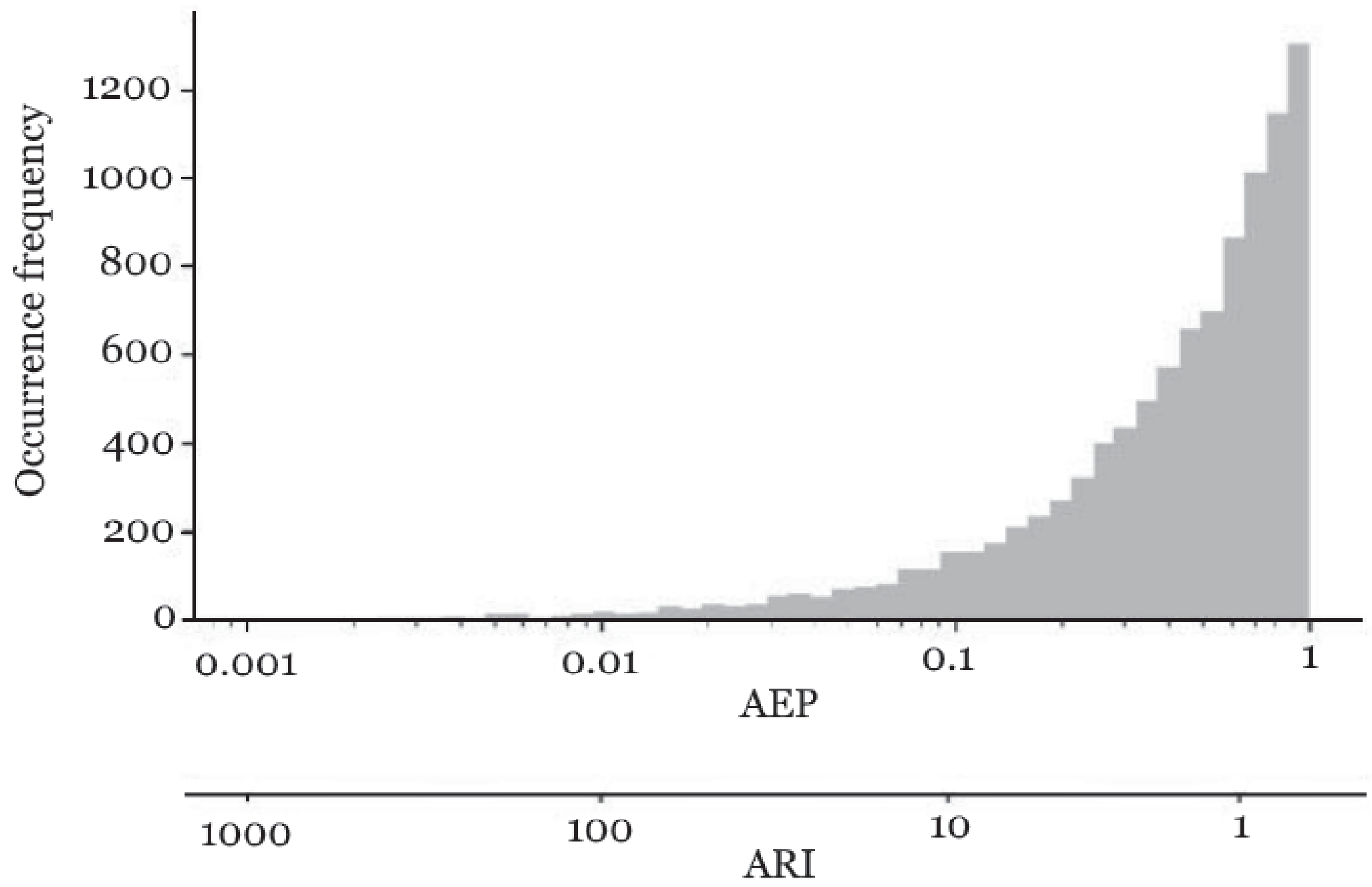

Figure 4 Uniform distribution of AEP values for generating storm demand volumes

The randomly generated AEP values are then converted to storm erosion volumes using empirical relationships. For beaches in NSW, it is reasonable to use the distribution of storm erosion volumes based on beach erosion data described in Gordon (1987), using the reference 100-year ARI storm demand volume for the beach in question. Gordon (1987) derived relationships between storm demand and ARI, in both "high demand" (at rip heads) and "low demand" (away from rip heads) areas (refer **Figure 5**). The "high demand" (rip head) values are adopted in the methodology.

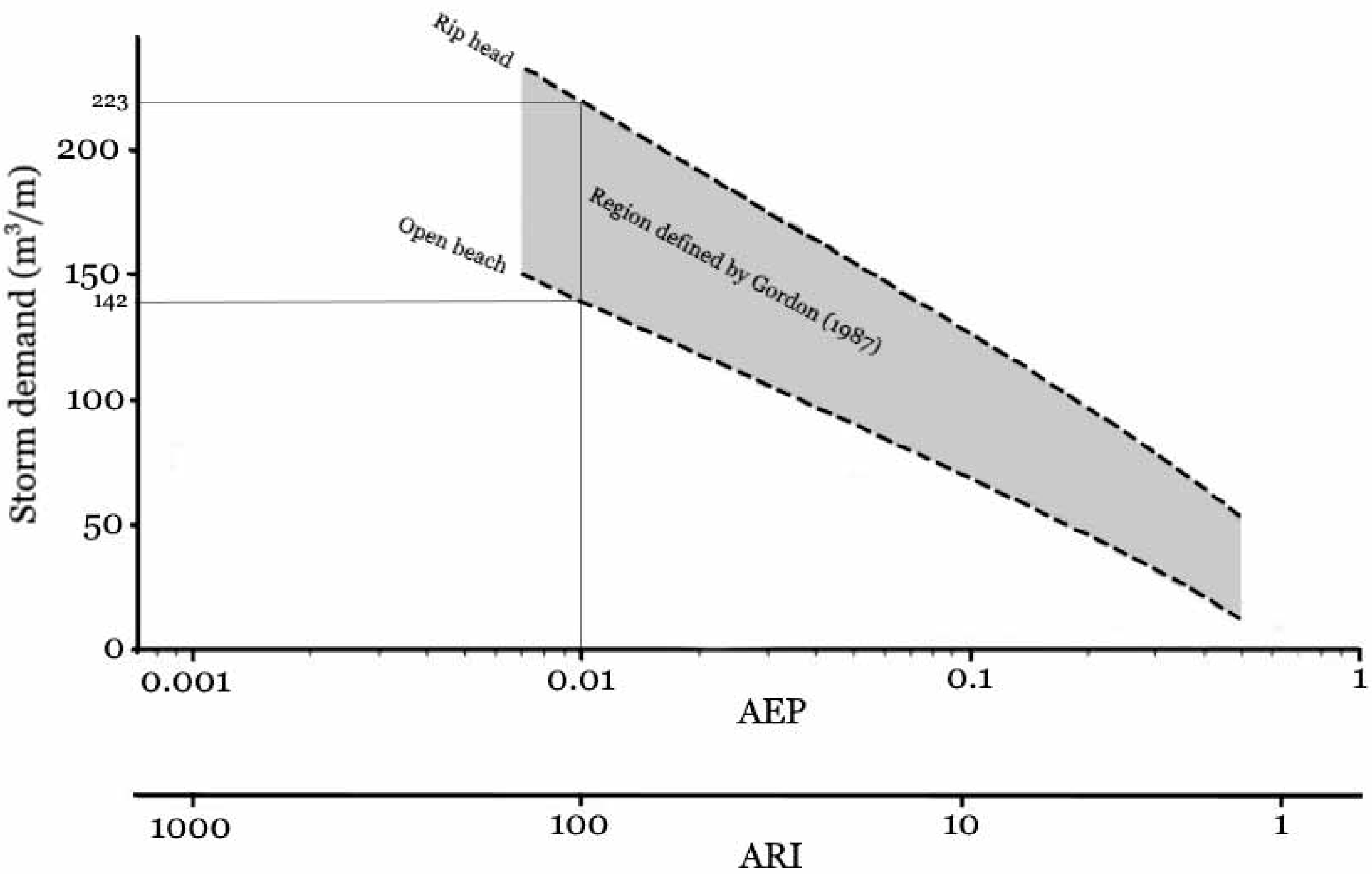

Figure 5 Storm demand volumes for exposed beaches in NSW (based on: Gordon, 1987)

In the following example, 100-year ARI storm demand values were estimated for a range of profiles based on SBEACH model results. The relationship between storm demand and ARI was then determined for each profile in accordance with the following methodology:

- Determine the ratio of the estimated 100-year ARI storm demand value to the appropriate ('low' or 'high' demand) Gordon (1987) 100-year ARI values (refer **Figure 5**); and
- Determine storm demand values for a range of ARIs by multiplying the appropriate Gordon (1987) storm demand values (describing 'low' or 'high' demand) by the storm demand scale factor (ratio) of that profile (re-interpolate to a range of nominated ARIs if applicable).

Example results of this exercise are presented in **Figure 6**.

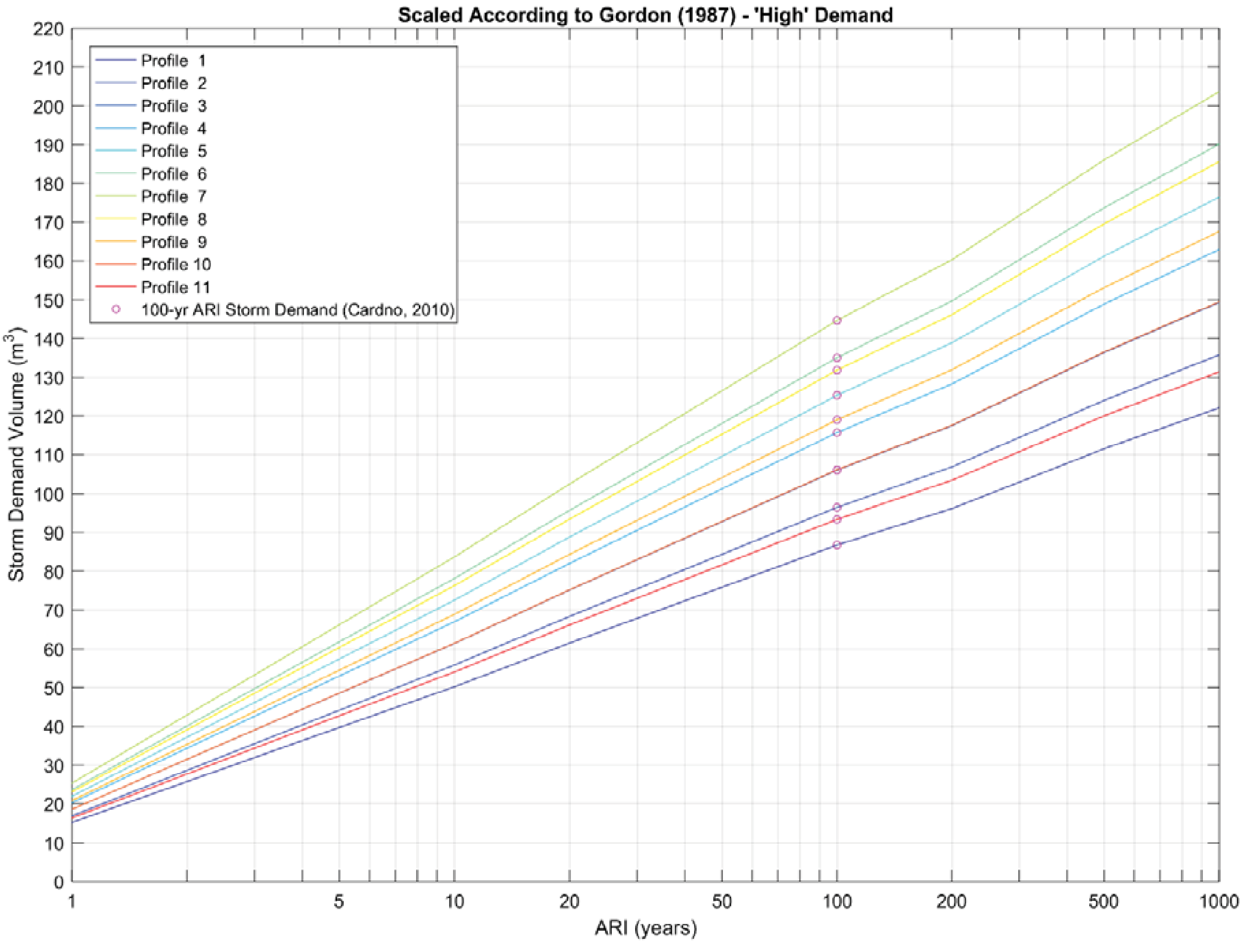

Figure 6 Example storm demand scaled according to Gordon (1987)

3 Monte Carlo Analysis Methodology

This section outlines the methodology followed in a CHA Monte Carlo analysis

3.1 Underlying Shoreline Recession

Further to **Section 2.1**, minimum, modal and maximum underlying shoreline recession values serve as input parameters for the triangular distribution of the long-term shoreline recession. One set of one million randomly-generated values of the long-term shoreline recession rate (m/year) is generated from the specified triangular distribution. These are essentially *annual* long-term shoreline recession values. The methodology to calculate *cumulative* long-term shoreline recession for each year is as follows:

- For each year in the planning period, for each of the one million randomly-generated values of *annual* long-term shoreline recession, calculate the *cumulative* long-term shoreline recession by multiplying the annual long-term shoreline recession value by the number of years passed in the planning period (subtract base year from the year under consideration)

Consequently, the above results in a matrix of one million (Monte Carlo simulations) by *n* (number of years in the planning period) of randomly-generated cumulative long-term shoreline recession values based on annual long-term shoreline recession values and its associated distribution (refer **Figure 7** for an example Monte Carlo results matrix).

Year in planning period

Monte Carlo simulation number

	1	2	3	4	5	6	96	97	98	99	100	101
1	0.1051	0.2102	0.3153	0.4204	0.5255	0.6306	10.0888	10.1939	10.2990	10.4041	10.5092	10.6143
2	0.0830	0.1660	0.2490	0.3321	0.4151	0.4981	7.9694	8.0524	8.1354	8.2185	8.3015	8.3845
3	0.0433	0.0865	0.1298	0.1731	0.2163	0.2596	4.1536	4.1969	4.2401	4.2834	4.3267	4.3699
4	0.0766	0.1531	0.2297	0.3062	0.3828	0.4593	7.3488	7.4254	7.5019	7.5785	7.6550	7.7316
5	0.0950	0.1900	0.2850	0.3800	0.4750	0.5700	9.1199	9.2149	9.3099	9.4049	9.4999	9.5949
6	0.0167	0.0335	0.0502	0.0669	0.0837	0.1004	1.6065	1.6232	1.6400	1.6567	1.6734	1.6902
7	0.0750	0.1500	0.2250	0.3000	0.3749	0.4499	7.1989	7.2739	7.3489	7.4238	7.4988	7.5738
8	0.0992	0.1984	0.2975	0.3967	0.4959	0.5951	9.5210	9.6201	9.7193	9.8185	9.9177	10.0169
9	0.0978	0.1955	0.2933	0.3911	0.4889	0.5866	9.3859	9.4837	9.5815	9.6792	9.7770	9.8748
10	0.0282	0.0565	0.0847	0.1130	0.1412	0.1695	2.7118	2.7401	2.7683	2.7966	2.8248	2.8531
11	0.0405	0.0811	0.1216	0.1622	0.2027	0.2433	3.8928	3.9333	3.9739	4.0144	4.0550	4.0955
999989	0.0429	0.0857	0.1286	0.1714	0.2143	0.2572	4.1145	4.1574	4.2002	4.2431	4.2860	4.3288
999990	0.0301	0.0602	0.0903	0.1203	0.1504	0.1805	2.8883	2.9184	2.9485	2.9786	3.0087	3.0388
999991	0.0814	0.1627	0.2441	0.3254	0.4068	0.4882	7.8105	7.8918	7.9732	8.0545	8.1359	8.2173
999992	0.0092	0.0185	0.0277	0.0369	0.0461	0.0554	0.8860	0.8952	0.9044	0.9136	0.9229	0.9321
999993	0.0111	0.0223	0.0334	0.0446	0.0557	0.0669	1.0699	1.0811	1.0922	1.1033	1.1145	1.1256
999994	0.1355	0.2710	0.4065	0.5420	0.6775	0.8130	13.0076	13.1431	13.2786	13.4141	13.5496	13.6851
999995	0.0793	0.1586	0.2379	0.3172	0.3965	0.4757	7.6119	7.6912	7.7705	7.8498	7.9291	8.0084
999996	0.0198	0.0395	0.0593	0.0790	0.0988	0.1186	1.8969	1.9167	1.9365	1.9562	1.9760	1.9957
999997	0.0319	0.0638	0.0958	0.1277	0.1596	0.1915	3.0645	3.0964	3.1284	3.1603	3.1922	3.2241
999998	0.0849	0.1697	0.2546	0.3394	0.4243	0.5091	8.1459	8.2308	8.3156	8.4005	8.4853	8.5702
999999	0.0400	0.0800	0.1200	0.1600	0.2000	0.2400	3.8397	3.8796	3.9196	3.9596	3.9996	4.0396
1000000	0.0655	0.1310	0.1964	0.2619	0.3274	0.3929	6.2863	6.3518	6.4172	6.4827	6.5482	6.6137

Figure 7 Example Monte Carlo results matrix for long-term recession

3.2 Shoreline Recession due to Sea Level Rise

As outlined in **Section 2.2**, shoreline recession due to SLR is a function of both SLR and the Bruun factor.

In regard to SLR, Monte Carlo simulations are assumed to be based on proposed minimum, modal and maximum SLR projections. Where the adopted projections or trajectories are available at discrete points in time (e.g. IPCC concentration pathways), a polynomial fit through these points is estimated (refer example in **Figure 8**).

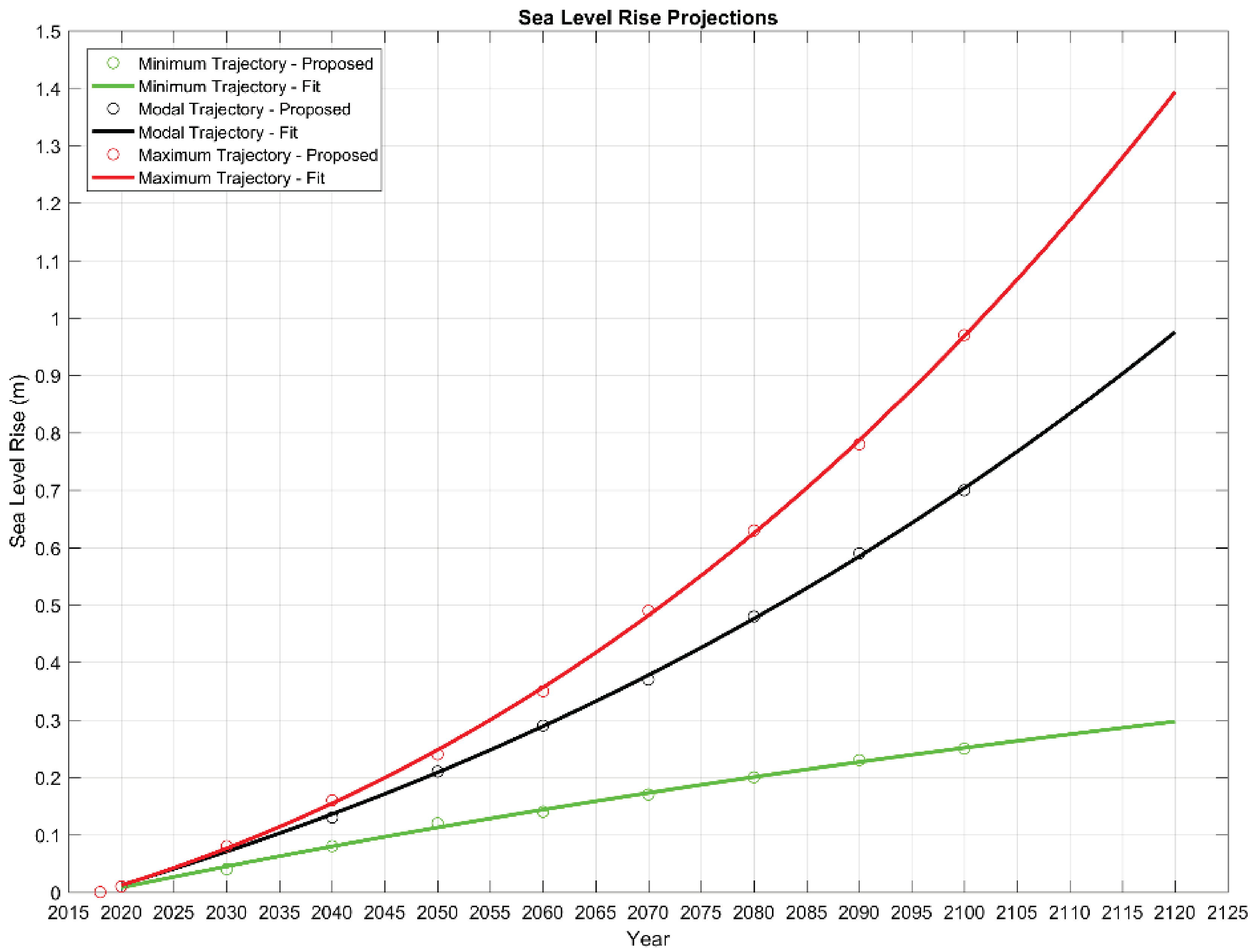

Figure 8 Example Sea Level Rise projections

A set of one million randomly-generated values of SLR for each year in the planning period is generated. The methodology is as follows:

- For each year in the planning period, the minimum, modal and maximum projected SLR is determined based on the above polynomial trajectory fits - these serve as input parameters for the triangular distribution of that year;
- Then, for each year in the planning period, one million random SLR values are generated from the specified triangular distribution of that year.

Note that in the case of SLR, relevant input parameters to the Monte Carlo simulation are set such that the algorithm (or 'set of rules') used to generate random SLR values is the same each year. In combination with a triangular distribution that changes from year to year (increasing minimum, maximum and modal values), basically one million random SLR *trajectories* are generated in the Monte Carlo simulations (refer **Figure 9** and **Figure 10**).

Year in planning period

Monte Carlo simulation number

	1	2	3	4	5	6	96	97	98	99	100	101
1	0.0127	0.0184	0.0228	0.0285	0.0343	0.0401	1.0160	1.0329	1.0500	1.0672	1.0846	1.1021
2	0.0127	0.0185	0.0232	0.0290	0.0349	0.0409	1.0915	1.1100	1.1287	1.1475	1.1665	1.1857
3	0.0123	0.0179	0.0184	0.0229	0.0274	0.0320	0.5650	0.5728	0.5806	0.5885	0.5965	0.6045
4	0.0128	0.0185	0.0233	0.0291	0.0350	0.0409	1.0992	1.1179	1.1367	1.1557	1.1749	1.1943
5	0.0125	0.0182	0.0219	0.0274	0.0329	0.0385	0.9085	0.9232	0.9379	0.9528	0.9679	0.9830
6	0.0123	0.0179	0.0180	0.0224	0.0269	0.0313	0.5306	0.5377	0.5448	0.5520	0.5592	0.5665
7	0.0124	0.0180	0.0198	0.0246	0.0296	0.0345	0.6991	0.7096	0.7201	0.7308	0.7415	0.7523
8	0.0125	0.0181	0.0215	0.0268	0.0322	0.0377	0.8649	0.8786	0.8925	0.9065	0.9206	0.9349
9	0.0128	0.0186	0.0234	0.0293	0.0353	0.0414	1.1531	1.1729	1.1929	1.2131	1.2334	1.2540
10	0.0128	0.0186	0.0235	0.0294	0.0354	0.0415	1.1646	1.1846	1.2048	1.2253	1.2459	1.2667
11	0.0123	0.0179	0.0187	0.0233	0.0279	0.0326	0.5968	0.6053	0.6137	0.6223	0.6309	0.6395
999989	0.0128	0.0186	0.0235	0.0294	0.0354	0.0416	1.1785	1.1989	1.2194	1.2401	1.2610	1.2821
999990	0.0125	0.0182	0.0217	0.0271	0.0326	0.0381	0.8874	0.9016	0.9159	0.9304	0.9449	0.9597
999991	0.0123	0.0178	0.0170	0.0212	0.0253	0.0295	0.4358	0.4410	0.4462	0.4515	0.4568	0.4621
999992	0.0126	0.0182	0.0221	0.0276	0.0332	0.0388	0.9232	0.9382	0.9532	0.9685	0.9838	0.9993
999993	0.0125	0.0181	0.0214	0.0267	0.0320	0.0374	0.8517	0.8652	0.8788	0.8925	0.9064	0.9203
999994	0.0127	0.0184	0.0229	0.0286	0.0344	0.0403	1.0293	1.0464	1.0638	1.0813	1.0989	1.1168
999995	0.0129	0.0187	0.0236	0.0295	0.0357	0.0419	1.2117	1.2328	1.2540	1.2754	1.2971	1.3189
999996	0.0127	0.0185	0.0232	0.0289	0.0348	0.0407	1.0761	1.0942	1.1126	1.1311	1.1498	1.1686
999997	0.0124	0.0179	0.0193	0.0240	0.0288	0.0336	0.6507	0.6602	0.6698	0.6794	0.6891	0.6989
999998	0.0125	0.0181	0.0213	0.0266	0.0320	0.0374	0.8511	0.8646	0.8782	0.8920	0.9058	0.9198
999999	0.0126	0.0183	0.0223	0.0278	0.0334	0.0391	0.9427	0.9580	0.9735	0.9892	1.0050	1.0209
1000000	0.0126	0.0182	0.0222	0.0277	0.0333	0.0390	0.9367	0.9520	0.9673	0.9828	0.9985	1.0143

Figure 9 Monte Carlo results matrix for SLR

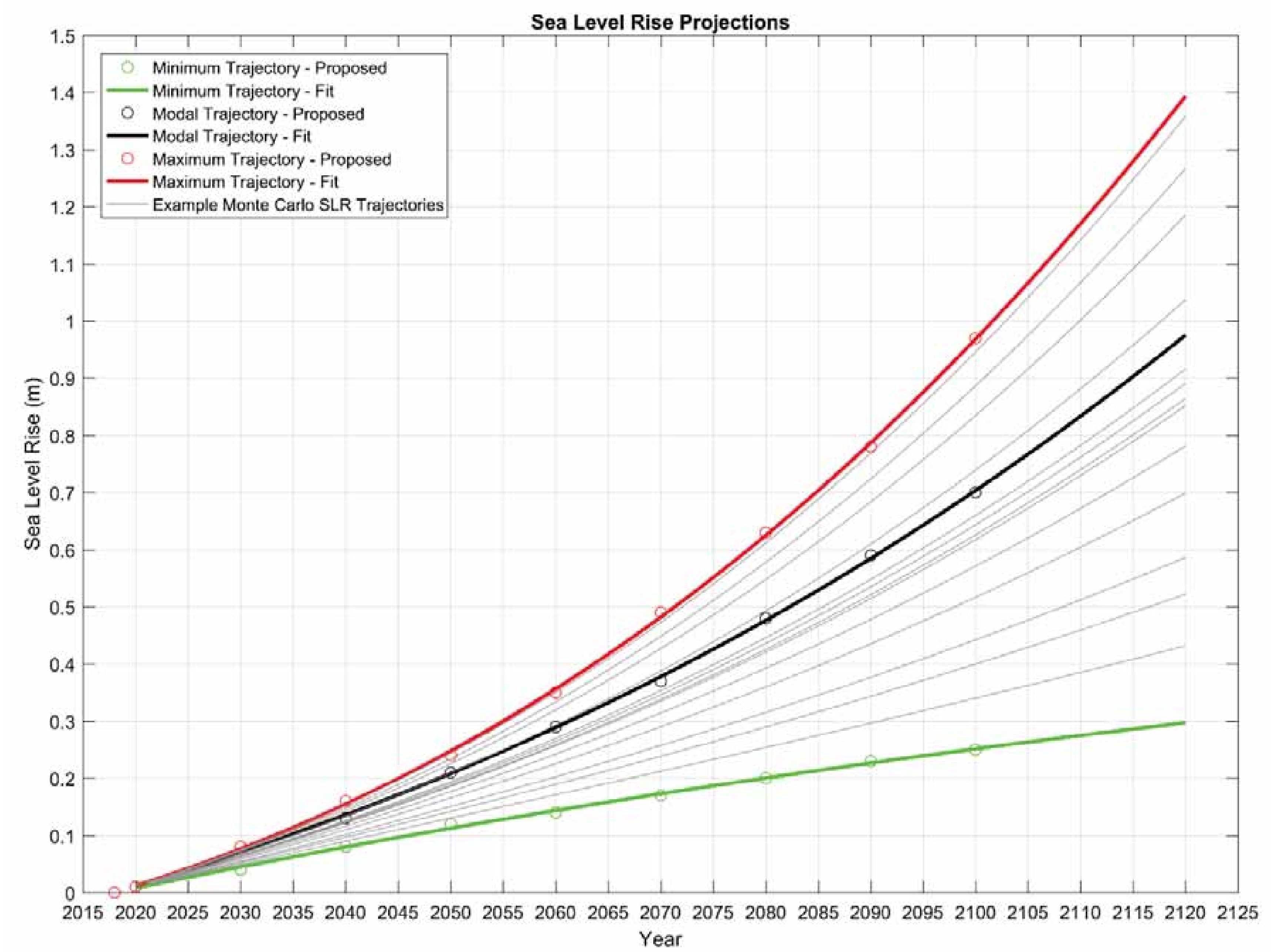

Figure 10 Example Monte Carlo Sea Level Rise trajectories

Similarly, minimum, modal and maximum values for the Bruun factor (which result from a separate assessment of dune height and local closure depth) serve as input parameters for the triangular distribution of the Bruun factor. One set of one million randomly-generated values of the Bruun factor is generated from the specified triangular Bruun factor distribution.

Monte Carlo simulation number

	1
1	46.9396
2	36.4402
3	38.7887
4	43.0681
5	45.2201
6	38.4200
7	40.4453
8	43.0260
9	40.0742
10	38.3600
11	32.4870
999989	41.1772
999990	38.1521
999991	40.9444
999992	46.7384
999993	43.6584
999994	40.5733
999995	45.4701
999996	38.0921
999997	38.2370
999998	39.9227
999999	41.8228
1000000	36.3170

Figure 11 Example Monte Carlo result values for the Bruun Factor

Randomly-generated values for shoreline recession due to SLR (one million for each year in the planning period) are then calculated using the probabilistic information of SLR and the Bruun factor. The methodology is as follows:

- For each year in the planning period, for each of the one million randomly-generated values of both SLR (for a particular year) and the Bruun factor, calculate the shoreline recession using the Bruun Rule equation (SLR multiplied by the Bruun factor - refer **Section 2.2**).

Consequently, the above procedure results in a matrix of one million (Monte Carlo simulations) by *n* (number of years in the planning period) of randomly-generated shoreline recession values based on SLR and the Bruun factor and their associated distributions (refer **Figure 12**).

Year in planning period

Monte Carlo simulation number

	1	2	3	4	5	6	96	97	98	99	100	101
1	0.5345	0.7756	0.9635	1.2036	1.4472	1.6943	42.8915	43.6051	44.3253	45.0521	45.7855	46.5256
2	0.5506	0.7990	1.0034	1.2537	1.5078	1.7659	47.1571	47.9561	48.7627	49.5769	50.3986	51.2281
3	0.5297	0.7687	0.7893	0.9835	1.1786	1.3745	24.2979	24.6327	24.9698	25.3092	25.6508	25.9947
4	0.4558	0.6615	0.8314	1.0388	1.2494	1.4634	39.2932	39.9602	40.6334	41.3130	41.9989	42.6912
5	0.5480	0.7952	0.9588	1.1973	1.4388	1.6834	39.6950	40.3345	40.9798	41.6306	42.2873	42.9496
6	0.3993	0.5794	0.5839	0.7274	0.8713	1.0157	17.2159	17.4463	17.6781	17.9114	18.1461	18.3823
7	0.4967	0.7208	0.7928	0.9888	1.1864	1.3855	28.0558	28.4755	28.8985	29.3248	29.7545	30.1875
8	0.4895	0.7104	0.8418	1.0510	1.2626	1.4767	33.8812	34.4204	34.9641	35.5126	36.0658	36.6237
9	0.5218	0.7573	0.9549	1.1935	1.4374	1.6861	46.9685	47.7747	48.5886	49.4103	50.2398	51.0771
10	0.4632	0.6721	0.8478	1.0600	1.2771	1.4985	42.0602	42.7838	43.5143	44.2519	44.9964	45.7480
11	0.5229	0.7587	0.7924	0.9876	1.1838	1.3810	25.3068	25.6639	26.0234	26.3855	26.7501	27.1173
999989	0.6094	0.8843	1.1157	1.3958	1.6825	1.9749	55.9356	56.9005	57.8746	58.8581	59.8510	60.8533
999990	0.4033	0.5853	0.6999	0.8739	1.0500	1.2283	28.5895	29.0473	29.5091	29.9749	30.4448	30.9188
999991	0.5121	0.7431	0.7097	0.8834	1.0571	1.2309	18.1887	18.4063	18.6247	18.8442	19.0646	19.2861
999992	0.5720	0.8300	1.0061	1.2565	1.5101	1.7670	42.0495	42.7303	43.4172	44.1102	44.8093	45.5145
999993	0.5893	0.8552	1.0079	1.2582	1.5114	1.7675	40.2043	40.8415	41.4842	42.1325	42.7862	43.4456
999994	0.5174	0.7508	0.9350	1.1681	1.4046	1.6445	42.0157	42.7171	43.4250	44.1394	44.8604	45.5880
999995	0.4726	0.6858	0.8653	1.0844	1.3086	1.5373	44.4702	45.2419	46.0212	46.8079	47.6023	48.4042
999996	0.4660	0.6763	0.8479	1.0594	1.2741	1.4920	39.4045	40.0699	40.7414	41.4193	42.1035	42.7940
999997	0.5059	0.7341	0.7883	0.9829	1.1788	1.3759	26.6472	27.0360	27.4277	27.8224	28.2200	28.6205
999998	0.5245	0.7612	0.8969	1.1196	1.3449	1.5728	35.7632	36.3299	36.9015	37.4780	38.0595	38.6459
999999	0.5291	0.7679	0.9367	1.1699	1.4062	1.6456	39.6536	40.2996	40.9515	41.6091	42.2726	42.9420
1000000	0.4211	0.6111	0.7442	0.9294	1.1170	1.3072	31.3772	31.8874	32.4022	32.9216	33.4456	33.9743

Figure 12 Example Monte Carlo results matrix for recession due to SLR

3.3 Combined Underlying Recession and Recession due to Sea Level Rise

Following from **Section 3.1** and **Section 3.2**, the combined long-term recession (refer **Figure 7**) and recession due to SLR (refer **Figure 12**) is simply calculated by summing the separate results (of each combination of Monte Carlo simulation number and year in the planning period) - refer **Figure 13**.

Year in planning period

Monte Carlo simulation number

	1	2	3	4	5	6	96	97	98	99	100	101
1	0.6396	0.9858	1.2788	1.6240	1.9727	2.3249	52.9803	53.7990	54.6243	55.4562	56.2947	57.1399
2	0.6336	0.9650	1.2524	1.5858	1.9229	2.2640	55.1265	56.0085	56.8981	57.7954	58.7001	59.6126
3	0.5730	0.8552	0.9191	1.1566	1.3949	1.6341	28.4515	28.8296	29.2099	29.5926	29.9775	30.3646
4	0.5324	0.8146	1.0611	1.3450	1.6322	1.9227	46.6420	47.3856	48.1353	48.8915	49.6539	50.4228
5	0.6430	0.9852	1.2438	1.5773	1.9138	2.2534	48.8149	49.5494	50.2897	51.0355	51.7872	52.5445
6	0.4160	0.6129	0.6341	0.7943	0.9550	1.1161	18.8224	19.0695	19.3181	19.5681	19.8204	20.0725
7	0.5717	0.8708	1.0178	1.2888	1.5613	1.8354	35.2547	35.7494	36.2474	36.7486	37.2533	37.7613
8	0.5887	0.9088	1.1393	1.4477	1.7585	2.0718	43.4022	44.0405	44.6834	45.3311	45.9835	46.6406
9	0.6196	0.9528	1.2482	1.5846	1.9263	2.2727	56.3544	57.2584	58.1701	50.0895	60.0168	60.9519
10	0.4914	0.7286	0.9325	1.1730	1.4183	1.6680	44.7720	45.5239	46.2826	47.0485	47.8212	48.6011
11	0.5634	0.8398	0.9140	1.1498	1.3865	1.6243	29.1996	29.5972	29.9973	26.3999	26.8051	27.2128
999989	0.6523	0.9700	1.2443	1.5672	1.8968	2.2321	60.0501	61.0579	62.0748	63.1012	64.1370	65.1821
999990	0.4334	0.6455	0.7902	0.9942	1.2004	1.4088	31.4778	31.9657	32.4576	32.9535	33.4535	33.9576
999991	0.5935	0.9058	0.9538	1.2088	1.4639	1.7191	25.9992	26.2981	26.5979	26.8987	27.2005	27.5034
999992	0.5812	0.8485	1.0338	1.2934	1.5563	1.8224	42.9355	43.6255	44.3216	45.0238	45.7322	46.4466
999993	0.6004	0.8775	1.0413	1.3028	1.5671	1.8344	41.2742	41.9226	42.5764	43.2358	43.9007	44.5712
999994	0.6529	1.0218	1.3415	1.7101	2.0821	2.4575	55.0233	55.8602	56.7036	57.5535	58.4100	59.2731
999995	0.5519	0.8444	1.1032	1.4016	1.7051	2.0130	52.0821	52.9331	53.7917	54.6577	55.5314	56.4126
999996	0.4858	0.7158	0.9072	1.1384	1.3729	1.6106	41.3014	41.9866	42.6779	43.3755	44.0795	44.7897
999997	0.5378	0.7979	0.8841	1.1106	1.3384	1.5674	29.7117	30.1324	30.5561	30.9827	31.4122	31.8446
999998	0.6094	0.9309	1.1515	1.4590	1.7692	2.0819	43.9091	44.5607	45.2171	45.8785	46.5448	47.2161
999999	0.5691	0.8479	1.0567	1.3299	1.6062	1.8856	43.4933	44.1792	44.8711	45.5687	46.2722	46.9816
1000000	0.4866	0.7421	0.9406	1.1913	1.4444	1.7001	37.6635	38.2392	38.8194	39.4043	39.9938	40.5880

Figure 13 Example Monte Carlo results matrix for combined long-term recession and recession due to SLR

An example overview of the statistical distribution of SLR as well as the recession parameters discussed above, is presented in **Figure 14**.

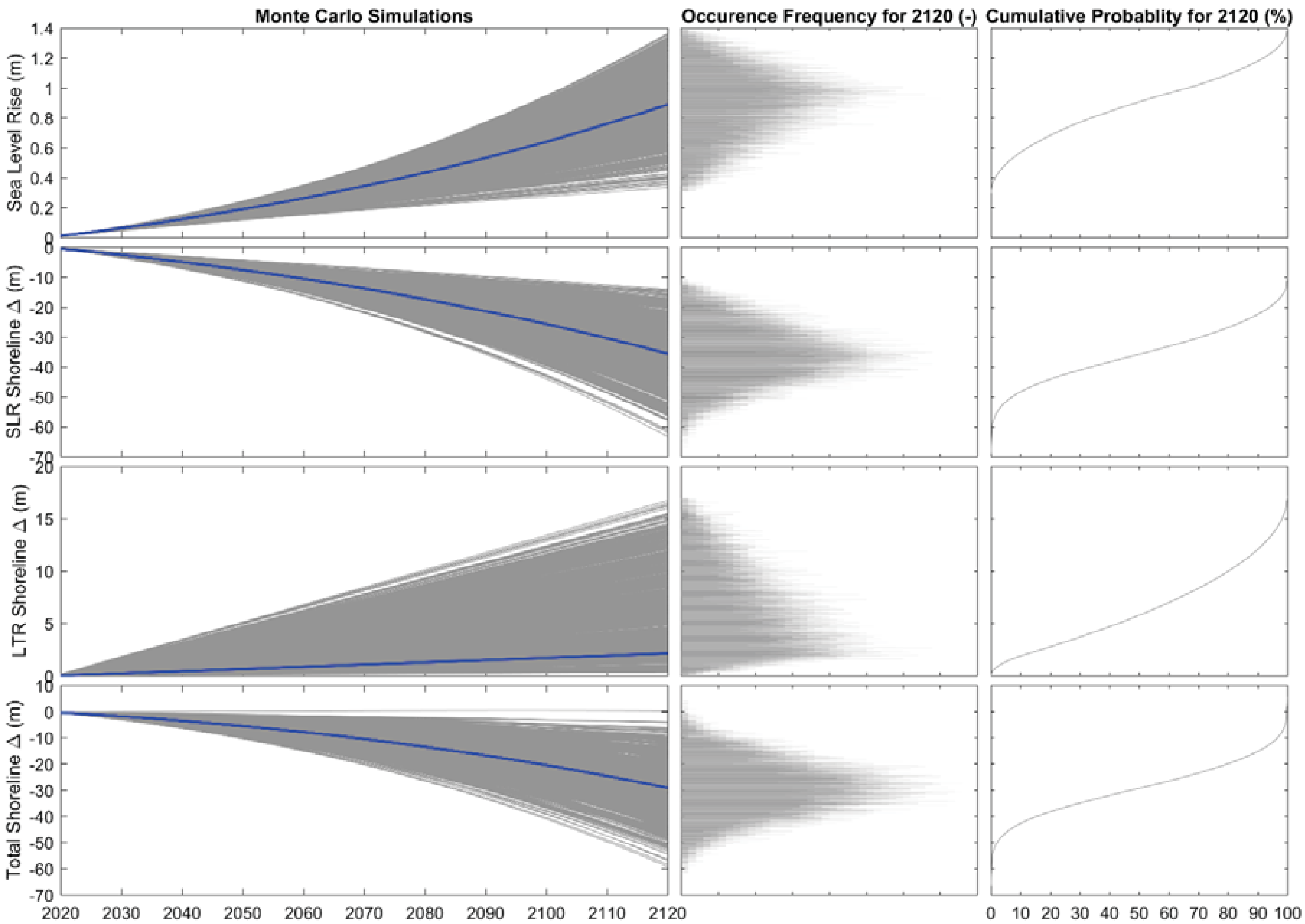

Figure 14 Example statistical distribution of SLR and recession input parameters

3.4 Storm Demand

As outlined in **Section 2.4**, storm demand probabilities for each year are calculated using a uniform distribution of AEP values, which vary between zero and one (inclusive). To this end, a random number generator, which generates numbers between zero and one (inclusive), is used to generate a matrix of one million (Monte Carlo simulations) by *n* (number of years in the planning period) of uniformly-distributed AEP values for storm demand (refer **Figure 15**).

Year in planning period

Monte Carlo simulation number

	1	2	3	4	5	6	---------->	96	97	98	99	100	101
1	0.5211	0.1433	0.1681	0.5705	0.1985	0.0676		0.0143	0.4133	0.5005	0.4970	0.4689	0.6261
2	0.8149	0.7980	0.4172	0.7914	0.8939	0.0206		0.6072	0.8694	0.8399	0.1100	0.2615	0.4325
3	0.5458	0.5477	0.3296	0.2688	0.2379	0.0655		0.3834	0.0830	0.8493	0.5362	0.0073	0.1695
4	0.5087	0.4707	0.0038	0.1373	0.3797	0.9081		0.7995	0.9138	0.9794	0.5510	0.9034	0.5027
5	0.9881	0.6417	0.3252	0.6651	0.7316	0.7733		0.9320	0.5714	0.6254	0.7152	0.4875	0.4066
6	0.4740	0.2762	0.1815	0.3050	0.8444	0.8813		0.9521	0.1355	0.4809	0.0581	0.1155	0.3953
7	0.4222	0.3398	0.9737	0.3651	0.8694	0.3812		0.6662	0.1313	0.5621	0.8765	0.4046	0.5181
8	0.7992	0.6367	0.9084	0.3498	0.3013	0.4366		0.9541	0.6667	0.8798	0.7209	0.2139	0.8878
9	0.7240	0.1421	0.1627	0.6812	0.4241	0.1054		0.0642	0.4773	0.9751	0.1608	0.8695	0.7144
10	0.4086	0.6729	0.9885	0.8283	0.6452	0.6493		0.8380	0.4518	0.7750	0.1011	0.7526	0.6143
11	0.9980	0.9046	0.7173	0.2221	0.3897	0.1093		0.3159	0.6629	0.6563	0.4835	0.2639	0.4399
↓													
999989	0.1365	0.5059	0.3831	0.5096	0.4849	0.7014		0.8971	0.8647	0.5013	0.5413	0.7999	0.6870
999990	0.5131	0.0999	0.9039	0.9366	0.5538	0.8772		0.5771	0.6315	0.3175	0.6496	0.4016	0.7901
999991	0.8088	0.7322	0.5738	0.0762	0.5157	0.9757		0.2237	0.6372	0.9301	0.0782	0.1860	0.8296
999992	0.8508	0.2440	0.4792	0.6550	0.5626	0.3994		0.7192	0.8316	0.0713	0.9394	0.8676	0.4612
999993	0.1214	0.2502	0.1058	0.5404	0.3929	0.2730		0.5313	0.5783	0.5392	0.7318	0.8102	0.7756
999994	0.0767	0.6440	0.3050	0.2651	0.5803	0.5584		0.6843	0.1969	0.9896	0.2547	0.7687	0.3575
999995	0.7449	0.5510	0.6578	0.9384	0.4688	0.5548		0.4908	0.2624	0.1648	0.7591	0.1004	0.9544
999996	0.2394	0.7564	0.5075	0.1577	0.7687	0.7278		0.0607	0.4223	0.5405	0.5732	0.8295	0.8812
999997	0.5580	0.2587	0.7511	0.0143	0.0549	0.1603		0.6783	0.4446	0.0175	0.9656	0.6234	0.5631
999998	0.2848	0.2011	0.8650	0.0453	0.8744	0.4970		0.0159	0.3791	0.9553	0.1719	0.3230	0.7761
999999	0.3229	0.5324	0.6930	0.3870	0.7697	0.4690		0.5372	0.0206	0.1524	0.6518	0.6741	0.2335
1000000	0.1346	0.5810	0.3792	0.4773	0.8346	0.0326		0.5292	0.1483	0.3098	0.6524	0.1953	0.8941

Figure 15 Example Monte Carlo results matrix for the storm demand AEP

These AEP values are translated to actual storm demand values on a per-profile basis. The methodology (applicable to each profile) is as follows:

- For each storm demand AEP value (converted from ARI values), post-storm setback distance from the zero-elevation (0m AHD) crossing are calculated for the following hazard 'zones' (refer Nielsen, 1992, and **Figure 16**):
    - o Zone of Wave Impact (ZWI);
    - o Zone of Slope Adjustment (ZSA); and
    - o Zone of Reduced Foundation Capacity (ZRFC).

  This is an iterative process whereby the area below the beach profile (or volume per metre run of beach) is matched against the relevant storm demand value, while obeying the geometrical constraints of the above zones outlined in Nielsen (1992). Example results are presented in **Figure 17** and **Figure 18**.
- For each of the above zones, a matrix of one million (Monte Carlo simulations) by *n* (number of years in the planning period) of post-storm setback distance values is calculated by interpolating the AEP values and associated setback distance values onto the uniformly-distributed AEP values for storm demand (refer **Figure 15**).

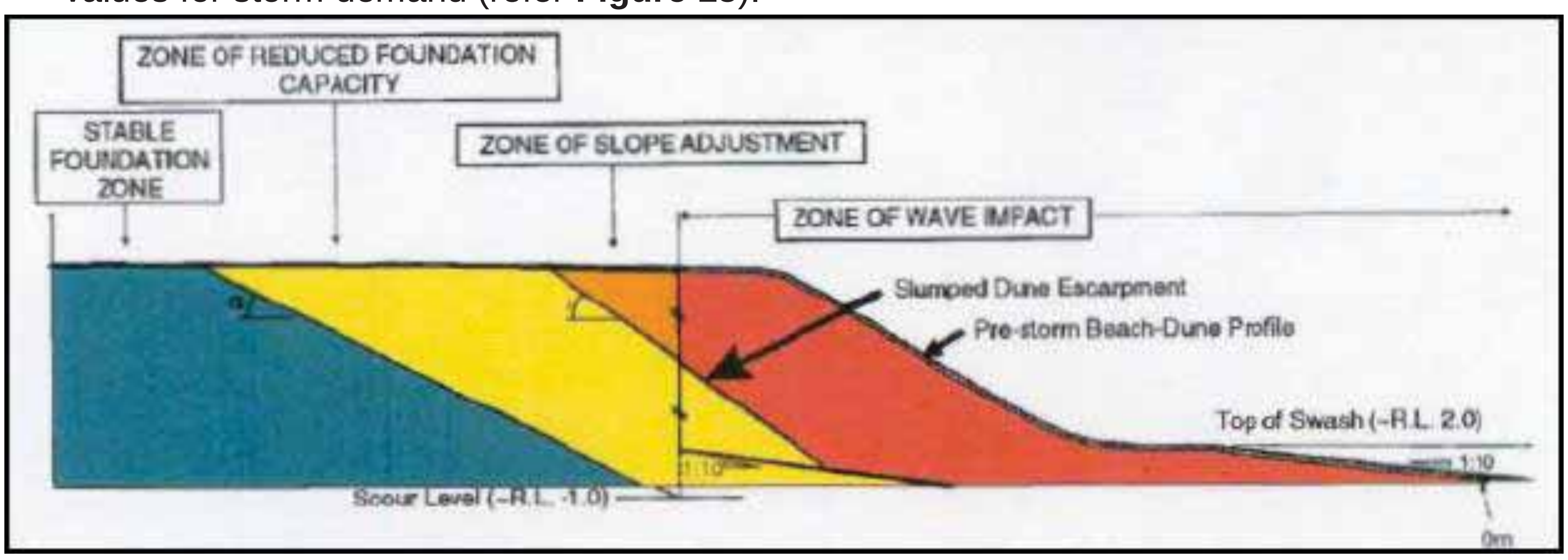

Figure 16 Schematic representation of coastline hazard zones (after Nielsen, 1992)

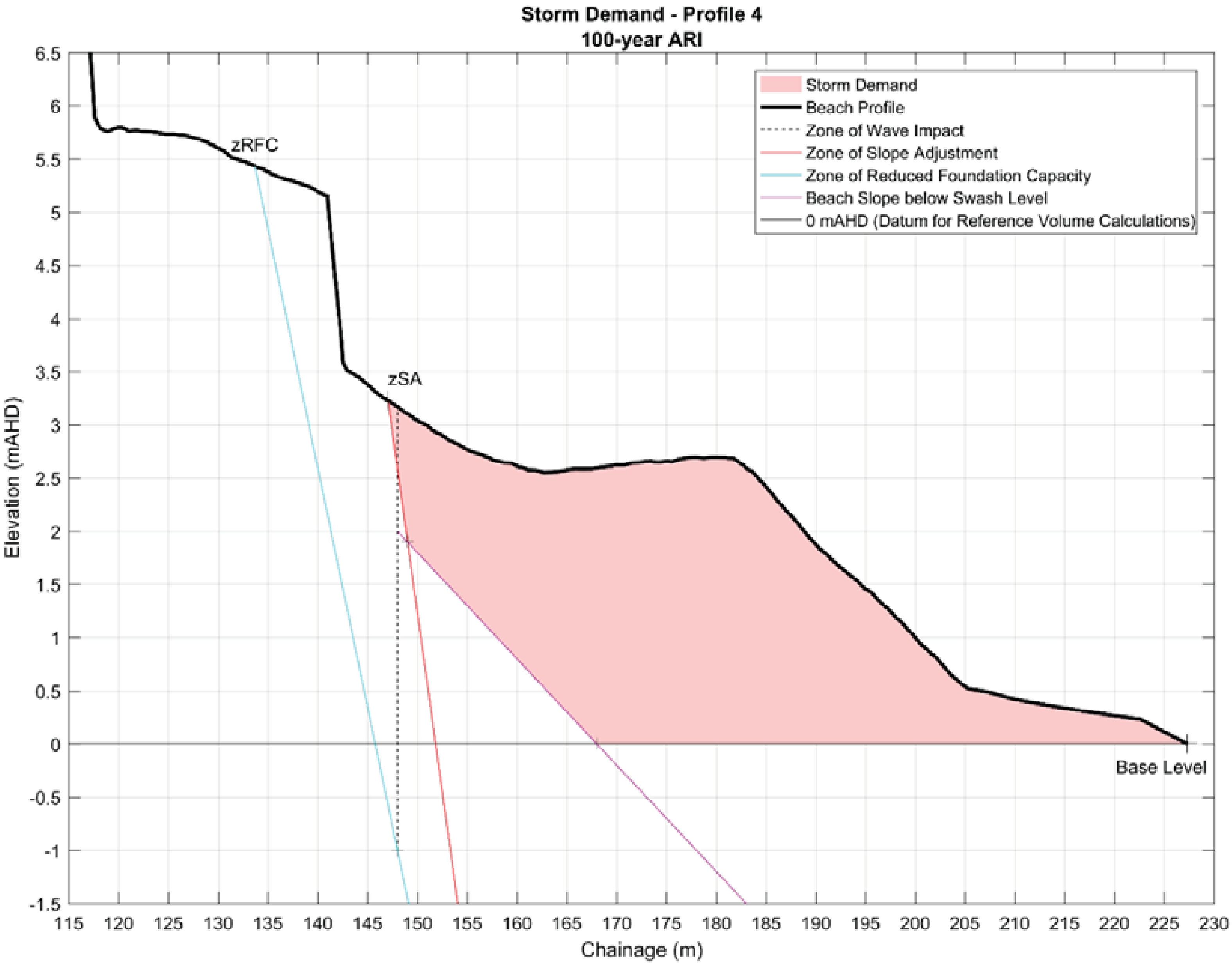

Figure 17 Example profile storm demand

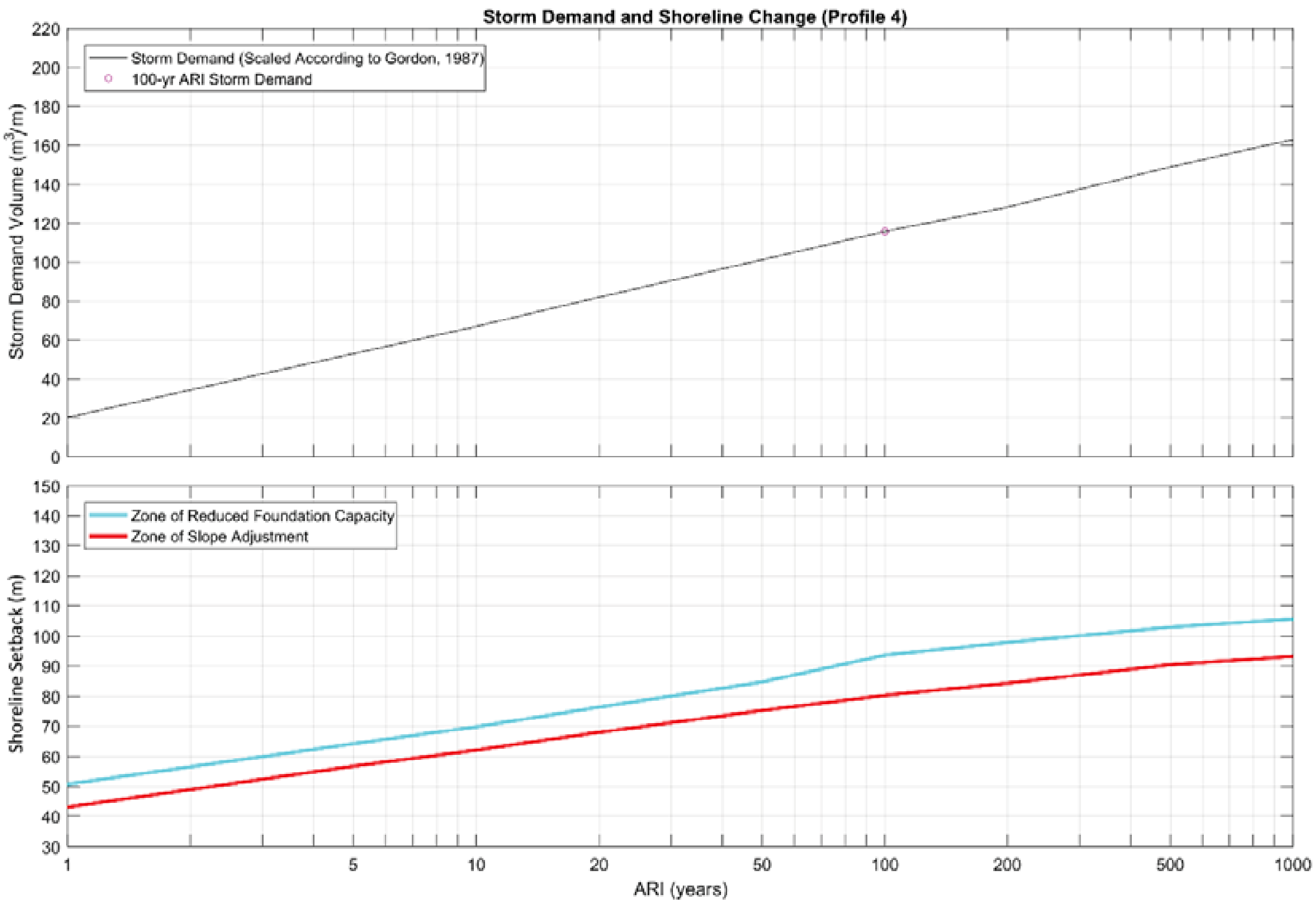

Figure 18 Example storm demand and shoreline setback distance

3.5 Combined Shoreline Position due to Underlying Recession, Sea Level Rise and Storm Demand

Total shoreline change for each of the hazard zones (ZWI, ZSA and ZRFC) outlined in **Section 3.4** is calculated by combining storm setback distances (cyan lines in **Figure 19**, presenting one example set of storm demand distances out of one million) with the 'combined recession' trajectories (grey lines and blue line, the latter representing one example trajectory out of one million) for each year in the planning period. The total shoreline change in each year (one million values in total – refer **Figure 19** for example distribution (in red) of the ZRFC setback distance in the final year of the planning period) is subsequently utilised to calculate probabilities of exceedance of each of the hazard zones and produce hazard lines on a map.

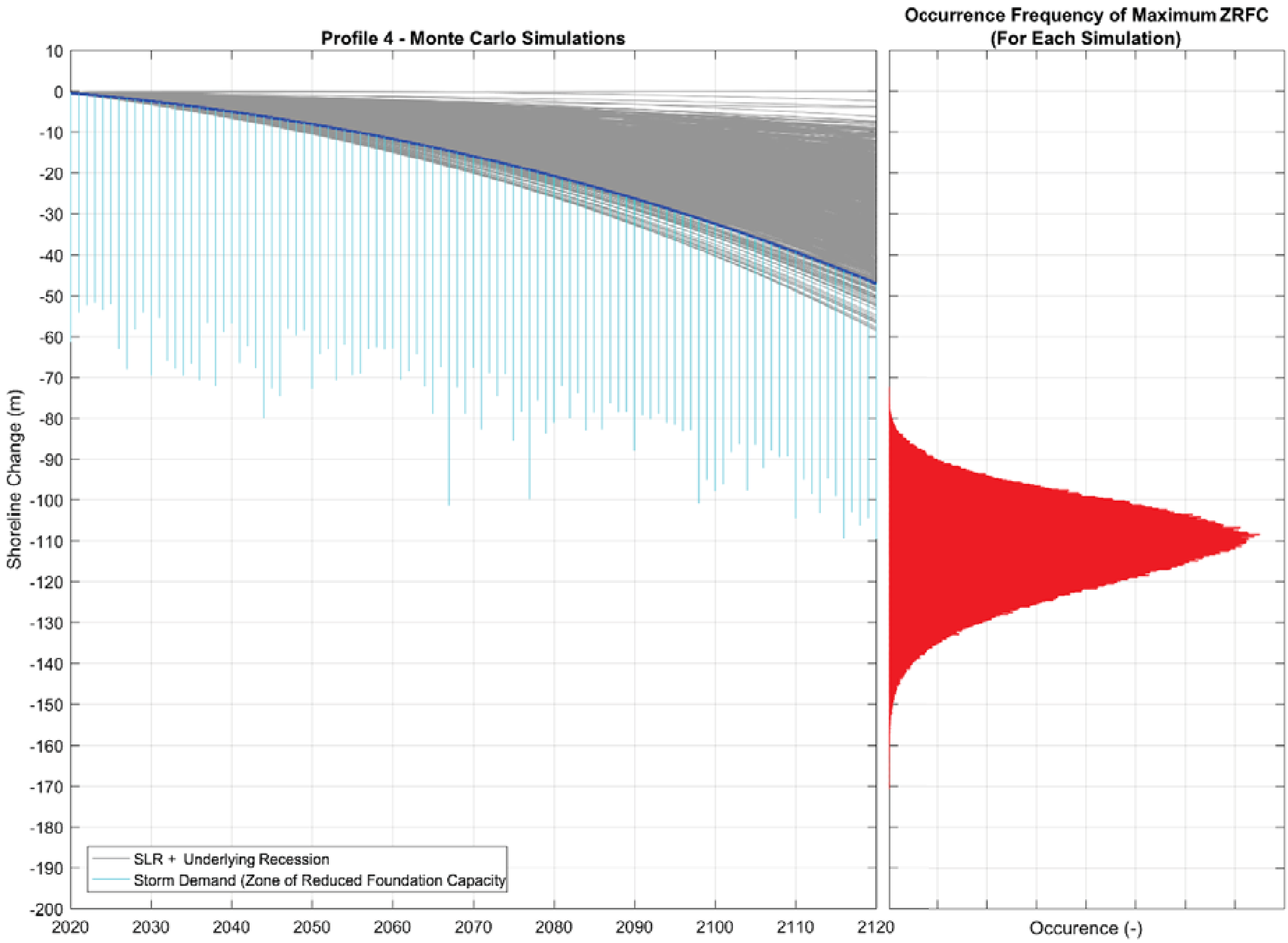

Figure 19 Example of simulated storm demand superimposed on background shoreline change due to combined recession

4 References

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Nielsen, A.F., D. B. Lord, H. G. Poulos (1992). Dune Stability Considerations for Building Foundations, Vol. CE34 No. 2 June 1992.

WRL (2017). Eurobodalla Coastal Hazard Assessment, WRL Technical Report 2017/09, October 2017.

Appendix B – Copy of Letter from RHDHV to Planners North dated 1 February 2019

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Email: kate@plannersnorth.com.au

Date:	01 February 2019	Contact name:	Greg Britton
Your reference:		Telephone:	61 2 8854 5000
Our reference:	PA1998MACO190117-coastal haz review	Email:	greg.britton@rhdhv.com

Dear Kate

Review of Assessments of Coastal Hazard at North Byron Beach

I refer to our recent discussions and to your letter of 14 November 2018 in which you requested a review of assessments of coastal hazard undertaken to date at North Byron Beach and, based on this review, provision of an opinion as to the suitability of a Planning Proposal developed by Planners North on behalf of North Byron Bay Resort Pty Ltd applying to certain land behind North Byron Beach. This letter report sets out the review and my opinion.

1. BACKGROUND

Planners North have prepared a Planning Proposal for submission to Byron Shire Council in relation to land at North Byron Beach identified as: Lots 1 & 2 DP1215893; Lots 12 & 13 DP243218; and Lot 449 DP812102. A copy of the Plan Set accompanying the application is included at **Appendix A**.

The subject land is presently identified by Byron Local Environmental Plan 2014 (BLEP14) as “Deferred Matter” and therefore the provisions of Byron Local Environmental Plan 1988 continue to apply to the land. Land identified as proposed for environmental zoning under BLEP14 was deferred from the LEP preparation process pending a review of the application of environmental zones by the Department of Planning & Environment. That review is complete and indicates that the subject land contains some areas of ecological significance and other areas which do not fit the criteria for the application of an E2 Environmental Conservation or E3 Environmental Management Zone.

An issue in determining the appropriate application of BLEP14 zones to the land is the extent to which the identified land is subject to coastal hazards. The following extract from the draft Planning Proposal supplied to Royal HaskoningDHV by Planners North outlined the position of the Proponent in relation to the coastal hazard.

The subject land is presently zoned 7(f1) Coastal Land in accordance with Byron Local Environmental Plan 1988 (BLEP88). This zoning reflects mapping undertaken in 1986 and adopted in Byron Development Control Plan 2010 (BDCP10) Chapter 1 Part J. Byron Shire Council has subsequently commissioned further coastline mapping and it is submitted that this mapping should form the basis for identifying land subject to the coastal hazard.

The mapping provided in Byron Shire Coastline Hazards Assessment Update Final Report September 2013, prepared by BMT WBM Pty Ltd for Byron Shire Council, reflects updated modelling. That mapping indicates that the immediate hazard line, minimum, best and maximum 2050 hazard lines and minimum, best and maximum 2100 hazard lines are significantly seaward of the lines previously identified in Part J of BDCP10. It is on this basis that it is submitted that the subject land should not be identified as subject to coastal hazard. It is also submitted that the resolution of the zoning for the subject land should therefore not be delayed to await the determination of the zoning regime which will be applied to other areas of the coastline which remain subject to coastal hazard.

Planners North propose that the E4 Environmental Living, E2 Environmental Conservation and SP3 Tourist zones are the appropriate zones to apply to the subject land based on the site constraints and attributes in accordance with the provisions of the Byron Local Environmental Plan 2014. The proposed zoning is considered by Planners North to be appropriate for a number of reasons including the view that the current coastal hazard assessment applying to the land (the BMT WBM update in September 2013) indicates the current land use zone (7(f1) Coastal Land) is not appropriate for the site.

In discussions between Planners North and Council it was considered that the Planning Proposal would be enhanced by a report which reviews the assessments of coastal hazard undertaken to date at the site and expresses an opinion as to the suitability of the land for the Proposal.

This letter report, prepared by Greg Britton, comprises the subject report. The qualifications and experience of the writer are set out in **Section 2**.

This report assumes the reader has a reasonable knowledge of the study area and an understanding of coastal hazard generally.

2. QUALIFICATIONS AND EXPERIENCE OF THE WRITER

Greg is the Technical Director of Royal HaskoningDHV in Australia. He is the former Manager of Coastal and Marine at WorleyParsons, and was a founding Director of Patterson Britton & Partners.

Greg has 41 years professional experience in the investigation, design, documentation, planning, environmental assessment, and project management of coastal, estuary and maritime projects. He received a Bachelor of Civil Engineering (First Class Honours, University Medal) from the University of New South Wales in 1976 and a Master of Engineering Science (Coastal Engineering) from the University of New South Wales in 1981. He is a Fellow of the Institution of Engineers Australia

He has provided expert advice on coastal, maritime and environmental engineering to the NSW Land and Environment Court, NSW Supreme Court, Queensland Supreme Court, Federal Court of Australia and several Commissions of Inquiry. He has fulfilled the role of a Court Appointed Expert (CAE) in the

NSW Land and Environment Court. In 2018 he was appointed by the NSW Minister for Planning to the Sydney District and Regional Planning Panels as a coastal expert.

Greg has undertaken a range of projects at Byron Bay over the past 20 years. These projects have included preparation of coastal engineering studies and coastal management advice for a range of land owners, including North Byron Bay Resort Pty Ltd, Department of Industry (Crown Land) and individual land owners, and for Byron Shire Council[1].

3. REVIEW OF ASSESSMENTS OF COASTAL HAZARD UNDERTAKEN TO DATE AT THE SITE

3.1 Introduction

The two key assessments of coastal hazard undertaken to date at the site are:

- the 1978 Byron Bay – Hastings Point Erosion Study prepared by the then NSW Department of Public Works (Department of Public Works, 1978). The findings of this study formed the basis of the hazard lines prepared in 1986 and included in Chapter 1 Part J of the Byron Development Control Plan 2010 (BDCP10);
- the 2013 Byron Shire Coastline Hazards Assessments Update prepared by BMT WBM Pty Ltd for Byron Shire Council (BMT WBM, 2013). The findings of this study have not as yet been included in any updated coastal hazard planning controls for Byron Shire.

The hazard lines determined from the 1978 study and included on Maps in Chapter 1 Part J of BDCP10 comprise an Immediate Impact Line and a 100 Year Impact Line, and are reproduced in **Figure 1**. The text in Part J states that the coastal hazards defined on the Maps were provided to Council by the then NSW Department of Land and Water Conservation. The 100 Year Impact Line would correspond to the year 2086, being 100 years from the date when the hazard lines were prepared.

[1] *Patterson Britton & Partners (2005), 'Scoping Study on Feasibility to Access the Cape Byron Lobe for Sand Extraction for Beach Nourishment', Draft Report for Byron Shire Council, November 2005.*

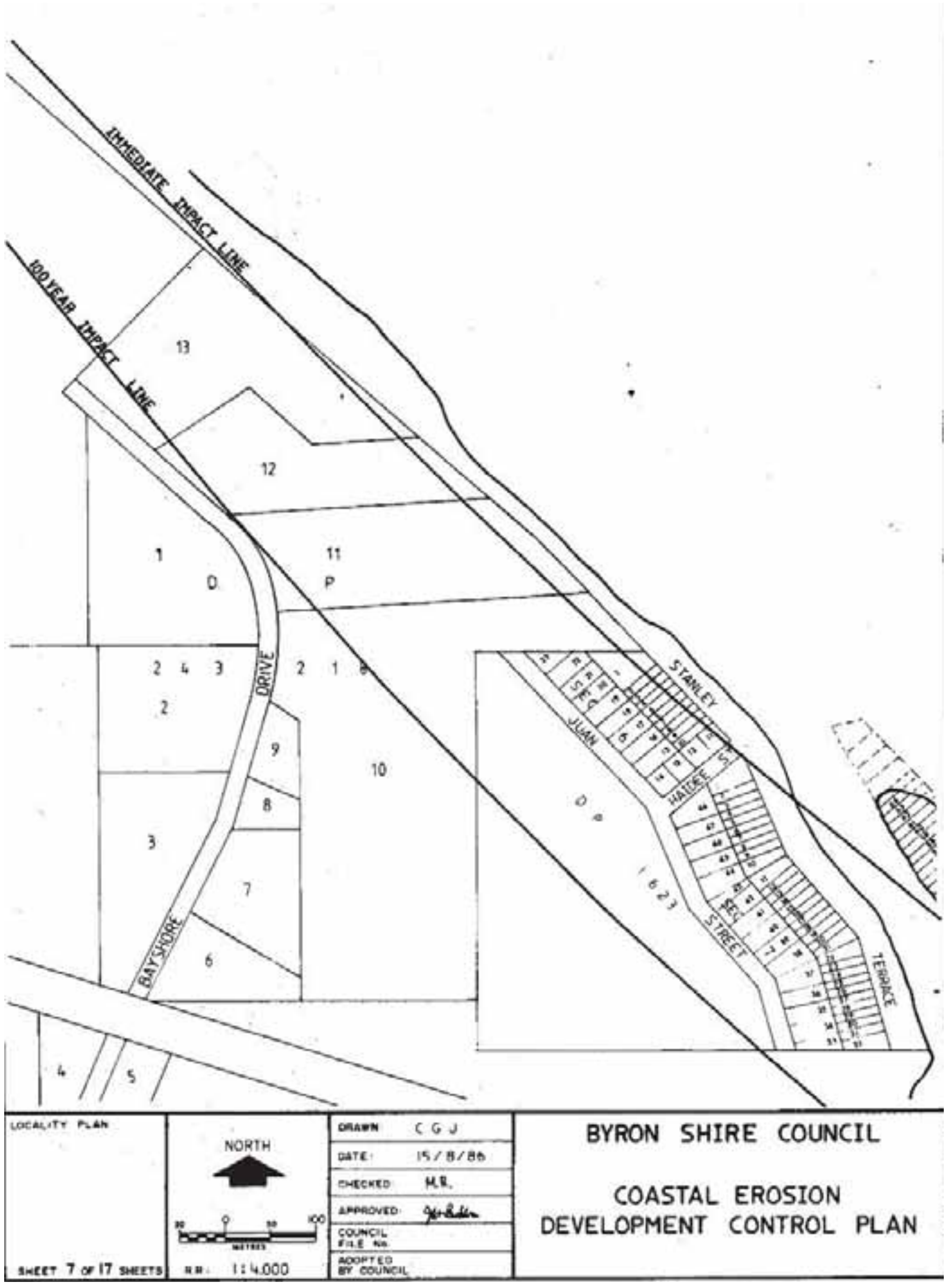


Figure 1: Immediate Impact Line and 100 Year Impact Line from Part J BDCP10

The hazard lines included in BMT WBM (2013) for the subject area have been determined for two erosion hazard scenarios:

- Scenario 1: Retention and permanent maintenance of all existing coastal erosion protection works and interim beach access stabilisation works along the Byron Bay Embayment; and
- Scenario 2: Retention of only the Jonson Street protection works and removal of all other coastal erosion protection works and interim beach access stabilisation works along the Byron Bay Embayment.

Future shoreline recession in the subject area would be greater under Scenario 1 than Scenario 2. It is also considered likely that Scenario 1 would prevail into the foreseeable future. For this reason the report herein assumes Scenario 1 would apply, which is conservative for the subject area.

BMT WBM (2013) includes an Immediate Hazard Line, a 2050 Hazard Line and a 2100 Hazard Line. In the case of the 2050 and 2100 hazard lines, three positions of the line are provided; a 'minimum', 'best' and 'maximum' position.

As suggested by the terminology, ‘best’ represents the best estimate of the hazard line into the future. The inclusion of ‘minimum’ and ‘maximum’ hazard lines is a recognition of the uncertainty inherent in modelling of future shoreline behaviour and/or factors that are difficult to otherwise quantify. The minimum and maximum positions of the hazard lines were determined by applying factors of ±20% relative to the ‘best estimate’ hazard lines distances.

The report herein considers all three positions of the hazard lines; ‘minimum’, ‘best’ and ‘maximum’, for the Scenario 1 erosion hazard.

The position of the 100 Year Impact Line in Chapter 1 Part J of BDCP10 (year 2086) and the position of the 2100 Hazard Lines for Scenario 1 in BMT WBM (2013) are quite different (even accounting for the different end dates), with the more recent hazard lines located significantly further seaward. **Figure 2** shows the relative positions of the hazard lines. This ‘best estimate’ 2100 Hazard Line in BMT WBM (2013) is approximately 170m seaward of the 100 Year Impact Line in Part J of BDCP10.

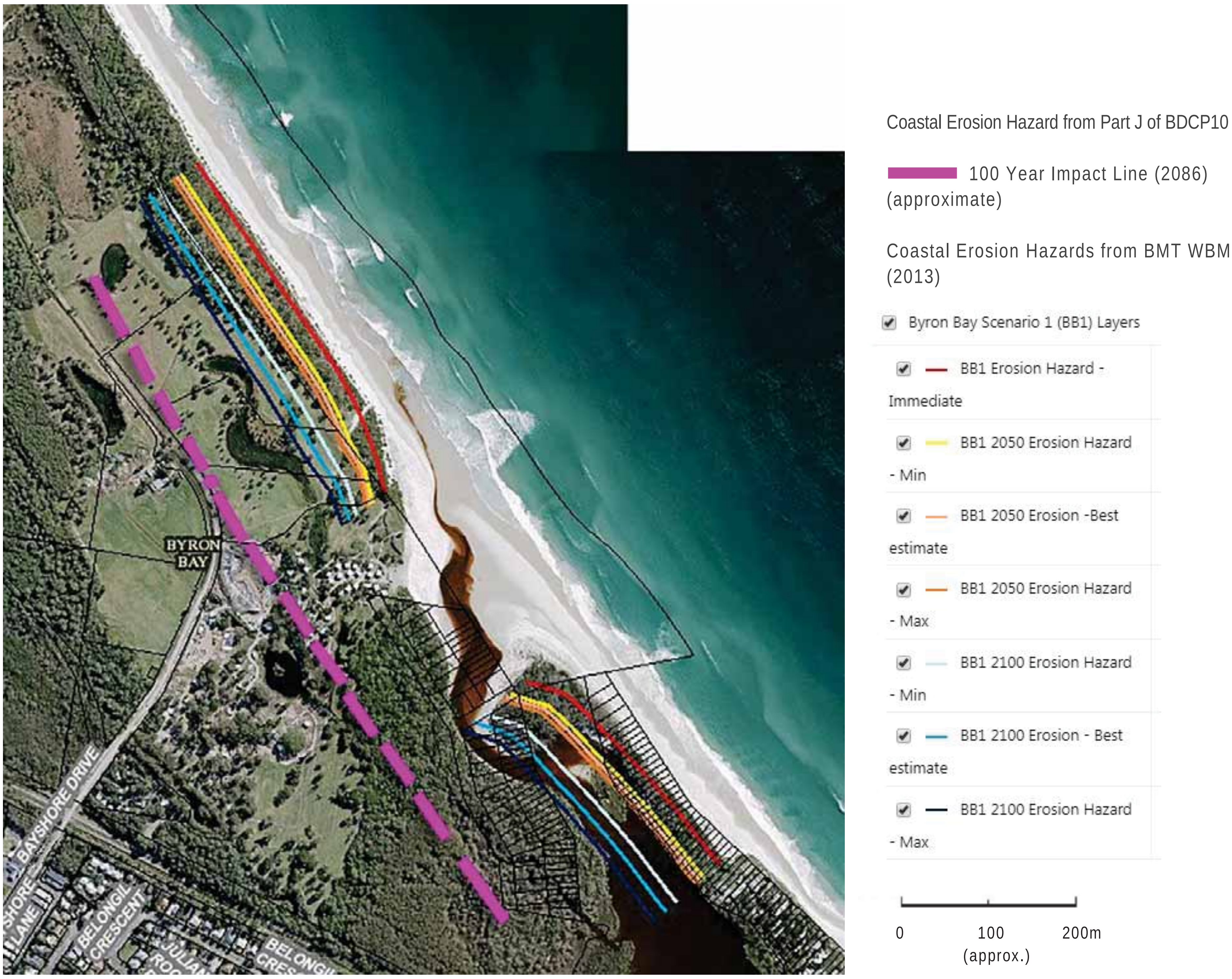


Figure 2: Relative positions of hazard lines in Part J BDCP10 and BMT WBM (2013)

3.2 Factors to be considered in the Review of Coastal Hazard

There are a number of individual factors which determine the position of the erosion hazard at a future time and which can be considered in the review; namely:

- planning period;
- storm bite or storm erosion demand;
- long term recession due to net sediment loss;
- long term recession due to sea level rise;
- selection of the pre-storm beach profile;
- the specific delineation of the hazard line at the end of planning period according to either the Zone of Wave Impact (ZWI), Zone of Slope Adjustment (ZSA) or Zone of Reduced Foundation Capacity (ZRFC), as defined in Nielsen et al (1992) and outlined further below.

Each of the above factors is considered in turn in **Section 3.3**. Discussion is also included in **Section 3.3** in relation to coastal entrance instability in the context of Belongil Creek.

The various hazard zones delineated in Nielsen et al (1992) at a particular point in time are shown in **Figure 3** and are defined in the text below the figure. The zones assume an entirely sandy (erodible) subsurface.

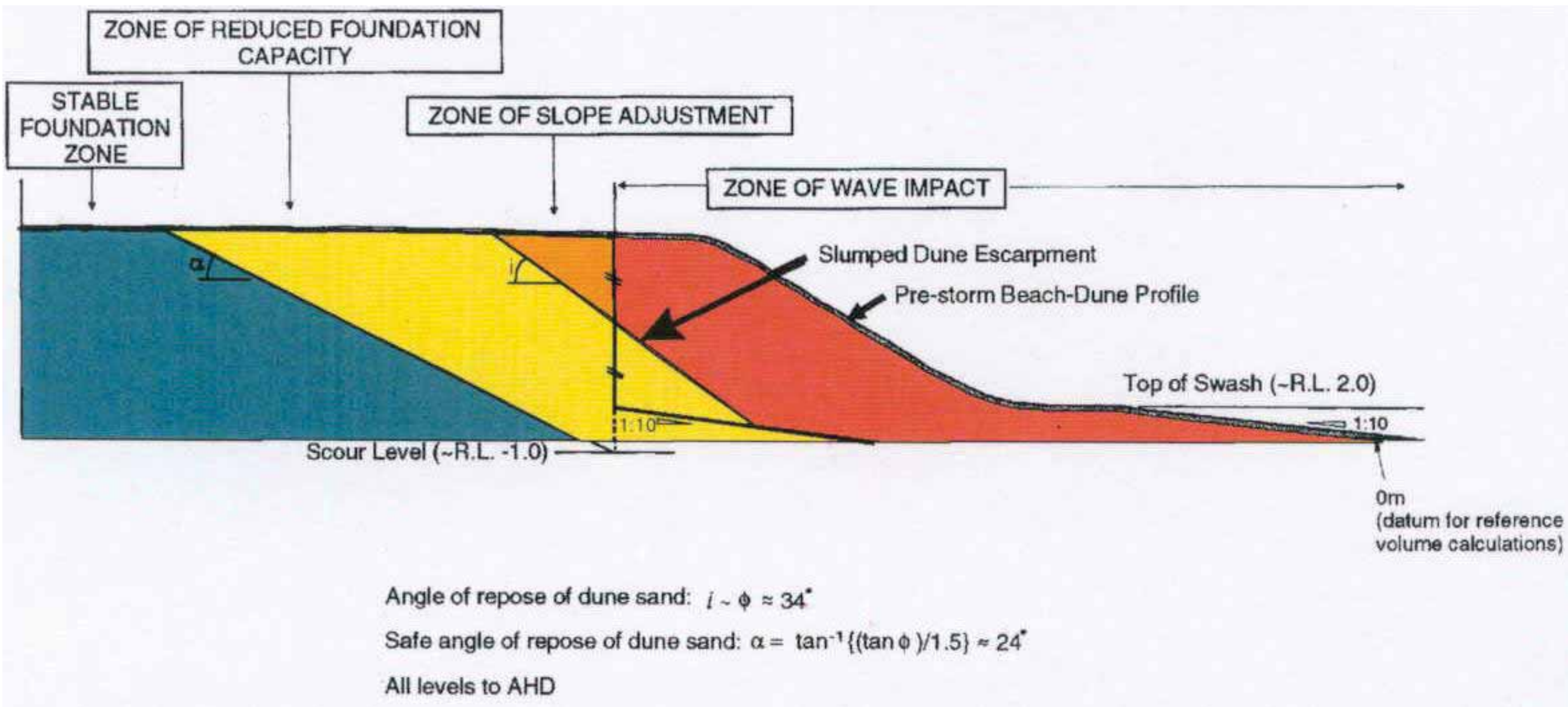


Figure 3: Schematic representation of coastline hazard zones (after Nielsen et al, 1992)

The ZWI delineates an area where any structure or its foundations would suffer direct wave attack during a severe coastal storm. It is that part of the beach which is seaward of the beach erosion escarpment.

A ZSA is delineated to encompass that portion of the seaward face of the beach that would slump to the natural angle of repose of the beach sand following removal by wave erosion of the design storm demand. It represents the steepest stable beach profile under the conditions specified.

A ZRFC for building foundations is delineated to take account of the reduced bearing capacity of the sand adjacent to the storm erosion escarpment. Nielsen et al (1992) recommended that structural loads should only be transmitted to soil foundations outside of this zone (i.e. landward or below), as the factor of safety within the zone is less than 1.5 during extreme scour conditions at the face of the escarpment. In general (without the protection of a terminal structure such as a seawall), dwellings/structures not piled and located with the ZRFC would be considered to have an inadequate factor of safety.

3.3 Review of Individual Factors

3.3.1 General

The individual factors listed in **Section 3.2** which determine the position of the erosion hazard are considered in turn below. For each factor, the approaches taken in Part J of BDCP10 and in BMT WBM (2013) are briefly outlined, followed by a discussion and opinion. Where necessary, in the case of Part J of BDCP10, reference is made back to the 1978 Byron Bay – Hastings Point Erosion Study (Department of Public Works, 1978).

3.3.2 Planning Period

Three planning periods were adopted in Part J of BDCP10; Immediate, 50 Year and 100 Year. Presumably these periods are measured from the date on the Maps; namely from 15 August 1986. Accordingly, the coastal hazard is defined at 1986, 2036 and 2086.

BMT WBM (2013) adopted three planning periods; Immediate, 2050 and 2100.

Guidance provided by the Office of Environment and Heritage (OEH) in Guidelines for Preparing Coastal Zone Management Plans (OEH, 2013a) notes that long term planning horizons to set strategic directions for coastal hazard areas would be 50 to 100 years.

Based on an understanding of the Planning Proposal, which involves creation of nine Lots, adoption of a planning period of 50 to 100 years is considered reasonable.

3.3.3 Storm Bite or Storm Erosion Demand

Storm erosion demand represents the volume of sand removed from a beach, measured above 0m relative to Australian Height Datum (AHD), in a severe storm or series of closely spaced storms. It is expressed in cubic metres per metre length of beach (m^3/m).

Part J of BDCP10 does not specifically state the storm erosion demand used to establish the Immediate Impact Line in the 1986 Maps. Department of Public Works (1978) noted in relation to short term erosion that accurate beach profile data was available for a period of six years from 1972 to 1978. This information was examined in the study to assess movement of mean sea level and the vegetation line.

It was noted that the position of mean sea level on the beach fluctuates markedly with time, with movements of 50 to 100m being not uncommon. Movement of the vegetation line was not subject to the same extent of short term fluctuations as mean sea level on the beach. Information for North Byron Beach was also confounded by the single available beach profile being located within the zone of influence of Belongil Creek. Generally, the information was dominated by a significant recovery of the beach over the period 1976-1978 which is not surprising given the severe cyclones of the late 1960s and early 1970s. Overall the interpretation of storm erosion demand was limited by the short period of record of only some 6 years (and the location of the particular beach profile).

BMT WBM (2013) was able to carry out a much more detailed assessment of storm erosion demand than was possible in the 1978 Erosion Study due to the longer period of historical data available and improved analysis techniques. The assessment included analysis of photogrammetric data over the 65 year period 1947 to 2012, comprising changes to beach volume and changes to the position of dunes (measured at specified dune contour level positions). On the basis of this analysis, a storm erosion demand of 250m^3/m was adopted for the North Byron Beach area.

A storm erosion demand of 250m^3/m is approximately equal to a 100 year Average Recurrence Interval (ARI) 'high demand' value at a rip head based on measurements at NSW beaches reported in Gordon (1987). It is similar to values adopted on the open coast by the writer and is considered reasonable for North Byron Beach.

3.3.4 Long Term Recession due to Net Sediment Loss

Long term recession due to net sediment loss refers to the shoreline recession due to ongoing sand losses from the coastal compartment. Commonly, these losses are the result of a difference in longshore sand transport out of a compartment compared to longshore sand supply into a compartment. This form of recession is considered separately to recession due to sea level rise. Typically, the assessment of recession due to net sediment loss is supported by development of a quantified conceptual model of sediment movement which explains the loss mechanism in physical terms.

Department of Public Works (1978) assessed 'long term erosion' based on three data sources:

- hydrographic surveys and associated survey data;
- historical, single point, data relating to a particular feature;
- aerial photographic coverage.

The greatest emphasis was placed on analysis of aerial photography, which covered the 30 year period 1947 to 1977. Erosion was examined in terms of movement of the back beach erosion escarpment located within the dunes. The accuracy of establishing the erosion escarpment at any point in time was considered to be ±20m.

The overall average long term recession rate for the entire Byron Bay to Hastings Point embayment was found to be 0.5m/yr. Localised average annual rates were up to 1.5m/yr in Byron Bay and 2.0m/yr at New Brighton. In the vicinity of North Byron Beach, average annual recession rates over the period 1947 to 1977 were approximately 1m/yr (Figure 5.7 in the 1978 Study).

Department of Public Works (1978) also set out a projected 50 Year and 100 Year shoreline position for the Byron Bay to Hastings Point embayment, measured from the present day (1978) erosion escarpment, based on a predictive model developed for the study area (Figure 13.1 in the 1978 Study). This information indicates, for the North Byron Beach area:

- the projected 50 Year shoreline position (2028) was greater than 100m landward of the 1978 erosion escarpment. Reference to historical photogrammetric beach profiles included in BMT WBM (2013) from 1958 to 2012 and examination of recent aerial photographs of the subject area (2018) show that this projected 50 Year shoreline position would not be expected to eventuate in practice. This outcome reduces the confidence in the predictive modelling in the 1978 Study;

- the difference between the 50 Year and 100 Year projected shoreline positions was approximately 100m, indicating that the model prediction for the average annual recession rate was around 2m/yr[2]. This rate is in excess of the measured data over the period 1947 to 1977 reported in the 1978 Study.

As noted earlier, the findings of the 1978 Byron Bay – Hastings Point Erosion Study formed the basis of the hazard lines prepared in 1986 by the NSW Department of Land and Water Conservation and supplied to Council, and which are included on Maps in Part J of BDCP10. Accordingly, the 100 Year Impact Line (position of erosion escarpment) shown in Part J of BDCP10 is considered unduly conservative.

BMT WBM (2013) assessed the historical long term recession due to net sediment loss principally through photogrammetric analysis of historical vertical aerial photography, covering the 65 year period 1947 to 2012. The analysis included determination of dune volume changes and movement of specific contour levels in the dunes; namely the 1.5m AHD, 2.5m AHD and 4.0m AHD contour levels.

The photogrammetric analysis indicated little persistent shoreline change in the subject area north of Belongil Creek entrance (Zones 0 and 1 in the analysis) until around 1985 to 1990, after which there was commencement of a marked trend of volume loss and dune scarp recession, indicating a present trend of recession (year 2013) of about 1.0m/yr.

It was noted that the more recent 2010-2012 beach/dune condition was affected by substantial storm erosion since 2009, potentially masking the ongoing longer term trend of change, with greater than the trend retreat of the erosion escarpment occurring in the period 2010-2012. Nevertheless, it was considered that recession in the unprotected shoreline north of the seawalls along Belongil Spit, ie. in the subject area, appeared to be accelerating consistent with a transfer of the overall net loss of sand from the whole Byron Bay Embayment (Cape Byron to Tyagarah Beach) towards the north-western (downdrift) end of the embayment.

BMT WBM (2013) sought to explain the differences in measured historical rates of recession by different parties and to isolate a suitable ongoing trend of shoreline change for future planning purposes by identifying several factors influencing shoreline position over time:

- the underlying long term recession trend (decades to centuries);
- medium term variability in shoreline position due to cycles of naturally varying sand supply to the embayment from the south, measured in years, which are superimposed on the long term trend; and
- short term variability due to storm erosion and recovery which are superimposed on both trends above.

[2] *In addition, the distance between the Immediate Impact Line and 100 Year Impact Line in the relevant Map for North Byron Beach in Part J of BDCP10 is approximately 200m, also indicating an adopted average annual recession rate of approximately 2m/yr.*

The above factors were illustrated conceptually by BMT WBM (2013) in Figure 4-27 of their report, reproduced here as **Figure 4**. It was also noted that the pattern of shoreline change over time is further complicated in the Byron Bay Embayment by the impacts of coastal protection works.

BMT WBM (2013) concluded that the assessment of shoreline recession in the 1978 Study, which gave values of up to 1.5m/yr in Byron Bay (1947-1977 analysis period), and the assessment of shoreline recession in WBM Oceanics Australia (2000), which gave a lower recession rate of 1.0m/yr (1947-2000 analysis period), were both influenced by the substantial storm erosion loss between 1947 and 1973 and the medium term variability involving a shoreline recession phase up to about 1980 (refer **Figure 4**). Accordingly, it was considered that both estimates were overestimates of the actual recession rates. It was noted that an estimate for the underlying long term trend of recession in the Byron Bay Embayment in Patterson (2013) was 0.25m/yr.

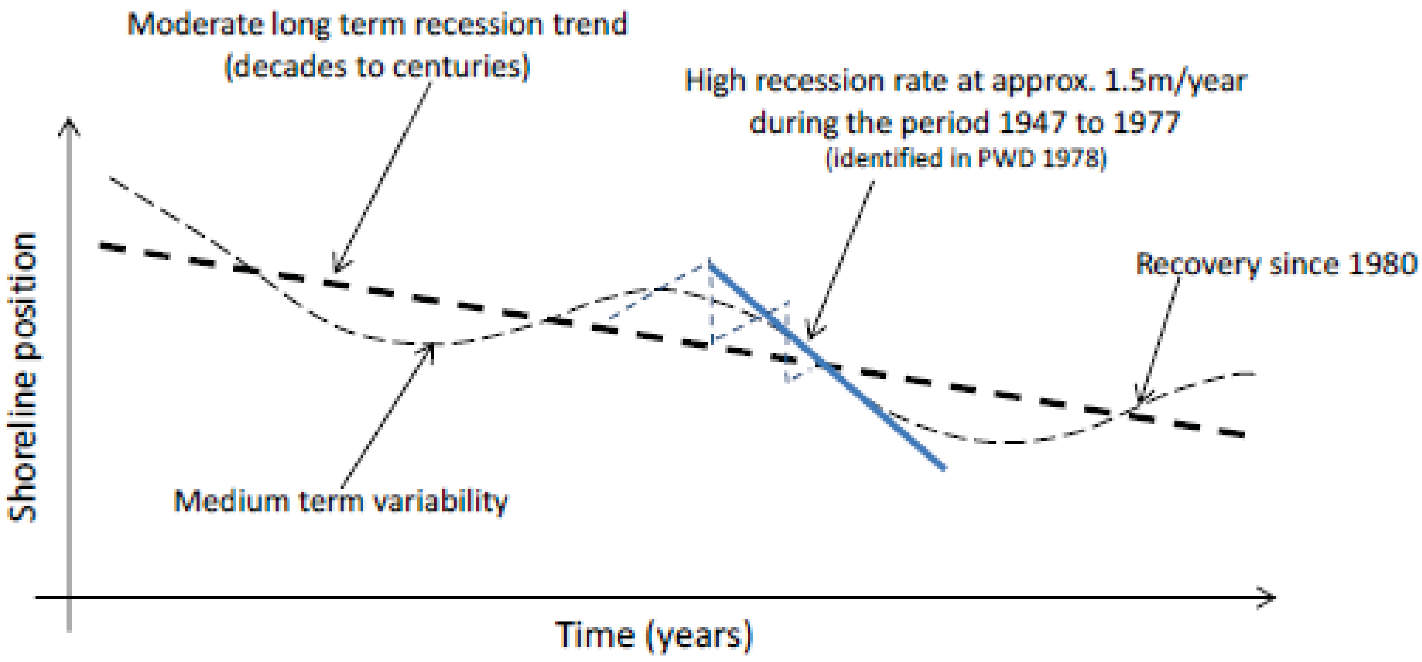


Figure 4: Conceptual representation of recession and variability in the Byron Bay Embayment

BMT WBM (2013) utilised a so-called EVO-MOD regional model, refined in detail within the Byron Bay Embayment, to project future shoreline behaviour. Use of a predictive model, rather than reliance completely on measured historic data, was considered unavoidable because:

- only by model simulation can the processes leading to reduction in the recession rate as the recession proceeds be simulated reasonably; and
- the non-uniform alongshore effects of headlands and coastal structures on shoreline response to sea level rise cannot be determined by other means.

Tables in BMT WBM (2013) indicated that the overall predicted recession rate due to net sediment loss adopted for the subject area in Scenario 1 (involving retention and permanent maintenance of all existing coastal protection works) was approximately 0.5m/yr for the period 2010 to 2050 and was approximately 0.45m/yr for the period 2050 to 2010.

The assessment of recession due to net sediment loss in BMT WBM (2013) involved a thorough analysis of photogrammetric data from historical aerial photography (1947-2012) and the establishment and validation of a predictive shoreline movement model that incorporates waves and sand transport.

While uncertainties exist with predictive modelling the approach taken in BMT WBM (2013) is considered to represent a sound basis for coastal hazard assessment in conjunction with the measured data. Uncertainties are provided for by adopting likely upper and lower limits for the future coastal hazard.

3.3.5 Long Term Recession due to Sea Level Rise

It is well accepted that a projected future climate change induced sea level rise will cause recession as the shoreline adjusts to the higher sea level.

Department of Public Works (1978) did not consider shoreline recession due to sea level as this phenomenon was not understood in the late 1970s.

BMT WBM (2013) used the EVO-MOD model to estimate shoreline recession due to projected sea level rise and compared these estimated recession distances to those calculated using the well-accepted Bruun Rule (Bruun, 1962).

Sea level rise estimates of 0.4m and 0.9m to the years 2050 and 2100 respectively (relative to 1990) were adopted. These estimates became 0.34m and 0.84m at 2050 and 2100 respectively when applied to the base year of 2010 in BMT WBM (2013). A best estimate Bruun Rule slope factor of 45:1 was adopted based on available data for the study region. To allow for the uncertainties involved in determining projected future sea level rise impacts at the shoreline, lower and upper limits of potential recession were set by applying variations of -20% and +30% to the best estimate slope factor, ie. a range of approximately 36:1 to 60:1, for 5m high dunes.

The EVO-MOD model approach gave somewhat higher estimated shoreline recession due to projected sea level than the Bruun Rule values and were adopted for establishing the future coastal hazards.

The approach adopted in BMT WBM (2013) for estimating shoreline recession due to projected sea level rise is considered sound. The values adopted for sea level rise are slightly higher than values recently adopted by the writer for the rezoning of coastal land on the Kurnell Peninsula in Sydney which were 0.22m and 0.72m at 2050 and 2100 respectively (relative to 2016). The latter values were based on the IPCC (2013) RCP6.0 (high) scenario, increased by 10% for local variation relative to the global mean values.

3.3.6 Selection of Pre-storm Profile

Selection of the pre-storm profile upon which to apply the storm erosion demand and subsequently the shoreline recession due to net sediment loss and due to sea level rise is important as this influences the ultimate position of the future coastal hazard.

In selecting the pre-storm profile the aim should be to adopt a relatively accreted beach profile, typically referred to by the writer as an ‘average beach full’ profile, as the high storm erosion demands selected in hazard analysis (such as 250m^3/m selected at North Byron Beach in BMT WBM (2013)), can only be realised in practice if accreted profiles exist (in the situation of eroded profiles there are large quantities of sand in offshore bars which dissipate wave energy giving lower storm erosion demands). The selected pre-storm profile should also, ideally, be contemporary.

PWD (1978) adopted the 'present day' (1978) erosion scarp to determine the immediate erosion hazard zone and the future 50 year and 100 year erosion hazard zones. The state of the beach in 1978 based on photos in PWD (1978) indicated beach recovery following the severe cyclones in the late 1960s and early 1970s but may not have represented 'average beach full'. In any case the profile is now quite dated.

BMT WBM (2013) adopted the 'baseline mean shoreline trend position' as at 2010 for the pre-storm profile with the provision that, following application of the design storm erosion demand, the immediate erosion hazard line extended as far landward as the crest of the most landward measured erosion escarpment in the historical record.

Of the two studies, the BMT WBM (2013) is the most contemporary and the pre-storm profile adopted in that study, established for 2010, is considered the most appropriate from the two studies. Having said that, the 'baseline mean shoreline trend position' is likely to be further landward than an 'average beach full' condition and therefore somewhat conservative.

3.3.7 Delineation of Hazard Line

The means of delineation of the hazard line at a particular point in time, ie. ZWI, ZSA or ZRFC from Nielsen et al (1992), affects the position of the hazard line 'on the ground' as outlined in **Section 3.2**.

PWD (1978) essentially adopted the ZSA, as they translated the position of the crest of the (slumped) erosion escarpment landward.

BMT WBM (2013) discussed the relevance of both the ZSA and ZRFC. The hazard definition maps included in the report corresponded to the landward edge of the ZSA and therefore did not include the ZRFC. It was noted that the actual geotechnical conditions on site (not known) will influence the extent of the ZRFC. It was recommended that expert geotechnical engineering assessment be sought to establish the structural stability of foundations located (or likely to be located) within the ZRFC, on a case by case basis.

The NSW Coastal Planning Guideline: Adopting to Sea Level Rise (NSW Department of Planning, 2010) provides some guidance as to how the Immediate Hazard line, 2050 Hazard Line and 2100 Hazard Line are defined relative to the erosion and recession hazards, and the ZRFC. In summary, the mapping lines are defined to <u>include</u> the ZRFC (refer to Glossary in NSW Department of Planning, 2010).

The above position in NSW Department of Planning (2010) is not to say development is necessarily prohibited seaward of, say, the 2100 Hazard Line as this would depend on provisions within the relevant LEP and DCP. Such development is in fact contemplated in the Planning Guideline, eg. refer Figure 4 in that document, and assessed on merit. It is essentially about managing risk.

3.3.8 Coastal Inlet Instability (Belongil Creek)

BMT WBM (2013) did not extend the coastal hazard mapping to include the entrance area of Belongil Creek, due to the effect of creek meandering on shoreline behaviour which can confound the analysis. It was noted that the more recent pattern of entrance behaviour appears to be one of southward migration associated with shoreline recession. There was considered to be a significant likelihood that the creek could break through to the ocean south of its current entrance location, in the Manfred Street area, in the short to medium term (less than 20 to 50 years), although it was noted that this predicted behaviour was somewhat speculative and uncertain.

A significant feature of the entrance area of Belongil Creek not referred to in BMT WBM (2013) has been the formation, naturally, over the past 25 years or so, of a recurved spit at the northern end of Belongil Spit and its continued vegetative stabilisation and growth in volume (visible in **Figure 2**). This feature has forced the creek to be diverted westward causing erosion of the left hand bank of the creek (looking downstream) and loss of Littoral Rainforest. This process can be expected to be ongoing whilever there is a supply of sand to the recurred spit from Belongil Spit.

A further relevant feature of the entrance area is the Temporary Coastal Protection Works (TCPW), comprising sand filled geotextile containers (geocontainers), constructed in March 2015 to protect the creek entrance frontage of the North Byron Beach Resort. The works are located wholly on private land owned by Ganra Pty Ltd (North Byron Beach Resort).

The TCPW were permissible under the Coastal Protection Act, 1979. There is an ongoing requirement on Ganra Pty Ltd to ensure the works are appropriately maintained in accordance with statutory requirements as set out in OEH (2013b).

In the event Belongil Creek breaks through to the ocean south of its current entrance location, in the Manfred Street area, as considered likely in BMT WBM (2013), the consequences for North Byron Bay Resort would be unlikely to be adverse and more likely beneficial. The existing entrance area would be expected to infill with sand supplied from the south and, over time, an incipient and frontal dune system would be expected to develop, providing greater erosion protection locally to the Resort.

In the interim prior to any breakthrough to the south, the preferred approach to management of the entrance area of Belongil Creek is considered to be construction of low key entrance training works and creek bank protection which stabilise the entrance location and arrest ongoing loss of Littoral Rainforest.

The existing TCPW will continue to provide a level of erosion protection to the creek entrance frontage of the Resort and can be maintained following any damage. The most significant form of coastal hazard for this area for the foreseeable future is likely to be the coastal inundation hazard.

4. SUMMARY OF OPINION

The 1978 Byron Bay – Hastings Point Erosion Study (Department of Public Works, 1978) which informs the coastal hazard in Part J of BDCP10 was a landmark coastal erosion hazard study at the time but is now some 40 years old. It is also evident, 40 years later, that projections of future shoreline position made in that Study are unduly conservative.

BMT WBM (2013) had the benefit of more than twice the period of historical record from aerial photography, the availability of more sophisticated analysis techniques and predictive modelling capability, and selection of a relatively contemporary pre-storm profile.

For the above reasons, BMT WBM (2013) is considered a preferred basis for assessment of coastal hazard for the subject area. It is considered reasonable to adopt the 'best estimate' position of the hazard line from this study[3].

In applying the findings of BMT WBM (2013) it should be noted that the extent of the coastal hazard does not include allowance for the ZRFC.

In the entrance area of Belongil Creek, where coastal hazards are not defined in BMT WBM (2013), adherence to maintenance responsibilities for the existing TCPW should be continued. The most significant form of coastal hazard for this area for the foreseeable future is likely to be the coastal inundation hazard. Construction of low key entrance training works and creek bank protection works would address the existing coastal entrance instability hazard and the current ongoing loss of Littoral Rainforest over the long term.

5. REFERENCES

BMT WBM (2013), '*Byron Shire Coastline Hazards Assessment Update*', prepared for Byron Shire Council, Final Report, R.B19093.001.03.docx, September 2013

Bruun P (1962), '*Sea Level Rise as a Cause of Shore Erosion*', Journal of Waterways and Harbours Division, American Society of Civil Engineers, Vol 88, pp117-130

Department of Public Works (1978), '*Byron Bay – Hastings Point Erosion Study', Coastal Engineering Branch*, Report No PWD 78026, November 1978

Gordon, AD (1987), '*Beach Fluctuations and Shoreline Change – NSW', Preprints of Papers, 8th Australasian Conference on Coastal and Ocean Engineering, Launceston*, 30 November to 4 December, Institution of Engineers Australia National Conference Publication No 87/17, pp. 103-167

Intergovernmental Panel on Climate Change (2013), *Climate Change 2013, The Physical Science Basis, Working Group/Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, [Stocker, TF; Qin, D; Plattner, G-K; Tignor, M; Allen, SK; Boschung, J; Nauels, A; Xia, Y; Bex, V and PM Midgley (editors)], Cambridge University Press, Cambridge, United Kingdom and New York, New York, USA

Nielsen, AF; Lord, DB and HG Poulos (1992), '*Dune Stability Considerations for Building Foundations'*, Australian Civil Engineering Transactions, Institution of Engineers Australia, Volume CE34, No. 2, June, pp. 167-173

NSW Department of Planning (2010), '*NSW Coastal Planning Guideline: Adapting to Sea Level Rise*', Pub no. DoP 10-022, ISBN 978-1-74263-035-9, August 2010

[3] The positions of the hazard lines in BMT WBM (2013) have been established using a 'deterministic' approach, which has been the traditional methodology adopted in NSW. In this approach, single values are adopted for the main parameters used to derive the hazard line, eg. storm erosion demand, recession rate due to net sediment loss, etc with generally conservative estimates applied. In addition, the design storm is assumed to occur at the end of the planning period. More recently, probabilistic approaches have been adopted for determination of coastal hazard lines. The probabilistic approach allows each input parameter to vary randomly according to appropriate probability distribution functions. In the experience of the writer, the deterministic approach gives more conservative outcomes compared to the probabilistic approach. In addition, the 2010 pre-storm profile adopted in BMT WBM (2013) is likely to be somewhat conservative.

Office of Environment and Heritage [OEH] (2013a), *Guidelines for Preparing Coastal Zone Management Plans*, OEH 2013/0224, ISBN 978-1-74359-054-6, July 2013

Office of Environment and Heritage [OEH] (2013b), *Guide to the Statutory Requirements for Temporary Coastal Protection Works*; OEH 2013/0638, ISBN 978-1-74359-272-4, August 2013

Patterson DC (2013), '*Modelling as an Aid to Understand the Evolution of Australia's East Coast in Response to Late Pleistocene – Holocene and Future Sea Level Change*', PhD Thesis, Civil Engineering, University of Queensland

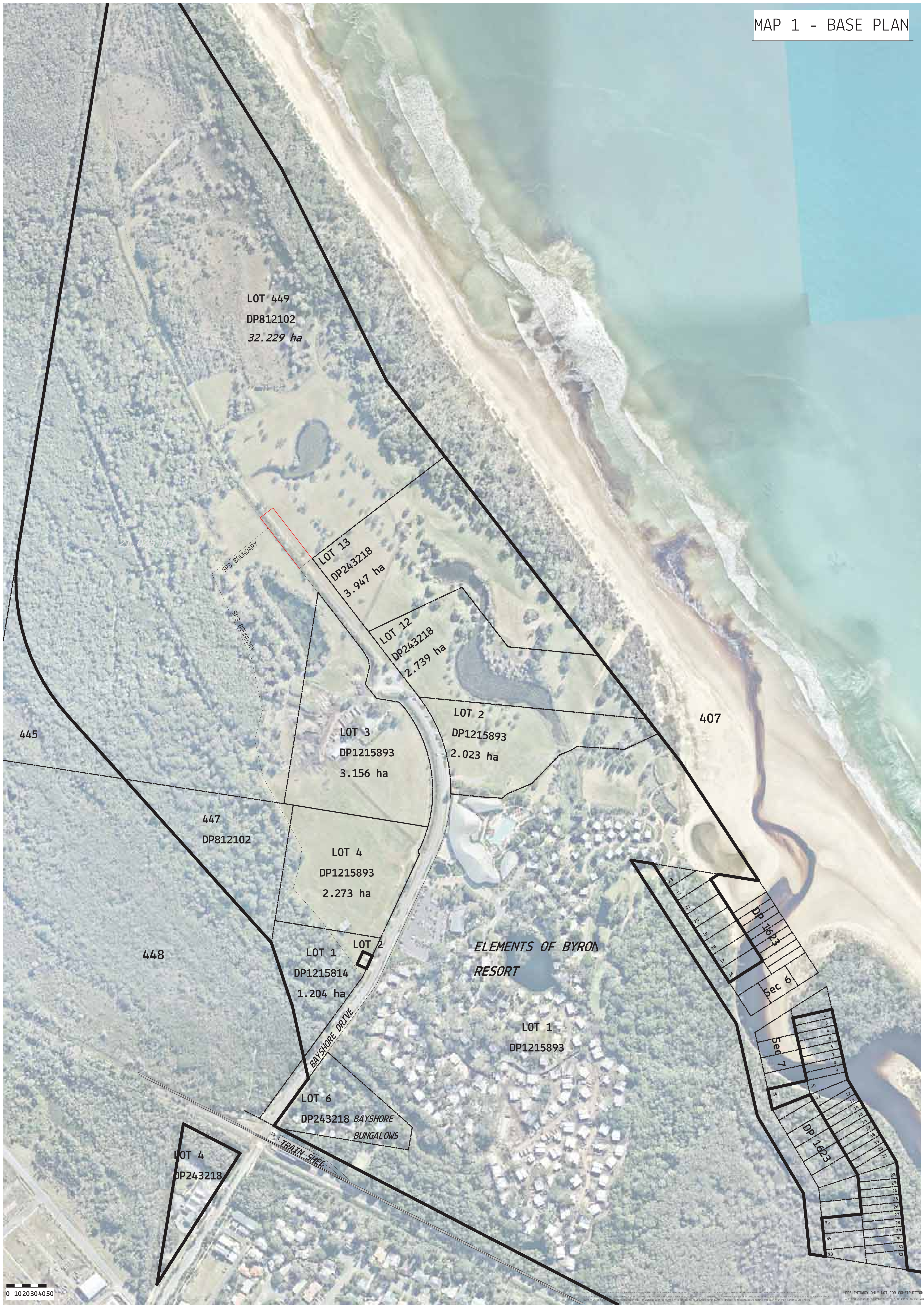
WBM Oceanics Australia (2000), '*Byron Shire Coastal Hazard Definition Study'*, prepared for Byron Shire Council

I trust the above meets your current requirements. Please call should you require any clarification or additional information.

Greg Britton
Yours faithfully

Technical Director
Maritime & Aviation, Australia

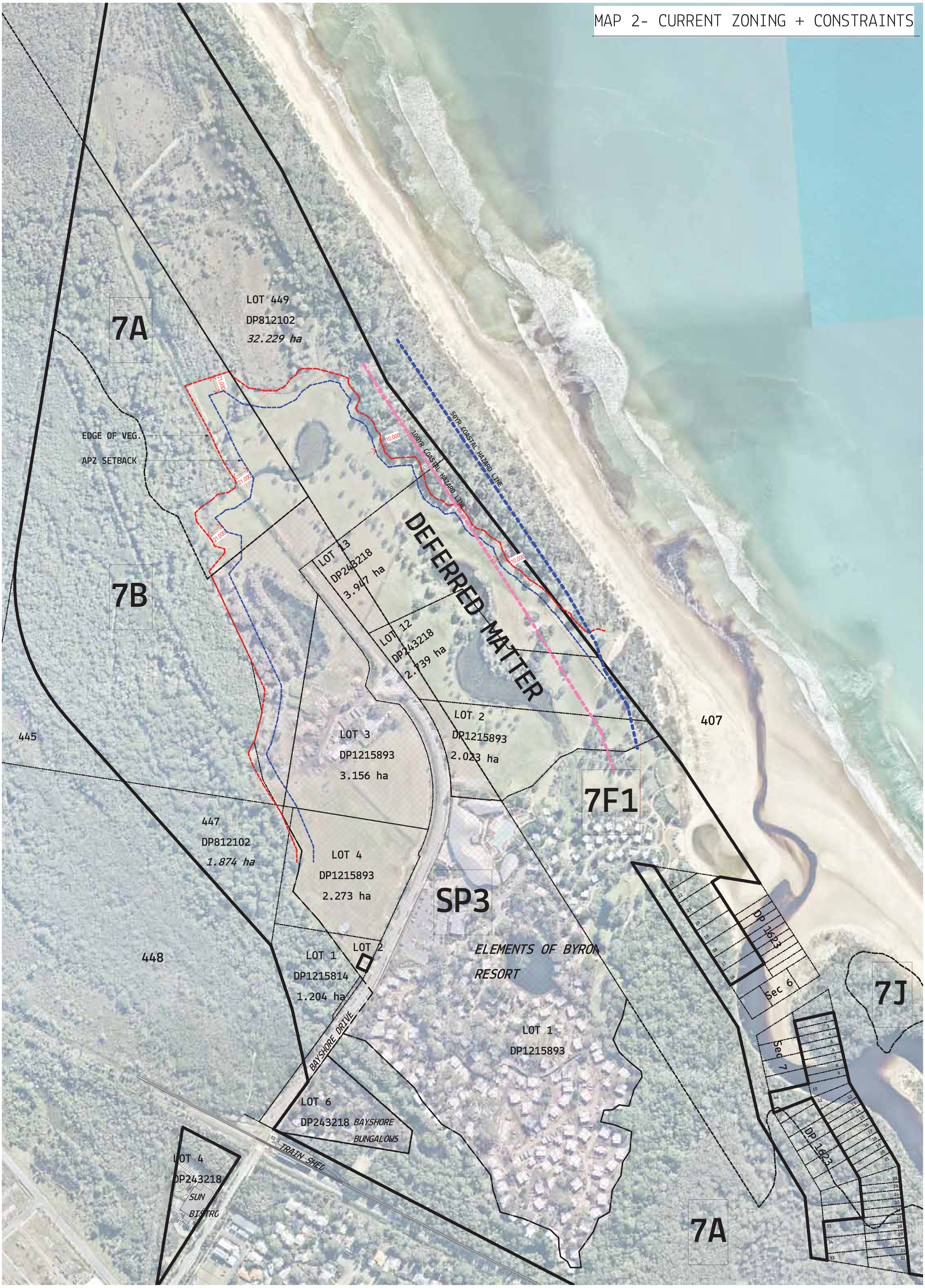
APPENDIX A – COPY OF PLAN SET PREPARED BY PLANNERS NORTH



MYERS ELLYETT

CLIENT	PROJECT	TRUE NORTH	PROJECT NORTH	SCALE (A1)	DRAWING NUMBER	STATUS	DATE	DRAWING
NORTH BYRON BEACH RESORT PTY LTD	NORTH BYRON BEACH RESORT			1 : 2000	TP2.001	PRELIMINARY	28.08.18	MAP 1 - NBBR LAND HOLDING - BASE PLAN

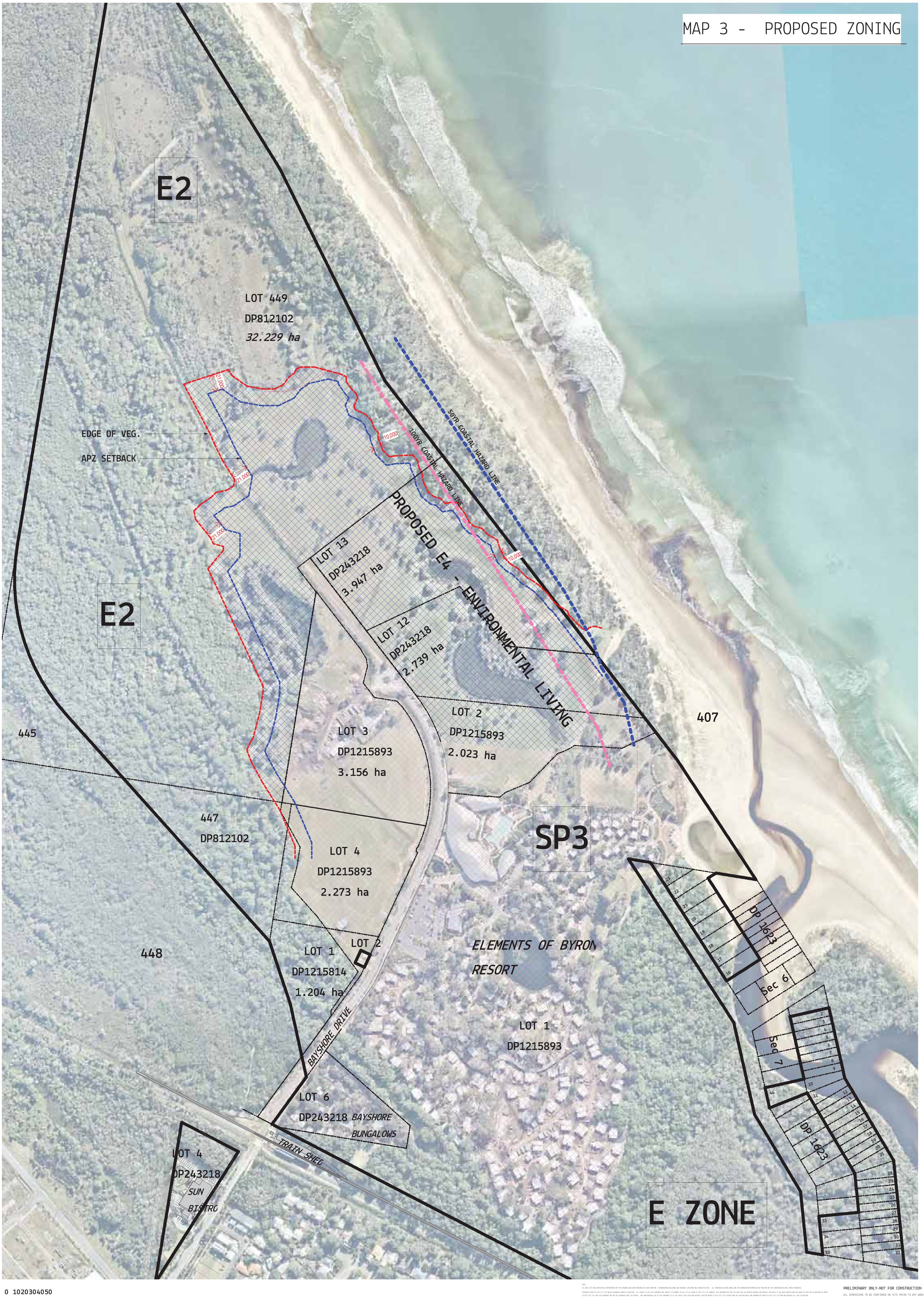
MAP 2- CURRENT ZONING + CONSTRAINTS



NOTE:
ALL REAL SITE DATA AND DETAILS REPRESENTED ON THIS DRAWING HAVE BEEN PROVIDED BY LAND SURVEYOR. NEIGHBOURING BUILDINGS AND DRIVEWAY LOCATIONS ARE INDICATIVE ONLY. ALL PROPOSED BUILDING WORKS ARE FOR COORDINATION PURPOSES ONLY AND ARE NOT FOR CONSTRUCTION UNTIL NOTED OTHERWISE.

PRELIMINARY ONLY-NOT FOR CONSTRUCTION
ALL DIMENSIONS TO BE CONFIRMED ON SITE PRIOR TO ANY WORK

MYERS ELLYETT	CLIENT	PROJECT	TRUE NORTH	PROJECT NORTH	SCALE (A1)	DRAWING NUMBER	STATUS	DATE	DRAWING
	NORTH BYRON BEACH RESORT PTY LTD	NORTH BYRON BEACH RESORT			1 : 2000	TP2.002	PRELIMINARY	28.08.18	MAP 2 - NBBR LAND HOLDING - CURRENT ZONING



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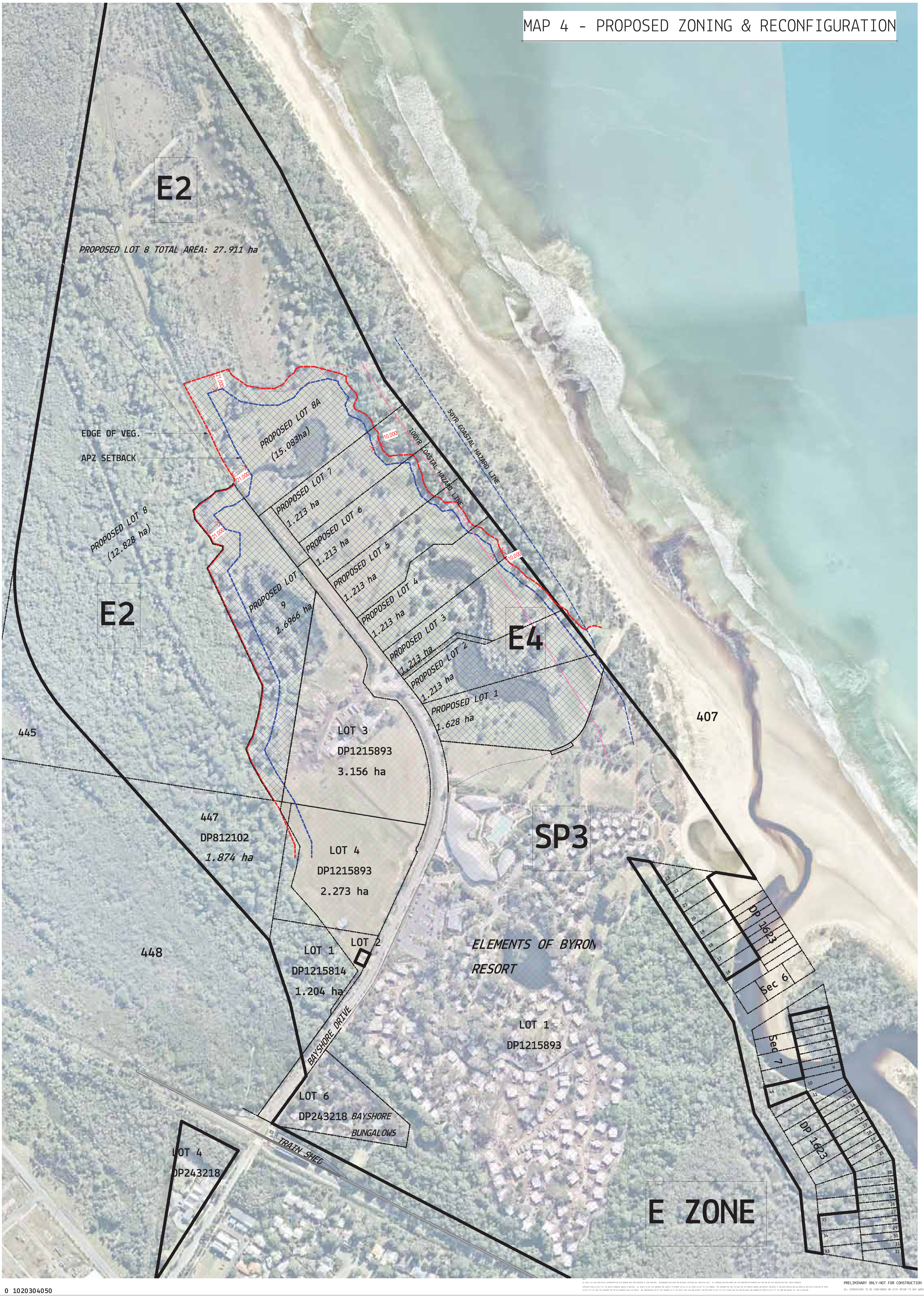
PRELIMINARY ONLY-NOT FOR CONSTRUCTION

ALL DIMENSIONS TO BE CONFIRMED ON SITE PRIOR TO ANY WORK

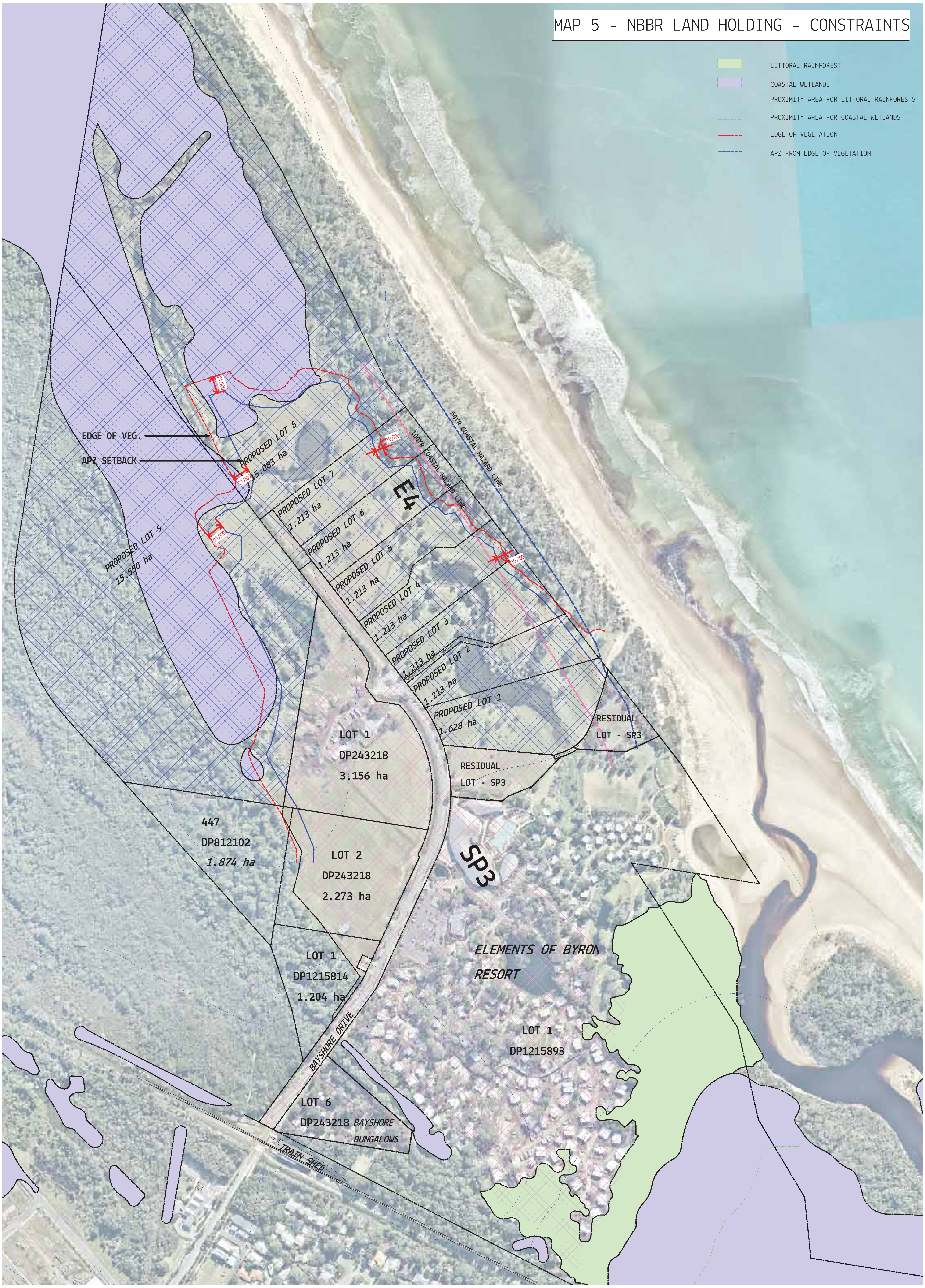
MYERS ELLYETT	CLIENT	PROJECT	TRUE NORTH	PROJECT NORTH	SCALE (A1)	DRAWING NUMBER	STATUS	DATE	DRAWING
	NORTH BYRON BEACH RESORT PTY LTD	NORTH BYRON BEACH RESORT			1 : 2000	TP2.003	PRELIMINARY	28.08.18	MAP 3 - NBBR LAND HOLDING - PROPOSED ZONING



PRELIMINARY ONLY-NOT FOR CONSTRUCTION

ALL DIMENSIONS TO BE CONFIRMED ON SITE PRIOR TO ANY WORK

MYERS ELLYETT	CLIENT	PROJECT	TRUE NORTH	PROJECT NORTH	SCALE (A1)	DRAWING NUMBER	STATUS	DATE	DRAWING
	NORTH BYRON BEACH RESORT PTY LTD	NORTH BYRON BEACH RESORT			1 : 2000	TP2.004	PRELIMINARY	20.09.18	MAP 4 - NBBR LAND HOLDING - PROPOSED ZONING SUBDIVISION



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PRELIMINARY ONLY-NOT FOR CONSTRUCTION
ALL DIMENSIONS TO BE CONFIRMED ON SITE PRIOR TO ANY WORK

MYERS ELLYETT	CLIENT	PROJECT	TRUE NORTH	PROJECT NORTH	SCALE (A1)	DRAWING NUMBER	STATUS	DATE	DRAWING
	NORTH BYRON BEACH RESORT PTY LTD	NORTH BYRON BEACH RESORT			As indicated	TP2.005	PRELIMINARY	21.01.19	MAP 5 - NBBR LAND HOLDING - CONSTRAINTS

Attachment 2 – Comments Register

Comments Register

Document name: Review of Coastal Hazard at North Byron Bay using a Probabilistic Approach – Methodology and Selection of Key Parameters – 3 October 2019 (RHDHV reference PA1998-ZZ-XX-RP-Z-0001)

Review Date	Reviewer	Section	Reviewers comment	RHDHV response
17.10.19	DPIE (Ben Fitzgibbon)	1.1 – Background	Date for Byron Bay – Hastings Point Erosion Study should be 1978 not 1998.	Thank you, this typo has been noted.
17.10.19	DPIE (Ben Fitzgibbon)	3.3 – Planning Period	The NSW Coastline Management Manual recommends a CMP should consider timeframes and planning horizons including immediate, 20 years, 50 years and 100 years (refer Part A, mandatory requirement 2). It is recommended the study assess the hazards over immediate, 20, 50 and 100 years.	Agreed. Study will assess the hazards at: • Immediate • 20 years (2040) • 50 years (2070 • 100 years (2120)
17.10.19	DPIE (Ben Fitzgibbon)	3.5 – Recession due to Sea Level Rise	In the interest of cost savings, Byron Shire Council <u>may</u> continue to use the BMT WBM (2013) Byron Shire Coastline Hazards Assessment Update Report (with possible probabilistic enhancement incorporating a greater sea level rise range assessment) as the basis of the hazard work for the CMP currently under development. This has not yet been confirmed. The BMT WBM (2013) work uses the old NSW SLR Policy benchmarks (0.4m and 0.9m of SLR relative to 1990 for 2050 and 2100). Councils current SLR policy is here: https://www.byron.nsw.gov.au/Services/Environment/Climate-change/Adaptation/Climate-Change-Strategic-Planning-Policy	The study will consider both Council's current SLR policy and a range of SLR projections provided in IPCC (2013). See also response under Point 4 – email 25.10.19.

Review Date	Reviewer	Section	Reviewers comment	RHDHV response
17.10.19	DPIE (Ben Fitzgibbon)	Appendix A – Figure 5 and Figure 6	This plot appears to show 'low demand' as based on Figure 5 above, not 'high demand'?	The plot does show 'high demand'. The particular example of the methodology provided within Appendix A happens to be for a sheltered beach (not North Byron Bay) where the storm demand is lower than for an open coast beach. The study will adopt high demand (rip head) values of storm demand, based on assessment of Byron Bay data by BMT WBM (2013) and review by RHDHV (100 year ARI value equal to 250m^3/m).
17.10.19	DPIE (Ben Fitzgibbon)	Appendix A – Figure 18	115m^3/m for the 100 year ARI storm demand?	Again Figure 18 shows an example only of the methodology, which happens to be for a sheltered beach. As noted above, 250m^3/m will be adopted in the study for the 100 year ARI storm demand.

Document name: Email from Ben Fitzgibbon (DPIE) to Kate Singleton (Planners North) and Greg Britton (RHDHV) dated 25.10.19

Review Date	Reviewer	Section	Reviewers comment	RHDHV response
25.10.19	DPIE (various)	Point 1	The proposed probabilistic methodology appears generally reasonable, however, we note the proposal does not list which bounding parameters will be used, or how closely the triangular distributions may fit the actual distribution of any applied parameters. Therefore we are unable to comment on whether or not these factors are fit for purpose.	Listing of bounding parameters: The following bounding parameters were listed in the report: • underlying recession (Section 3.4): - peak/modal value (best estimate): 0.5m/yr; - minimum: 0.4m/yr (-20%); and - maximum: 0.6m/yr (+20%).

Review Date	Reviewer	Section	Reviewers comment	RHDHV response
				• Sea level rise (Section 3.5): Both the adjusted curve of best fit based on DECCW (2009), as presented in Figure 3-5 and the following trajectories from IPCC (2013) (5% and 95% percentile values), increased by 10% to account for local variation in sea level rise relative to the global mean: - peak/modal trajectory: RCP 6.0 (high); - minimum trajectory: RCP 2.6 (low); and - maximum trajectory: RCP 8.5 (high). All the above sea level rise projections were illustrated in Figure 3-6; • Bruun slope factor for dune crest level of 5m AHD, 8m AHD and 10m AHD (Section 3.5): - peak/modal values (best estimate): 45:1, 40:1, 35:1 - minimum: 36:1, 32:1, 28:1 (all -20%); and - maximum: 60:1, 54:1, 47:1 (all +35%). • storm demand (Section 3.6): Relationship developed by Gordon (1987) for high demand (rip head) areas, adjusted such that 100 year ARI event is set at 250m^3/m (increased from 220m^3/m), ARI values are re-expressed as AEP, and range of ARI (AEP) extended to cover both more frequent events (1 year ARI) and rarer events (1000 year ARI). The proposed relationship was shown in Figure 3-7. How closely triangular distributions fit actual distribution

Review Date	Reviewer	Section	Reviewers comment	RHDHV response
				Triangular distributions were proposed for: • underlying recession; • sea level rise (set to follow a specified trajectory); and • Bruun slope factor. It is noted that in the paper by Kinsela et al (2017), referred to by DPIE, and stated to represent ‘some of the more contemporary science in this space’, triangular distributions are also adopted for the above parameters. Kinsela et al state ‘….. This simplistic representation of the uncertainty space is commensurate with the state of knowledge, in that sufficient data or scientific understanding may exist to define the feasible range and best estimate value of a model parameter or variable, although the exact shape of the probability distribution remains largely unknown’. In the circumstances, adoption of a triangular distribution for the above parameters is considered reasonable.
25.10.19	DPIE (various)	Point 2	The attached paper by Dr. Mike Kinsela (Kinsela et al. (2017) Journal of Marine Science & Engineering) represents some of the more contemporary published science in this space.	The paper by Dr Mike Kinsela has been noted. Reference to it is made within this Comments Register.
25.10.19	DPIE (various)	Point 3	In the case of previously completed probabilistic hazard studies as referenced on Page 12 of the methodology report (Sutherland Shire study), the trajectories	The advice by DPIE is noted that increasing IPCC (2017) values by 10% does not represent a formal position by the NSW Government.

Review Date	Reviewer	Section	Reviewers comment	RHDHV response
			adopted/endorsed by Council and OEH i.e. all IPCC values increased by 10%, do not represent a formal position on the use of these values by the NSW Government. Therefore, it's recommended that the use of IPCC values and any potential variations should be considered on a case by case basis.	Be that as it may, application of an increase of 10% is considered to be a reasonable conservatism in the current assessment of the coastal hazard at North Byron Bay.
25.10.19	DPIE (various)	Point 4	When considering published IPCC sea level rise projections, it's noted these projections (e.g. RCP 6.0 modal, RCP 2.6 min, RCP 8.5 max) only cover the 17th-83rd (likely) percentile range. Therefore, consideration of the expanded dataset would be warranted to effectively cover the 0-100th percentile ranges.	The study will consider the expanded data set to effectively cover the 0-100th percentile ranges.
25.10.19	DPIE (various)	Point 5	Its noted distributions are to be defined through triangular distribution, whilst such an approach is useful when the distribution is not fully known, recent advancements in the science around storm demand (fluctuating beach erosion volumes) suggest these distribution are better defined through the application of a gamma distribution (see Kinsela et al. (2017) Journal of Marine Science & Engineering) and may warrant further consideration.	The comment suggests the study proposes adoption of a triangular distribution for storm demand. This is <u>not</u> the case. The proposed distribution for storm demand is shown in Figure 3-7 and is based on Gordon (1987) which proposed a linear relationship between storm demand and the logarithm of ARI (over the range of approximately 2 year ARI to 100 year ARI). It is noted that Kinsela et al also adopt Gordon (1987) as a basis. The proposed distribution and the gamma distribution are quite similar as indicated by the values below: • 99th percentile values: - proposed 250m^3/m - gamma 250m^3/m

Review Date	Reviewer	Section	Reviewers comment	RHDHV response
				• 50th percentile values: - proposed 75m^3/m - gamma 85m^3/m
25.10.19	DPIE (various)	Point 6	The proposed methodology does not appear to consider potential implication of off-axis sink effects that may result under sea level rise from Belongil Creek in line with a sediment compartment type approach. Given the proximity of Belongil Creek to the location of the assessment, consideration should be given for sequestration of sand to the estuary under such scenarios, which may lead to an increased sediment loss (recession) on adjacent area of the shoreline. Given uncertainty surrounding this response, this component should also be treated probabilistically.	Kinsela et al (2017) consider the influence of potential sequestration of sand to an estuary under rising sea level. The sediment loss from the beach is taken to be the product of the sea level rise over the planning period and the submerged area of the active flood tide delta deposits. The potential sand loss to the estuary is distributed along the length of sandy shoreline within the sediment compartment. Belongil Creek is a small estuarine system with a limited submerged area of active flood delta. When considered together with predicted sea level rise over, say, 50 to 100-year planning periods, and the length of the sediment compartment, it can be shown that the contribution to shoreline recession of potential sequestration of sand to Belongil Creek is very small compared to other factors. Treating this contribution probabilistically is not considered warranted. The potential influence of sequestration can be considered analytically at the conclusion of the probabilistic assessment of the coastal hazard.