“Where will our knowledge take you?”

Whitsunday Regional Council Coastal Hazard Mapping Refinement

September 2018

Document Control Sheet

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Executive Summary

Priority gap studies needed to support the development of the Whitsunday Regional Council Coastal Hazards Adaptation Strategy (CHAS) have been completed, namely:

- The development of storm tide hazard mapping for the CHAS planning horizons (present-day, 2050 and 2100) across the entire local government area;
- The development of coastal erosion prone area hazard mapping for the CHAS planning horizons at eight open coast locations of interest; and
- The development of permanent inundation due to sea level rise mapping the CHAS planning horizons across the entire local government area.

The storm tide inundation and extreme wave assessments were an extension of the recently completed Bowen Water Hazards Study (BMT WBM & SEA 2017) and provide statistics up to the 10,000 year Average Recurrence Interval (or 0.01% Average Exceedance Probability) across the local government area.

Following the Queensland Government Coastal Hazard Technical Guide (DEHP 2013), the open coast calculated erosion distance was refined through consideration of the design storm conditions, dune slumping, long term recession and the shoreline response to sea-level rise. In addition, and for consistency with the State-defined erosion prone area definition, the permanent tidal inundation due to sea-level rise hazard area has also been established. At some locations, the recalculated erosion width at 2100 was greater than the State-declared erosion prone area.

The hazard mapping will be used to support ongoing stakeholder consultation and a risk assessment process in accordance with AS/NZS ISO 31000:2009, the State Planning Policy (SPP) and QCoast$_{2100}$ Minimum Standards & Guidelines.

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1 Introduction

The Whitsunday Regional Council (WRC) has completed the Coastal Hazard Mapping Refinement Study described in this report to assist in the implementation of the Resilient Whitsundays: Coastal Hazards and Response Project, which includes the development of a Coastal Hazard Adaptation Strategy (CHAS).

Mapping is required to understand the extent of current and future coastal hazard areas so that potentially impacted assets and values can be identified. The refined mapping is intended to complement other available mapping products, such as the State-declared erosion prone areas. The mapping produced as part of this study assists with understanding the likelihood and consequence of coastal hazard events and provides the basis for a more detailed risk assessment in accordance AS/NZS ISO 31000:2009, the State Planning Policy (SPP) and other State guideline documents.

The QCoast$_{2100}$ Minimum Standards & Guidelines (MS&G) provide guidance to local government wishing to prepare a CHAS. The guidelines set the minimum requirements to be included in a CHAS as well as providing information on leading practices to facilitate continuous improvement. The minimum standards set a benchmark for undertaking such studies in Queensland so that coastal hazard adaptation decision-making is approached in a consistent and systematic manner. The MS&G are structured to address the key phases of a CHAS which are illustrated in Figure 1-1. This report is a key output of Phase 3 – *the identification of areas exposed to current and future coastal hazards.*

Figure 1-1 QCoast$_{2100}$ Phases

1.1 Report Structure

The coastal hazards specifically addressed in this report include:

- Storm tide inundation and extreme waves (Chapter 2)
- Coastal erosion (Chapter 3)
- Permanent inundation due to sea-level rise (Chapter 4)

The storm tide inundation and extreme wave assessments build upon the recently completed Bowen Water Hazards Study. Full details of the modelling system and technical approaches used to support this work are provided in BMT WBM & SEA (2017).

A selection of mapping outputs is presented at a broad scale in the Appendices to this report. This data is also provided in digital format to allow interrogation using GIS software and identification of assets and values within the defined hazard areas. Following the QCoast$_{2100}$ program described in the MS&G, asset identification will be completed during Phase 4 of the CHAS development.

2 Design Storm Tide & Wave Assessment

2.1 Background

The storm tide inundation hazard across the Bowen region was recently assessed as part of the Bowen Water Hazards Study (BMT WBM & SEA 2017). The technical assessments to derive statistical descriptions of extreme coastal water levels and waves due to the combined effect of tide, surge and wave processes followed the work flow summarised in Figure 2-1.

The storm tide statistics and recommended water levels derived as part of the Bowen Water Hazards Study considered:

- The tropical cyclone (TC) generated ‘surge plus tide’ water level statistics derived through detailed numerical modelling of the selected SEAsim events, corresponding to:
  - 378 unique 2017 current climate events;
  - 433 unique 2050 future climate events; and
  - 413 unique 2100 future climate events.
- The non-TC water level statistics derived through the tidal residual analysis and the offsets developed relative to the so-called ‘HAT Proxy’.
- The combining or ‘blending’ of the TC and non-TC water level statistics.
- The contribution of waves to the potential extreme water levels.

For the present-day, 2050 and 2100 planning horizons these assessments delivered:

- Surge plus tide levels for the 5, 10, 50, 100, 200, 500, 1000, 2000, 5000 and 10000 year ARI.
- Tropical cyclone wave conditions for the 100, 200, 500, 1000, 2000, 5000 and 10000 year ARI.
- Recommended design ‘sustained peak’ and ‘coastal zone’ water levels for the 100, 200, 500, 1000, 2000, 5000 and 10000 year ARI.

This previous work was considered suitable for estimating storm tide statistics from the northern boundary of the Whitsunday local government area to Edgecombe Bay (to the west coast of Cape Gloucester).

Due to potential differences in the TC and non-TC climatology for locations south of Edgecombe Bay, additional technical work was needed to extend the storm tide assessment to the entire local government area. The assessments described in this Chapter relate specifically to the additional technical work which has provided coastal water level statistics between Hideaway Bay to the southern boundary of the local government area (referred to as the ‘Airlie Beach region’). Full details of the modelling system used to support this work are provided in BMT WBM & SEA (2017), it is recommended that this report is read prior to this Chapter.

The 445 unique locations for reporting water level statistics across the two packages of technical work are shown in Figure 2-2. The statistics provide the key inputs for storm tide inundation hazard mapping, required to support strategic planning throughout the Whitsunday region. The mapping will also provide the basis for storm tide hazard risk assessment as part of the CHAS.

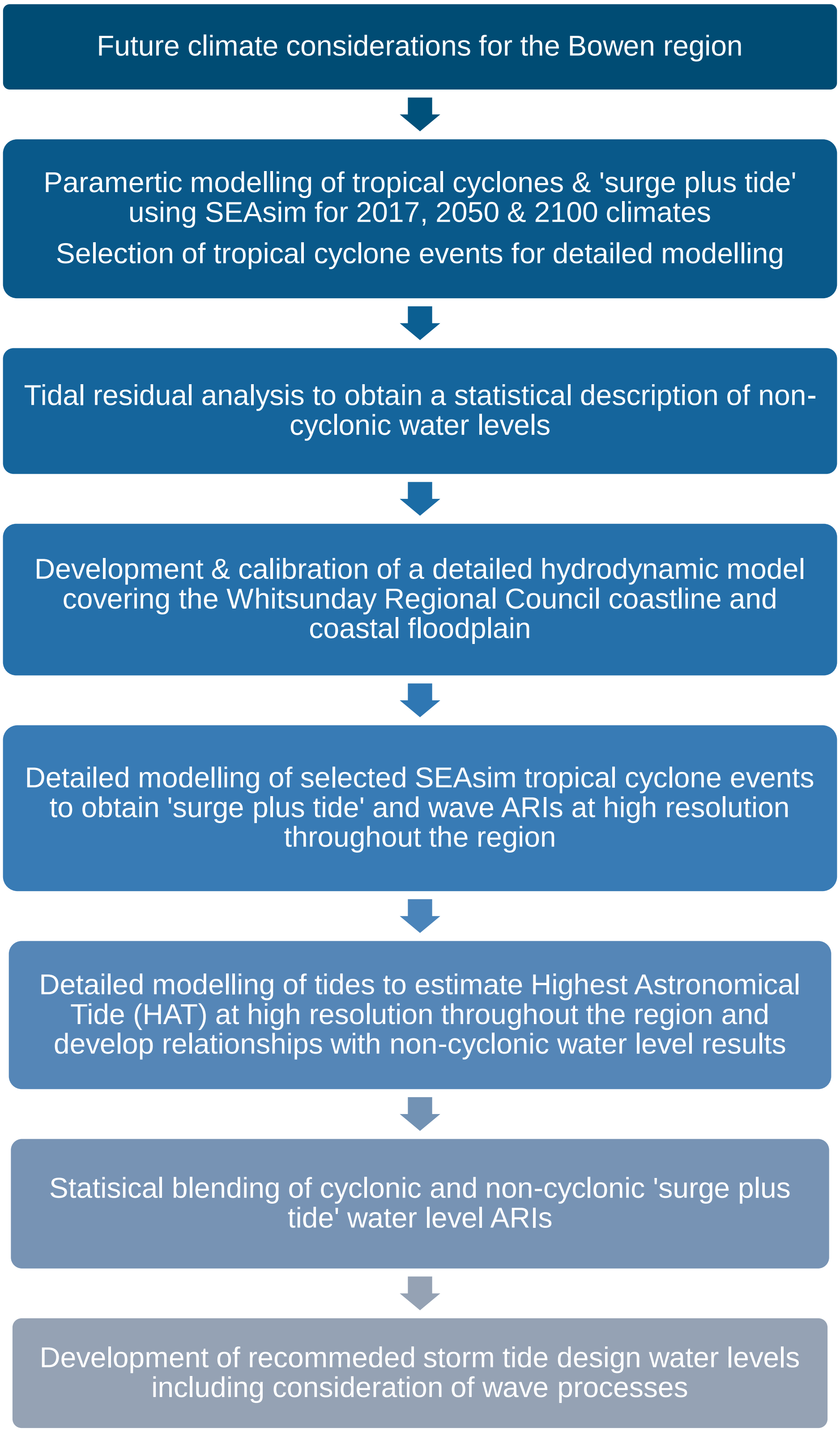

Figure 2-1 Storm tide hazard assessment work flow (BMT WBM & SEA 2017)

Title:

Water Level Statistics Reporting Locations

Figure: 2-2

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Approx. Scale

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2.2 Selected SEAsim Tropical Cyclone Events

2.2.1 Basis of the Extreme Tropical Cyclone Event Design

The design TC event assessment is based on analyses using the recently-developed SEAsim model, which is a variant of the real-time storm tide forecasting model SEAtide (SEA 2016a) currently utilised by the Bureau of Meteorology (BOM) in Queensland and the Northern Territory and the Queensland State Government. SEAtide is a further development of BOM-sponsored parametric TC storm surge model development following the Queensland Climate Change Study initiative (e.g. Harper 2001; SEA 2002).

SEAsim differs from SEAtide in that, rather than simulating the effects of individual real-time TCs, it simulates the long-term statistical storm tide response across many coastal locations. It achieves this by coupling with an Australia-wide synthetic climatology of TCs (Harper and Mason 2016). SEAsim has been used to simulate storm tide risks around the entire Australian coastline that is subject to TC impacts. For example, the Northern Territory Government Department of Land Resource Management (SEA 2016b) recently utilised SEAsim estimates for risk assessment of remote indigenous communities across the "Top End".

SEAsim replaces and extends the earlier functionality of the SATSIM model that has provided statistical storm tide design water levels throughout Australia since the mid-1980s (e.g. Harper 2001). The new model combines regional parametric storm tide response models with the synthetic TC climatology and the astronomical tide variability to generate the equivalent synthetic time history of storm tide events, including nearshore wave conditions and estimated breaking wave setup.

Similar to the recent study for the Bowen region (BMT WBM & SEA 2017), the approach for the Airlie Beach region is to select a number of candidate extreme TC events from the SEAsim statistical simulation and for each of these events to be modelled in greater detail by full hydrodynamic models using the SEAsim-generated wind and pressure fields.

2.2.2 SEAsim Surge plus Tide Statistics

Figure 2-3 summarises the TC generate peak 'surge plus tide' return period curve for Airlie Beach based on the SEAsim 50,000 year simulation at the study site extending to the 10,000 year ARI event. The 2017 HAT level at this location is approximately 2.2 mAHD.

Figure 2-4 and Figure 2-5 summarise the peak 'surge plus tide' components from the future climate 2050 and 2100 simulation at Airlie Beach, where the red dashed line indicates the assumed 2050 and 2100 HAT level of 2.6 and 3.0 mAHD respectively (assumed 0.4 and 0.8 m increase to mean sea level).

The figures below show that the TC events are projected to not exceed HAT until beyond about the 90 year ARI event at Airlie Beach. In north Queensland, the water level statistics at the lower end of the return period curve are generally dominated by 'non-TC' storms and other long waves (such as continental shelf waves) that generate tidal anomalies. The analysis to derive non-TC extreme water level events (up to approximately the 100 year ARI) is described in BMT WBM & SEA (2017).

The adopted method for combining the TC and non-TC water level statistics as it applies to the Airlie Beach region is described in Section 2.3.

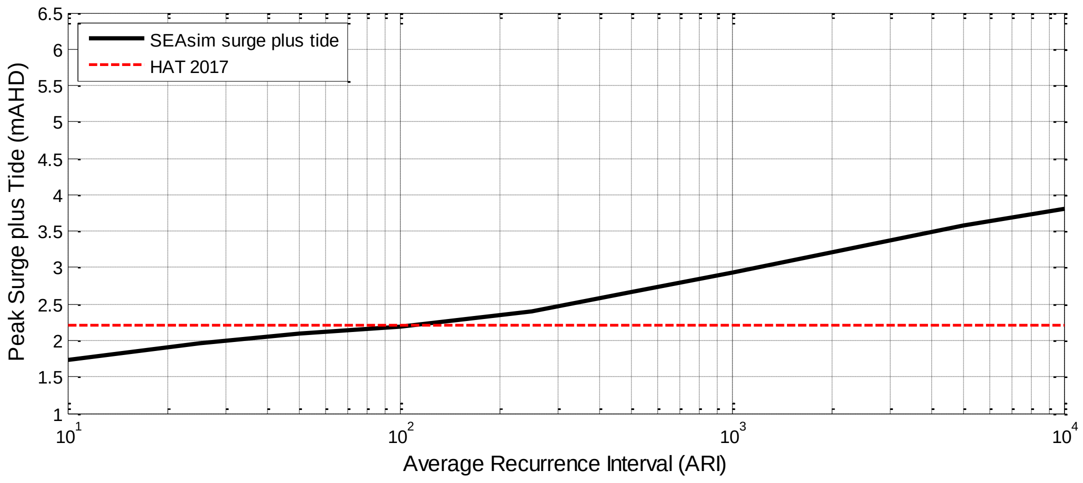


Figure 2-3 Simulated TC surge plus tide for present climate at Airlie Beach

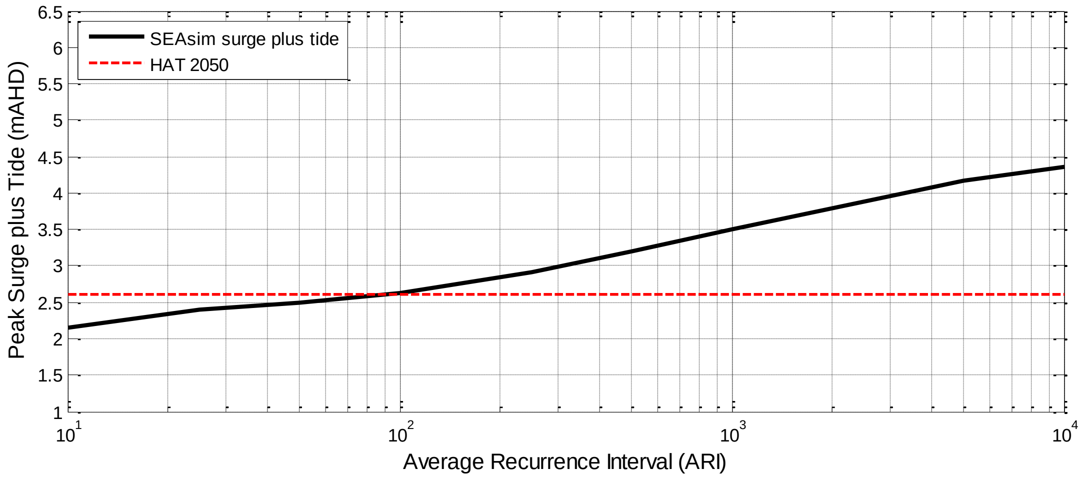


Figure 2-4 Simulated TC surge plus tide for 2050 climate at Airlie Beach

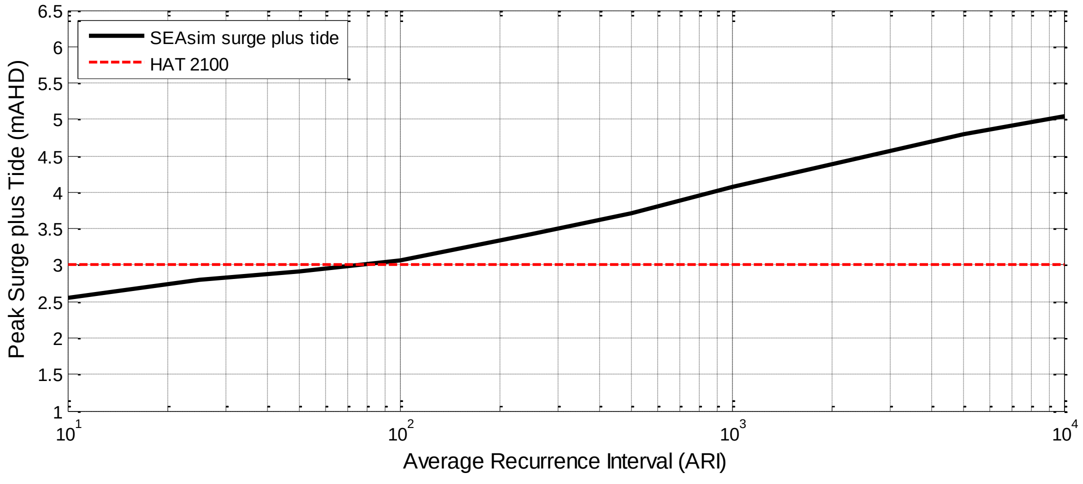


Figure 2-5 Simulated TC surge plus tide for 2100 climate at Airlie Beach

2.2.3 Selected Events for Detailed Modelling

The sections above briefly describe the basis for understanding the storm tide hazard for the Airlie Beach region. This analysis has provided nearshore 'surge plus tide' statistics at a few point locations relevant to the study area. Further detailed hydrodynamic modelling of the SEAsim TC events is required to understand the local-scale variation in water level statistics and the patterns of inundation over land.

To avoid detailed modelling of TC events expected to generate only minor storm tide conditions, a threshold water level was established and only SEAsim events that produced 'surge plus tide' levels greater than or equal the 100 year ARI value were selected[1]. The number of events selected for each of the planning years of interest is of the order of 200 to 300, with the single highest value being assigned the 1 in 50,000 year ARI probability of exceedance. Ranking the lower events and assigning an ARI will reproduce the 'surge plus tide' curves in Figure 2-3, Figure 2-4 and Figure 2-5. A summary of the water level threshold and number of events for each planning year is provided in Table 2-1. Each selected event has a specific date-time context, which specifies the peak tide level and, relative to the timing and shape of the peak surge, the peak 'surge plus tide' water level.

This was a key stage of additional work required to extend the assessments originally completed for the Bowen region to the southern extent of the local government area. Table 2-1 also indicates the number of SEAsim events for Airlie Beach that are common with the equivalent analysis at Bowen. The fact that less than half the Airlie Beach TC events are common with Bowen suggests a significant difference in TC climatology and associated storm tide statistics between the two regions.

Table 2-1 Airlie Beach SEAsim events selected for detailed modelling

Planning Year	100 year ARI surge plus tide threshold (mAHD)	Number of SEAsim events exceeding thresholds	Number of SEAsim events in common with Bowen
Present-day	2.2	170	62
2050	2.6	274	105
2100	3.0	294	104

2.2.4 Hydrodynamic Model Validation with SEAsim

A complete description of the numerical modelling system used simulate tide, surge and wave processes for the Airlie Beach region is provided in BMT WBM & SEA (2017). Outputs from the hydrodynamic modelling, namely peak 'surge plus tide', was used to validate the model performance against the SEAsim outputs.

It is noted that detailed hydrodynamic modelling of the individual schematised TC storm events will differ slightly from the SEAsim parametric modelling described above due to the resolution of coastal features, bathymetry, land elevations, wetting and drying algorithms, model physical

[1] In north Queensland the water level statistics for more frequent events (up to approximately the 100 year ARI) is typically dominated by non-TC storms and other long waves such as continental shelf waves.

constants, and especially modelled tidal phase and amplitude. However, it can be expected that if all SEAsim events are re-modelled then the peak nearshore water level results will be similar in a statistical context.

Comparisons of the detailed hydrodynamic model and SEAsim peak ‘surge plus tide’ ARIs at Airlie Beach are provided in Figure 2-6, Figure 2-7 and Figure 2-8 for the current climate, future climate scenarios. The independent modelling approaches yield similar results up to and beyond the 10,000 year ARI. There is some discrepancy between the modelling approaches beyond the 10,000 year ARI. The exact cause for this has not been explored but is possibly related to wind model parametrisation. Since events rarer than the 10,000 year ARI are not typically used for strategic planning or engineering design purposes the differences in the ‘surge plus tide’ statistics at the extreme limit of the return period curve have not been considered further.

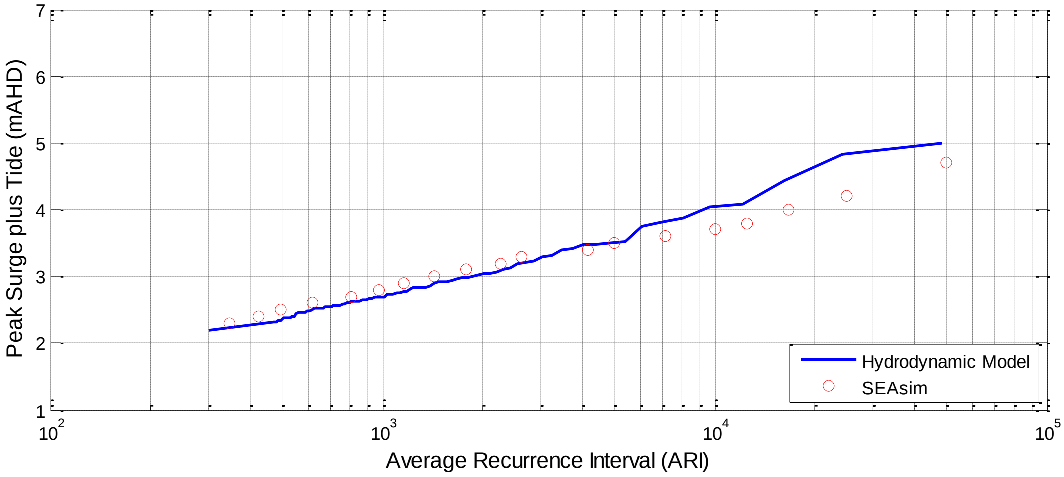


Figure 2-6 Hydrodynamic model and SEAsim comparison – 2017 Climate

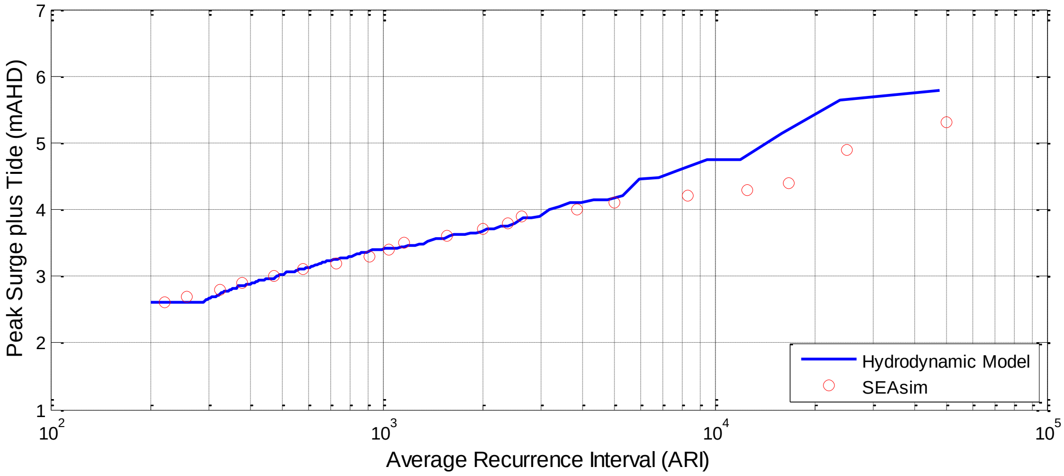


Figure 2-7 Hydrodynamic model and SEAsim comparison – 2050 Climate

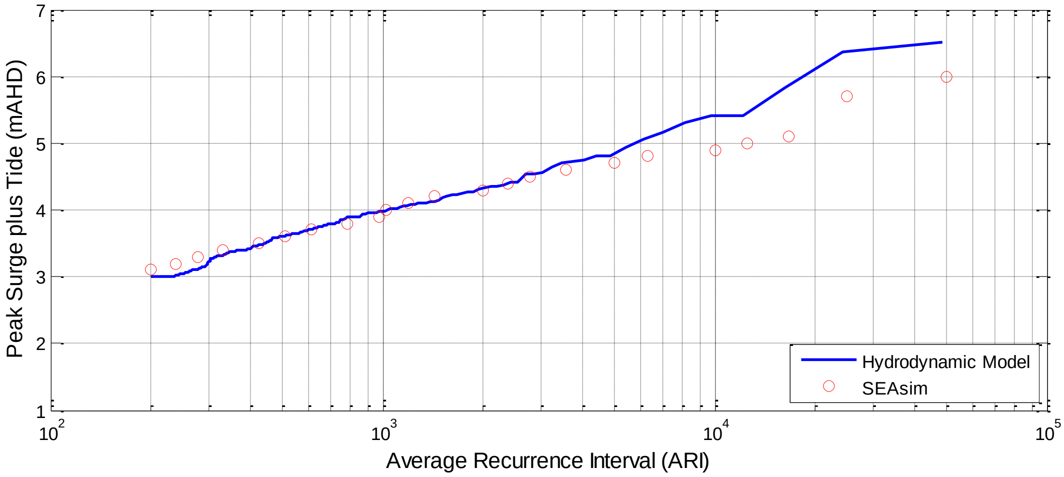


Figure 2-8 Hydrodynamic model and SEAsim comparison – 2100 Climate

2.3 Non-TC Tidal Residual Analysis

The tidal residual analysis is used to determine statistics for common non-extreme total water level events and follows the method briefly described in Hardy et al. (2004) used for estimating extra-tropical storm surge contributions in the Townsville region. Termed here the TRRM (Tide and tidal Residual Recombination Model), it is based on the re-sampling of the tidal residual (residual) event record from suitably long and reliable tide gauge records in the region of interest. It is assumed that the residual and the astronomical tide are uncorrelated and occur in random combination to produce the total storm tide level recorded by each gauge. Recombination of the randomly re-sampled residual (excluding TC events) effectively extends the available record.

Application of the TRRM based on recorded tide data at Bowen and Shute Harbour and the approach for blending the TC and non-TC water level statistics has been previously described by BMT WBM & SEA (2017). For the present study, this analysis was extended to Airlie Beach whereby the non-TC water level is calculated based on the tidal range difference from nearby Shute Harbour. The resulting combined ‘surge plus tide’ ARI curves for Bowen, Shute Harbour and Airlie Beach are shown in Figure 2-9, together with the non-TC and SEAsim TC components. Table 2-2 presents a selection of ARI water levels from these graphs together with MSQ (2017) HAT values.

The non-TC tidal residual results for each location are used as the basis for determining water level statistics at other nearby locations. This involves calculating HAT ratios relative to the non-TC water level statistics summarised in Table 2-3. This approach is described further in Section 2.4.

Table 2-2 TC and non-TC water level components and the blended values

Location	HAT	10	50	100	500	1000	5000	10000
SEAsim TC surge plus tide levels (mAHD)								
Bowen	1.95	1.64	1.96	2.14	2.91	3.29	4.30	4.64
Shute Harbour	2.42	1.91	2.28	2.35	2.67	2.90	3.44	3.56
Airlie Beach	2.19	1.74	2.09	2.19	2.67	2.93	3.58	3.80
Non-TC surge plus tide levels (mAHD)								
Bowen	1.95	1.97	2.07	2.10	2.18	2.22	2.30	2.32
Shute Harbour	2.42	2.50	2.58	2.62	2.69	2.71	2.77	2.80
Airlie Beach	2.19	2.27	2.35	2.38	2.44	2.46	2.51	2.53
Combined SEAsim TC and non-TC surge plus tide levels (mAHD)								
Bowen	1.95	1.98	2.10	2.20	2.91	3.29	4.30	4.64
Shute Harbour	2.42	2.50	2.59	2.63	2.74	2.90	3.44	3.56
Airlie Beach	2.19	2.27	2.36	2.40	2.67	2.93	3.58	3.80

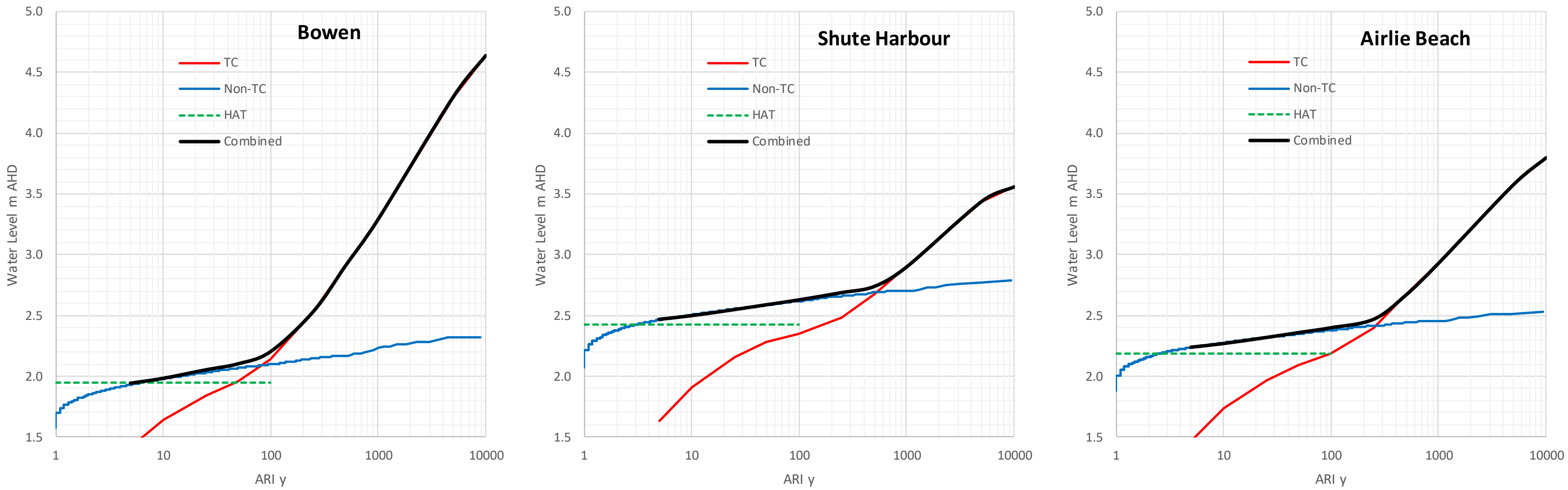


Figure 2-9 Blended TC and Non-TC surge plus tide extreme water levels for Bowen, Shute Harbour & Airlie Beach (BMT WBM & SEA 2017)

Table 2-3 HAT ratios relative to non-TC water levels for Bowen, Shute Harbour & Airlie Beach

Location	Non-TC Water Level (mAHD)										
	HAT	5 year ARI	10 year ARI	50 year ARI	100 year ARI	200 year ARI	500 year ARI	1,000 year ARI	2,000 year ARI	5,000 year ARI	10,000 year ARI
Bowen tide gauge	1.95	1.93	1.97	2.07	2.10	2.12	2.18	2.22	2.24	2.30	2.32
Bowen HAT ratio	*1.00*	*0.99*	*1.01*	*1.06*	*1.08*	*1.09*	*1.12*	*1.14*	*1.15*	*1.18*	*1.19*
Shute Harbour tide gauge	2.42	2.47	2.50	2.58	2.62	2.64	2.69	2.71	2.73	2.77	2.80
Shute Harbour HAT ratio	*1.00*	*1.02*	*1.03*	*1.07*	*1.08*	*1.09*	*1.11*	*1.12*	*1.13*	*1.14*	*1.16*
Airlie Beach	2.19	2.24	2.27	2.35	2.38	2.40	2.44	2.46	2.47	2.51	2.53
Airlie Beach HAT ratio	*1.00*	*1.02*	*1.04*	*1.07*	*1.09*	*1.10*	*1.11*	*1.12*	*1.13*	*1.15*	*1.16*

2.4 Surge plus Tide Average Recurrence Interval

Using the outcomes from BMT WBM & SEA (2017) and the additional work described in this Chapter, peak surge plus tide water levels were derived at 445 output locations throughout the local government area using a combination of:

(1) Non-TC tidal residual analysis at Bowen supplemented with harmonic analysis of hydrodynamic model outputs from a 2-month astronomic tide only simulation; and

(2) Detailed modelling of the selected SEAsim TC events.

Regarding (1), a tidal analysis was performed on the astronomic tide time series results at each output location to derive tidal constituents. At each location, the tidal constituents were summed to obtain a proxy for HAT, which gives an indication of the variation in tidal amplitude along the coast.

The non-TC water level ARIs for Bowen, Shute Harbour and Airlie Beach were then used to calculate ratios relative to the HAT. The ratio for a given ARI at each location is summarised in Table 2-3. These ratios have been applied to the HAT Proxy at each output location throughout the local government area to allow an estimate of non-TC water level ARIs.

With reference to (2), for each simulated TC event a time series of ‘surge plus tide’ water level was stored at each output location. The peak ‘surge plus tide’ level was extracted from these results and subsequently ranked in order so that the corresponding ARIs could be derived.

Finally, the non-TC and TC water level statistics were combined to derive peak ‘surge plus tide’ water level ARIs throughout the study area. This procedure is described in BMT WBM & SEA (2017).

The current climate, future climate 2050 and future climate 2100 ‘surge plus tide’ levels for key locations throughout the study area are summarised in Table 2-4, Table 2-5 and Table 2-6.

Table 2-4 Current climate surge plus tide Average Recurrence Interval at key locations

Location	Water Level (mAHD)										
	HAT Proxy	5 year ARI	10 year ARI	50 year ARI	100 year ARI	200 year ARI	500 year ARI	1,000 year ARI	2,000 year ARI	5,000 year ARI	10,000 year ARI
Molongle Creek	2.03	2.00	2.04	2.14	2.18	2.24	2.62	3.26	3.77	4.40	4.80
Abbot Point	1.90	1.88	1.92	2.02	2.05	2.09	2.20	2.37	2.62	3.17	3.32
Queens Bay	1.92	1.90	1.94	2.04	2.08	2.13	2.31	2.62	2.88	3.19	3.81
Horseshoe Bay	1.92	1.90	1.94	2.04	2.08	2.13	2.28	2.53	2.80	3.12	3.62
Kings Beach	1.94	1.92	1.96	2.06	2.10	2.16	2.37	2.67	3.00	3.35	3.81
Bowen	1.98	1.96	2.00	2.10	2.14	2.23	2.67	3.07	3.50	3.97	4.48
Heronvale	1.98	1.96	2.00	2.10	2.14	2.23	2.66	3.13	3.53	4.04	4.66
Brisk Bay	1.99	1.97	2.01	2.11	2.16	2.25	2.79	3.29	3.66	4.28	4.98
Edgecombe Bay	2.01	1.99	2.03	2.13	2.17	2.25	2.73	3.26	3.77	4.44	5.29
Sinclair Bay	2.01	1.99	2.03	2.14	2.18	2.23	2.41	2.92	3.39	4.12	4.78
Cape Gloucester	1.99	1.97	2.01	2.12	2.16	2.20	2.33	2.70	3.01	3.59	4.26
Hideaway Bay	2.05	2.10	2.13	2.20	2.23	2.25	2.31	2.57	2.87	3.21	3.40
Dingo Beach	2.05	2.10	2.13	2.20	2.23	2.25	2.31	2.62	2.87	3.20	3.42
Cannonvale Beach	2.20	2.25	2.28	2.36	2.39	2.42	2.48	2.74	3.06	3.60	4.10
Airlie Beach	2.20	2.25	2.28	2.36	2.39	2.42	2.48	2.62	2.94	3.37	3.90
Shute Harbour	2.46	2.51	2.54	2.62	2.66	2.68	2.74	2.76	2.82	3.03	3.59
Conway Beach	3.31	3.38	3.42	3.53	3.59	3.62	3.70	3.75	4.12	5.23	5.54
Wilson Beach	3.31	3.38	3.42	3.53	3.59	3.62	3.70	3.75	4.12	5.23	5.54

Table 2-5 Future climate 2050 surge plus tide Average Recurrence Interval at key locations

Location	Water Level (mAHD)										
	HAT Proxy	5 year ARI	10 year ARI	50 year ARI	100 year ARI	200 year ARI	500 year ARI	1,000 year ARI	2,000 year ARI	5,000 year ARI	10,000 year ARI
Molongle Creek	2.43	2.40	2.44	2.54	2.58	2.66	3.31	4.02	4.59	5.24	5.61
Abbot Point	2.30	2.28	2.32	2.42	2.45	2.51	2.71	2.95	3.25	3.85	3.98
Queens Bay	2.32	2.30	2.34	2.44	2.49	2.56	2.91	3.24	3.52	3.89	4.54
Horseshoe Bay	2.32	2.30	2.34	2.44	2.48	2.56	2.85	3.14	3.45	3.77	4.34
Kings Beach	2.34	2.32	2.36	2.46	2.51	2.59	2.97	3.32	3.67	4.07	4.55
Bowen	2.38	2.36	2.40	2.50	2.57	2.72	3.35	3.76	4.23	4.79	5.28
Heronvale	2.38	2.36	2.40	2.50	2.57	2.73	3.36	3.82	4.31	4.84	5.48
Brisk Bay	2.39	2.37	2.41	2.51	2.59	2.76	3.52	4.02	4.46	5.13	5.83
Edgecombe Bay	2.41	2.39	2.43	2.53	2.58	2.70	3.44	3.97	4.53	5.31	6.17
Sinclair Bay	2.41	2.39	2.43	2.54	2.58	2.66	3.06	3.60	4.16	4.91	5.61
Cape Gloucester	2.39	2.37	2.41	2.52	2.56	2.62	2.89	3.37	3.73	4.34	5.05
Hideaway Bay	2.45	2.50	2.53	2.60	2.63	2.67	2.79	3.25	3.51	3.89	4.10
Dingo Beach	2.45	2.50	2.53	2.60	2.63	2.68	2.78	3.27	3.52	3.89	4.13
Cannonvale Beach	2.60	2.65	2.68	2.76	2.81	2.86	3.06	3.44	3.73	4.30	4.80
Airlie Beach	2.60	2.65	2.68	2.76	2.80	2.84	2.96	3.27	3.57	4.07	4.59
Shute Harbour	2.86	2.84	2.87	2.95	2.99	3.02	3.07	3.10	3.2	3.535	4.11
Conway Beach	3.71	3.78	3.82	3.93	3.99	4.02	4.11	4.23	4.84	6.02	6.39
Wilson Beach	3.71	3.78	3.82	3.93	3.99	4.02	4.11	4.23	4.84	6.02	6.39

Table 2-6 Future climate 2100 surge plus tide Average Recurrence Interval at key locations

Location	Water Level (mAHD)									
	HAT Proxy	5 year ARI	10 year ARI	50 year ARI	100 year ARI	200 year ARI	500 year ARI	1,000 year ARI	2,000 year ARI	5,000 year ARI	10,000 year ARI
Molongle Creek	2.83	2.80	2.84	2.94	2.98	3.06	3.85	4.67	5.32	5.95	6.37
Abbot Point	2.70	2.68	2.72	2.82	2.85	2.92	3.20	3.50	3.83	4.46	4.62
Queens Bay	2.72	2.70	2.74	2.84	2.89	2.99	3.44	3.84	4.18	4.55	5.21
Horseshoe Bay	2.72	2.70	2.74	2.84	2.89	2.98	3.38	3.71	4.07	4.40	5.01
Kings Beach	2.74	2.72	2.76	2.86	2.92	3.02	3.52	3.92	4.31	4.73	5.24
Bowen	2.78	2.76	2.80	2.90	2.99	3.19	3.91	4.39	4.93	5.54	6.02
Heronvale	2.78	2.76	2.80	2.90	2.99	3.21	3.95	4.46	4.99	5.59	6.23
Brisk Bay	2.79	2.77	2.81	2.91	3.00	3.25	4.08	4.70	5.15	5.92	6.62
Edgecombe Bay	2.81	2.79	2.83	2.93	2.99	3.13	3.98	4.56	5.17	6.04	6.96
Sinclair Bay	2.81	2.79	2.83	2.94	2.98	3.07	3.57	4.15	4.77	5.57	6.35
Cape Gloucester	2.79	2.77	2.81	2.92	2.96	3.03	3.39	3.93	4.34	5.03	5.76
Hideaway Bay	2.85	2.90	2.93	3.00	3.40	3.50	3.78	4.32	4.62	5.09	5.41
Dingo Beach	2.85	2.90	2.93	3.00	3.41	3.51	3.77	4.34	4.65	5.08	5.44
Cannonvale Beach	3.00	3.05	3.08	3.16	3.56	3.71	4.06	4.49	4.85	5.45	6.03
Airlie Beach	3.00	3.05	3.08	3.16	3.56	3.66	3.95	4.34	4.68	5.22	5.82
Shute Harbour	3.26	3.31	3.34	3.42	3.46	3.49	3.55	3.62	3.87	4.19	4.83
Conway Beach	4.11	4.18	4.22	4.33	4.39	4.43	4.52	4.82	5.51	6.74	7.21
Wilson Beach	4.11	4.18	4.22	4.33	4.39	4.43	4.52	4.82	5.51	6.74	7.21

2.4.1 Tropical Cyclone Wave Conditions

For each SEAsim TC event simulated with the numerical modelling system, the time series of significant wave height and wave peak period at each output location was stored. The peak wave conditions were extracted from these results and subsequently ranked in order so that the corresponding ARIs could be derived. A summary of the peak significant wave height and peak period throughout the local government area is given in Table 2-7, Table 2-8 and Table 2-9 for the current climate 2017, future climate 2050 and future climate 2100. The derived wave statistics are used to:

- Estimate the contribution of wave setup to the ‘sustained peak’ water level experienced throughout the region; and
- Estimate the wave runup potential within the ‘coastal zone’, assumed to be within 200 m of the ‘surge plus tide’ shoreline.

This procedure is described further below and in Section 2.5.

2.4.1.1 Wave Setup and Runup

Wave setup is an elevation of the mean (time averaged) water surface due to the pumping effect of waves. Wave setup has the potential to cause a small to moderate increase in water levels in the coastal waterways and floodplains. The wave setup contribution to the mean water level along exposed coastal locations can be significant (of the order 0.5 to 1.0 m).

Wave runup is the intermittent process of advancement and retreat of the instantaneous shoreline position on a timescale that is of the order of the incoming wave period (~10 s for cyclone generated waves). Along exposed coastlines the wave runup can be a significant contributor to the peak water levels and inundation associated with the overtopping of coastal barriers. Furthermore, the large quantity of energy contained in individual wave runup can pose a serious risk to coastal barriers (natural or man-made) within the wave runup zone.

The wave setup and runup contribution to shoreline water levels within the coastal zone has been estimated using the SWAN model output and an empirical formulation based on 10 dynamically diverse field experiments described in Stockdon et al (2006). The runup height predicted with this formula is the level above the offshore mean water level that is exceeded by 2% of runup events (R_2). This formulation was demonstrated in previous studies to provide robust estimates of surveyed debris levels associated with TC Winifred, TC Larry and TC Yasi (BMT WBM 2008, BMT WBM 2016). The general expression for wave setup and wave runup on beaches provided in Stockdon et al. (2006) is provided below.

Wave setup

$$S_{shoreline} = 0.35\beta_f \left(H_0 L_0\right)^{1/2}$$

Equation 2-1

Wave runup

$$R_2 = 1.1\left(S_{shoreline} + \frac{H_0 L_0 \left(0.563\beta_f^2 + 0.004\right)^{1/2}}{2}\right)$$

Equation 2-2

Where β_f is the foreshore slope, H_0 is the deep water significant wave height and L_0 is the deep water wave length.

Table 2-7 Current climate tropical cyclone wave Average Recurrence Interval at key locations

Location	100 year ARI		200 year ARI		500 year ARI		1,000 year ARI		10,000 year ARI	
	Hsig (m)	Tp (s)	Hsig (m)	Tp (s)	Hsig (m)	Tp (s)	Hsig (m)	Tp (s)	Hsig (m)	Tp (s)
Molongle Creek	1.92	8.48	2.35	9.11	2.89	9.75	3.11	10.41	3.79	11.58
Abbot Point	3.16	8.53	3.62	9.33	4.01	10.26	4.27	10.53	4.97	11.55
Queens Bay	2.32	8.41	2.86	9.25	3.25	10.20	3.45	10.45	4.25	11.52
Horseshoe Bay	2.74	8.39	3.54	9.27	4.08	10.29	4.39	10.57	5.28	11.50
Kings Beach	2.61	8.40	3.01	9.27	3.42	10.30	3.71	10.55	4.49	11.48
Bowen	1.51	4.15	1.88	4.59	2.44	6.47	2.71	6.68	3.43	7.57
Heronvale	1.74	5.39	2.51	6.65	3.26	9.05	3.56	9.38	4.42	10.37
Brisk Bay	1.58	5.01	2.13	6.07	2.71	7.37	3.01	9.10	3.80	10.34
Edgecombe Bay	1.33	5.70	1.99	8.43	2.60	9.41	2.92	10.05	3.70	10.87
Sinclair Bay	1.17	3.93	1.71	8.00	2.32	9.37	2.59	10.12	3.27	11.03
Cape Gloucester	1.17	4.78	1.68	7.33	2.27	9.34	2.58	9.82	3.32	10.91
Hideaway Bay	2.74	8.38	2.98	9.01	3.22	9.64	3.46	10.40	4.16	11.57
Dingo Beach	2.80	8.44	3.05	9.07	3.30	9.71	3.52	10.39	4.17	11.57
Cannonvale Beach	2.39	8.20	2.60	8.81	2.81	9.43	3.03	10.22	3.63	11.52
Airlie Beach	2.44	8.71	2.66	9.36	2.87	10.01	3.07	10.33	3.67	11.60
Shute Harbour	2.46	5.71	2.68	6.14	2.90	6.57	3.44	6.84	4.62	7.82
Conway Beach	2.21	5.85	2.40	6.29	2.60	6.73	2.98	7.40	3.59	8.23
Wilson Beach	2.21	5.85	2.40	6.29	2.60	6.73	2.98	7.40	3.59	8.23

Table 2-8 Future climate 2050 tropical cyclone wave Average Recurrence Interval at key locations

Location	100 year ARI		200 year ARI		500 year ARI		1,000 year ARI		10,000 year ARI	
	Hsig (m)	Tp (s)	Hsig (m)	Tp (s)	Hsig (m)	Tp (s)	Hsig (m)	Tp (s)	Hsig (m)	Tp (s)
Molongle Creek	2.36	5.41	2.71	7.93	3.17	9.23	3.41	9.69	4.14	10.86
Abbot Point	3.74	9.28	3.96	9.86	4.34	10.51	4.58	11.15	5.33	11.79
Queens Bay	2.90	9.20	3.16	9.50	3.54	10.40	3.76	10.78	4.61	11.68
Horseshoe Bay	3.58	9.18	3.94	9.68	4.41	10.51	4.73	11.12	5.75	11.74
Kings Beach	3.11	9.20	3.35	9.62	3.73	10.52	4.01	11.15	4.86	11.68
Bowen	1.86	4.55	2.14	4.99	2.75	6.62	3.01	7.09	3.76	7.66
Heronvale	2.43	6.12	2.89	6.89	3.57	9.16	3.87	9.61	4.80	10.73
Brisk Bay	2.12	5.96	2.48	6.59	3.02	7.55	3.33	9.19	4.16	10.69
Edgecumbe Bay	1.91	8.18	2.33	9.06	2.92	9.84	3.21	10.23	4.03	11.36
Sinclair Bay	1.66	4.87	1.99	8.58	2.60	9.71	2.84	10.27	3.56	11.35
Cape Gloucester	1.57	5.53	1.92	8.44	2.55	9.65	2.86	10.16	3.63	11.30
Hideaway Bay	3.00	8.99	3.27	9.66	3.53	10.34	3.77	11.10	4.58	11.79
Dingo Beach	3.08	9.00	3.35	9.67	3.62	10.34	3.82	10.91	4.50	11.85
Cannonvale Beach	2.67	8.88	2.91	9.54	3.14	10.20	3.33	10.53	3.96	11.65
Airlie Beach	2.72	8.94	2.96	9.61	3.20	10.28	3.37	10.81	3.96	12.01
Shute Harbour	2.90	5.89	3.15	6.33	3.41	6.77	3.98	7.37	4.92	8.21
Conway Beach	2.49	6.38	2.71	6.86	2.93	7.34	3.30	7.60	3.90	8.36
Wilson Beach	2.49	6.38	2.71	6.86	2.93	7.34	3.30	7.60	3.90	8.36

Table 2-9 Future climate 2100 tropical cyclone wave Average Recurrence Interval at key locations

Location	100 year ARI		200 year ARI		500 year ARI		1,000 year ARI		10,000 year ARI	
	Hsig (m)	Tp (s)	Hsig (m)	Tp (s)	Hsig (m)	Tp (s)	Hsig (m)	Tp (s)	Hsig (m)	Tp (s)
Molongle Creek	2.39	5.27	2.87	7.80	3.42	9.26	3.66	9.78	4.41	11.12
Abbot Point	3.79	9.19	4.15	10.09	4.61	10.76	4.86	11.35	5.67	12.27
Queens Bay	2.94	9.11	3.34	9.71	3.80	10.52	4.03	11.20	4.95	12.05
Horseshoe Bay	3.57	9.12	4.12	9.90	4.69	10.73	5.03	11.35	6.15	12.21
Kings Beach	3.16	9.14	3.55	9.80	4.01	10.75	4.29	11.36	5.21	12.16
Bowen	1.86	4.52	2.25	5.01	2.94	6.74	3.24	7.31	4.07	8.13
Heronvale	2.36	6.02	3.02	6.90	3.81	9.17	4.15	10.10	5.13	11.08
Brisk Bay	2.11	5.87	2.60	6.64	3.25	7.57	3.60	9.25	4.49	11.16
Edgecumbe Bay	1.87	6.16	2.42	8.90	3.12	10.09	3.45	10.30	4.35	11.47
Sinclair Bay	1.61	4.63	2.06	8.24	2.75	10.04	3.06	10.33	3.84	11.51
Cape Gloucester	1.52	5.35	2.00	7.97	2.70	9.85	3.06	10.25	3.92	11.43
Hideaway Bay	3.26	9.24	3.52	9.87	3.79	10.50	4.06	11.34	4.91	12.29
Dingo Beach	3.32	9.28	3.59	9.92	3.86	10.55	4.09	11.29	4.81	12.35
Cannonvale Beach	2.89	9.09	3.13	9.71	3.37	10.33	3.57	10.98	4.24	12.16
Airlie Beach	2.95	9.19	3.19	9.81	3.43	10.44	3.59	11.29	4.23	12.50
Shute Harbour	3.15	6.07	3.41	6.48	3.67	6.90	4.20	7.47	5.23	8.31
Conway Beach	2.72	6.55	2.94	6.99	3.16	7.44	3.53	7.92	4.22	8.56
Wilson Beach	2.72	6.55	2.94	6.99	3.16	7.44	3.53	7.92	4.22	8.56

2.5 Recommended Design Water Levels

The recommended current climate, future climate 2050 and future climate 2100 design water levels for key locations throughout the study area are summarised in Table 2-10, Table 2-11 and Table 2-12. The 'sustained peak' design water level considers the combined non-TC and TC 'surge plus tide' statistics following the methodology described in Section 2.3. The sustained peak also includes an allowance for wave setup (following Equation 2-1) and is assumed to persist for a sufficient duration to cause inundation of land areas below this design water level.

The 'coastal zone' levels are to be considered within a 200 m buffer measured landward from the shoreline. These levels represent the peak elevation of the intermittent process of advancement and retreat of the shoreline associated with wave processes during the coastal inundation event and include an allowance for wave setup and wave runup (following Equation 2-2). The coastal zone levels are not expected to be sustained for an extended period. Where overtopping of the coastal barrier occurs due to wave processes 'coastal zone' design water levels are expected to be conservatively high. Nevertheless, coastal zone locations behind the coastal barrier and below the estimated design level are considered high hazard areas.

The design levels provided in Table 2-10, Table 2-11 and Table 2-12 do not include an additional freeboard allowance which should be applied to account for unresolved processes, such as high frequency water surface oscillations during an event. Freeboard allowance is set by Council policy. For coastal inundation events BMT recommend the following:

- + 0.5m for the sustained peak inundation level; and
- + 1.0m for exposure to intermittent wave processes within the coastal zone.

General model uncertainties and study limitations are discussed further in BMT WBM & SEA (2017).

2.6 Storm Tide Inundation Mapping

Broad scale mapping showing the storm tide inundation hazard depth and extent for the 100 year ARI current and future climate scenarios is presented in Appendix E. This and other data relating to other storm tide event magnitudes is also available in digital format.

For this study, the tidal extent of rivers and creeks was not modelled in detail. Consequently, the mapping is based on the 'coastal zone' and 'sustained peak' levels only. The 'sustained peak' levels are applied within tidal waterways. As discussed above, this may be a conservative assumption in some locations but is considered appropriate for local government area scale assessments.

Table 2-10 Current climate recommended design water level Average Recurrence Interval at key locations (freeboard allowance not included)

Location	HAT Proxy (mAHD)	Water Level (mAHD)									
		100 year ARI		200 year ARI		500 year ARI		1,000 year ARI		10,000 year ARI	
		Sustained Peak*	Coastal Zone**	Sustained Peak*	Coastal Zone**	Sustained Peak*	Coastal Zone**	Sustained Peak*	Coastal Zone**	Sustained Peak*	Coastal Zone**
Molongle Creek	2.03	2.32	2.62	2.48	2.98	2.96	3.64	3.62	4.35	5.24	6.15
Abbot Point	1.90	2.38	3.05	2.48	3.26	2.65	3.55	2.85	3.81	3.88	5.02
Queens Bay	1.92	2.36	2.92	2.48	3.17	2.71	3.53	3.04	3.90	4.33	5.38
Horseshoe Bay	1.92	2.38	2.99	2.51	3.28	2.73	3.65	3.01	3.99	4.20	5.36
Kings Beach	1.94	2.40	3.00	2.51	3.22	2.79	3.63	3.11	4.01	4.34	5.42
Bowen	1.98	2.26	2.48	2.37	2.65	2.89	3.34	3.31	3.80	4.79	5.41
Heronvale	1.98	2.30	2.61	2.46	2.92	3.02	3.74	3.52	4.30	5.14	6.10
Brisk Bay	1.99	2.30	2.57	2.45	2.84	3.06	3.59	3.64	4.33	5.42	6.31
Edgecombe Bay	2.01	2.32	2.61	2.51	3.03	3.06	3.73	3.64	4.39	5.75	6.67
Sinclair Bay	2.01	2.27	2.46	2.46	2.92	2.72	3.35	3.28	4.00	5.22	6.10
Cape Gloucester	1.99	2.27	2.50	2.41	2.83	2.64	3.26	3.04	3.74	4.69	5.57
Hideaway Bay	2.05	2.54	3.15	2.59	3.28	2.69	3.45	3.04	3.84	3.94	4.96
Dingo Beach	2.05	2.54	3.17	2.60	3.30	2.70	3.48	3.12	3.90	4.58	4.98
Cannonvale Beach	2.20	2.67	3.23	2.74	3.36	2.83	3.53	3.02	3.91	4.39	5.55
Airlie Beach	2.20	2.69	3.29	2.75	3.43	2.85	3.60	3.02	3.82	4.39	5.37
Shute Harbour	2.46	2.86	3.25	2.90	3.35	2.98	3.48	3.04	3.60	3.96	4.70
Conway Beach	3.31	3.78	4.17	3.83	4.26	3.93	4.41	4.03	4.59	5.88	6.57
Wilson Beach	3.31	3.78	4.17	3.83	4.26	3.93	4.41	4.03	4.59	5.88	6.57

*For locations outside of the direct coastal zone or where wave runup processes do not occur. The ‘sustained peak’ includes surge, tide and wave setup components.

**For locations within 200 m of the ‘surge plus tide’ shoreline and where wave runup processes occur. The ‘coastal zone’ includes surge, tide, wave setup and 2% wave runup components.

Table 2-11 Future climate 2050 recommended design water level Average Recurrence Interval at key locations (freeboard allowance not included)

Location	HAT Proxy (mAHD)	Water Level (mAHD)									
		100 year ARI		200 year ARI		500 year ARI		1,000 year ARI		10,000 year ARI	
		Sustained Peak*	Coastal Zone**	Sustained Peak*	Coastal Zone**	Sustained Peak*	Coastal Zone**	Sustained Peak*	Coastal Zone**	Sustained Peak*	Coastal Zone**
Molongle Creek	2.43	2.76	3.13	2.95	3.52	3.67	4.40	4.41	5.20	6.10	7.07
Abbot Point	2.30	2.70	3.50	2.85	3.72	3.19	4.15	3.47	4.53	4.58	5.78
Queens Bay	2.32	2.70	3.40	2.85	3.60	3.33	4.20	3.70	4.62	5.08	6.19
Horseshoe Bay	2.32	2.73	3.50	2.89	3.74	3.33	4.30	3.66	4.73	4.95	6.20
Kings Beach	2.34	2.74	3.46	2.90	3.68	3.41	4.31	3.80	4.79	5.12	6.25
Bowen	2.38	2.64	2.91	2.86	3.18	3.59	4.08	4.03	4.57	5.61	6.26
Heronvale	2.38	2.71	3.13	2.98	3.49	3.74	4.51	4.24	5.07	6.00	7.04
Brisk Bay	2.39	2.71	3.10	2.99	3.45	3.80	4.38	4.39	5.13	6.31	7.27
Edgecombe Bay	2.41	2.72	3.22	2.95	3.56	3.81	4.55	4.37	5.18	6.67	7.68
Sinclair Bay	2.41	2.57	2.84	2.82	3.36	3.41	4.10	3.97	4.74	6.08	7.03
Cape Gloucester	2.39	2.55	2.86	2.78	3.30	3.23	3.91	3.74	4.50	5.52	6.47
Hideaway Bay	2.45	2.98	3.66	3.05	3.83	3.21	4.07	3.72	4.67	4.65	5.77
Dingo Beach	2.45	2.98	3.68	3.06	3.85	3.21	4.08	3.73	4.67	4.68	5.79
Cannonvale Beach	2.60	3.12	3.77	3.21	3.93	3.46	4.26	3.86	4.71	5.31	6.33
Airlie Beach	2.60	3.12	3.77	3.20	3.93	3.36	4.18	3.70	4.58	5.11	6.16
Shute Harbour	2.86	3.28	3.72	3.33	3.83	3.41	3.97	3.50	4.15	4.63	5.43
Conway Beach	3.71	4.21	4.66	4.27	4.77	4.39	4.94	4.54	5.15	6.75	7.48
Wilson Beach	3.71	4.21	4.66	4.27	4.77	4.39	4.94	4.54	5.15	6.75	7.48

*For locations outside of the direct coastal zone or where wave runup processes do not occur. The ‘sustained peak’ includes surge, tide and wave setup components.

**For locations within 200 m of the ‘surge plus tide’ shoreline and where wave runup processes occur. The ‘coastal zone’ includes surge, tide, wave setup and 2% wave runup components.

Table 2-12 Future climate 2100 recommended design water level Average Recurrence Interval at key locations (freeboard allowance not included)

Location	HAT Proxy (mAHD)	Water Level (mAHD)									
		100 year ARI		200 year ARI		500 year ARI		1,000 year ARI		10,000 year ARI	
		Sustained Peak*	Coastal Zone**	Sustained Peak*	Coastal Zone**	Sustained Peak*	Coastal Zone**	Sustained Peak*	Coastal Zone**	Sustained Peak*	Coastal Zone**
Molongle Creek	2.83	3.16	3.52	3.35	3.93	4.22	4.98	5.08	5.91	6.88	7.91
Abbot Point	2.70	3.24	4.03	3.37	4.28	3.71	4.73	4.04	5.15	5.26	6.55
Queens Bay	2.72	3.24	3.93	3.38	4.17	3.88	4.79	4.33	5.33	5.80	6.98
Horseshoe Bay	2.72	3.27	4.03	3.42	4.31	3.89	4.92	4.27	5.39	5.67	7.01
Kings Beach	2.74	3.27	3.99	3.43	4.24	3.99	4.94	4.43	5.47	5.85	7.08
Bowen	2.78	3.12	3.39	3.35	3.68	4.16	4.67	4.67	5.26	6.38	7.10
Heronvale	2.78	3.19	3.60	3.47	4.00	4.34	5.13	4.91	5.82	6.78	7.89
Brisk Bay	2.79	3.19	3.57	3.48	3.95	4.38	4.98	5.08	5.86	7.13	8.18
Edgecombe Bay	2.81	3.17	3.54	3.43	4.05	4.37	5.16	4.98	5.83	7.48	8.54
Sinclair Bay	2.81	3.11	3.37	3.33	3.85	3.94	4.67	4.54	5.34	6.84	7.84
Cape Gloucester	2.79	3.10	3.40	3.28	3.78	3.74	4.46	4.32	5.11	6.25	7.25
Hideaway Bay	2.85	3.40	4.14	3.50	4.32	3.78	4.68	4.32	5.33	5.41	6.61
Dingo Beach	2.85	3.41	4.16	3.51	4.34	3.77	4.69	4.34	5.35	5.44	6.63
Cannonvale Beach	3.00	3.56	4.24	3.71	4.47	4.06	4.89	4.49	5.41	6.03	7.14
Airlie Beach	3.00	3.56	4.25	3.66	4.43	3.95	4.81	4.34	5.29	5.82	6.95
Shute Harbour	3.26	3.70	3.26	3.75	4.17	3.84	4.28	3.95	4.42	5.24	5.42
Conway Beach	4.11	4.63	4.11	4.69	5.11	4.81	5.22	5.14	5.39	7.60	7.84
Wilson Beach	4.11	4.63	4.11	4.69	5.11	4.81	5.22	5.14	5.39	7.60	7.84

*For locations outside of the direct coastal zone or where wave runup processes do not occur. The ‘sustained peak’ includes surge, tide and wave setup components.

**For locations within 200 m of the ‘surge plus tide’ shoreline and where wave runup processes occur. The ‘coastal zone’ includes surge, tide, wave setup and 2% wave runup components.

3 Erosion Prone Area Assessment

3.1 Background

These assessments have been undertaken with the key objective of developing maps suitable for the Whitsunday Regional Council CHAS and to better understand the potential erosion hazard area and associated risk to assets and values at key locations within the local government area.

3.1.1 Erosion Prone Area Definition & Coastal Hazard Area Mapping

The State Erosion Prone Area (EPA) plans are intended to assist development assessment and to inform the preparation of planning instruments, such as planning schemes and regional plans under the *Planning Act 2016*.

Erosion prone areas have been declared for all coastal LGAs in Queensland. The Whitsunday Region Local Government Area Plan WHR3A is available online via DEHP website:

https://www.ehp.qld.gov.au/coastal/development/assessment/pdf/whitsunday-erosion-prone-area-plan.pdf

The EPA applies to land subject to inundation by the Highest Astronomical Tide (HAT) by the year 2100 or at risk from sea erosion. On land adjacent to tidal water the EPA is defined by whichever of the following methods gives the greatest width:

(1) 40 m buffer from the present-day HAT contour

(2) Calculated erosion distance shown in Table 1 of the statutory plan

(3) Permanent inundation due to SLR in 2100 (defined by present-day HAT plus 0.8 m).

The 40 m buffer from present-day HAT (component 1) generally applies within estuarine areas not exposed to open coast processes. This approximate method is intended to account for the migration of channels within tidal waterways with natural (undeveloped) shorelines.

The calculated erosion distance (component 2) is intended to cater for the potential loss of land for open coast locations. Both short term (storm-related) and longer term (gradual) trends are included in the assessment together with an allowance for potential SLR associated with climate change. Provision is also included for a factor of safety on the estimates and an allowance made for slumping of the dune scarp that is often observed after significant storm erosion has occurred. For the Whitsunday Regional Council CHAS, this component of the EPA definition has been reassessed and is discussed further in Section 3.2.

The Whitsunday Region Local Government Area Plan WHR3A (WHR3A, Table 1) provides a summary of the calculated erosion distance for open coast locations. Consideration of the potential presence of bedrock is included however it is noted that the State plans do not capture all local-scale natural and/or manmade features that may limit the landward extent of shoreline erosion.

The permanent inundation due to SLR (component 3) represents the HAT coastline (or elevation contour) in 2100 in the absence of any adaptation response to treat the risk, such as filling land to an elevation above the threshold water level. This component has also been reassessed for the planning horizons relevant to the CHAS (see Chapter 4).

The approximate erosion prone area footprint (combining the three erosion components) for the Whitsunday region is shown on the Coastal Hazard Area maps:

https://environment.ehp.qld.gov.au/coastal-hazards/

It is noted that the footprint on the Coastal Hazard Area maps is for illustrative purposes only and that the definition provided by Whitsunday Region Local Government Area Plan WHR3A prevails in the instance of discrepancy between the two products.

The EPAs determined by the State define a hazard extent at a single specified planning horizon (the year 2100) and probability (representative 100 year ARI). The EPAs are therefore useful for 'first-pass risk screening' however do not provide sufficient information regarding likelihood and consequence to undertake a more detailed risk assessment in accordance AS/NZS ISO 31000:2009, the State Planning Policy or other State guideline documents (such as the $QCoast_{2100}$ Minimum Standards and Guidelines). This knowledge gap has been addressed through the erosion hazard area assessments described in this Chapter.

3.2 Calculated Erosion Distance Assessment

The potential coastal erosion hazard and risk throughout the study area arises from a combination of:

- The physical processes that are causing (or threatening to cause) erosion;
- The assets and values potentially affected by the erosion; and
- The timeframe over which the threat may act upon the assets and values.

In order to assess the erosion hazard for the open coast beaches throughout the Whitsunday region, it is necessary to understand which areas are presently within the short term storm erosion zone and areas that may become threatened in the future.

To effectively assess the open coast erosion hazard a vulnerable zone is typically determined for a specific planning period. The erosion vulnerability zone should include the following components, consistent with the Queensland Government Coastal Hazard Technical Guide (DEHP 2013):

- Short term storm erosion;
- Continuation of the long term historical shoreline position trend (if this can be identified);
- Cyclic morphological change observed at river and creek mouths; and
- Additional future effects of climate change induced SLR.

The selected planning period influences:

- The design event characteristics adopted for the short term erosion assessment;
- The duration that the long term erosion component is applied; and
- The choice of an appropriate SLR projection.

3.2.1 Open Coast Calculated Erosion Distance Formula

The open coast erosion hazard areas are determined to cater for potential erosion of the dune system over a specified planning period. Both short term (storm-related) and longer term (gradual) trends are included in the assessment together with an allowance for potential SLR associated with climate change. Provision is also included for a factor of safety on the estimates and an allowance made for slumping of the dune scarp that is often observed after significant storm erosion has occurred. The following relationship was originally used by the former Beach Protection Authority (BPA) for determining erosion hazard area widths throughout Queensland. This formula continues to be recognised by DEHP (2013) as a reasonable method of assessing the erosion hazard on sandy coastlines.

$$E = [(N \times R) + C + S] \times (1 + F) + D$$

Equation 3-1

Where *E* = calculated erosion distance or width (metres)
N = planning period (years)
R = rate of long term erosion (metres per year)
C = short term erosion from the design storm event (metres)
S = erosion due to SLR (metres)
F = factor of safety
D = dune scarp component (metres)

In the assessments for the locations described in this Chapter, the values of *C*, *S* and *D* have been determined for individual beach compartments using existing beach profile survey data, site specific modelling and SLR projections adopted for the CHAS. Insufficient data is available to accurately assess *R* on an individual beach basis and this component is simply accounted for by adopting an allowance of 10 m (the minimum allowance for *R* required by DEHP 2013). The limited data and anecdotal evidence suggests that most beaches within the region are ‘dynamically stable’ and are not displaying trends of long term recession that can be linked to a deficit in sand supply. This assumption was discussed with DES and confirmed as generally appropriate for the beaches considered in this study. The one exception was for Queens Beach where periods of persistent recession trends have been observed. While these trends appear to have stabilised in more recent years, a more detailed analysis of the historical imagery was deemed appropriate at this location and is presented in Section 3.4.

The assessments described in this Chapter focus on the locations shown in Figure 3-2, Figure 3-3 and Figure 3-4. The calculated erosion distance at these locations provided by the Whitsunday Region Local Government Area Plan WHR3A are summarised in Table 3-1.

3.2.1.1 Application of the Calculated Erosion Distance Formula

DEHP (2013) guidelines require that the open coast erosion hazard distance is measured landward from the seaward toe of the frontal dune. This is normally approximated by the seaward limit of terrestrial vegetation or, where this cannot be determined, the level of present day HAT. The coastal zone is highly dynamic and significant fluctuations can occur in the dune profile and correspondingly the location of the seaward toe of the frontal dune. At some locations and times there can be a large height (and therefore volume) difference between the higher hind dune areas and the low foredunes which can be quite wide.

The calculation of the short term erosion component (*C*) is volumetric based and where there is a broad low foredune, the calculated distance from the seaward toe of that dune can be large. The adopted formula for calculating the overall erosion hazard area width also includes a factor of safety that is applied to the short term erosion component (*C*). In situations with a broad low frontal dune, this can lead to an unrealistic overestimation of the width of the short term erosion threat as measured from the seaward toe of the frontal dune. Accordingly, for the present study, this short term erosion component has been split into two sections (*C1* and *C2*) with the revised calculated erosion distance formula as follows:

$$E = [(N \times R) + C1 + S] \times (1 + F) + D + C2$$

Equation 3-2

Where *C1* = short term erosion from the design storm event, measured from the location where the design water level intersects the pre-storm beach profile (metres)

C2 = distance from the seaward toe of the frontal dune to the location where the design water level intersects the pre-storm initial beach profile (metres)

The modified calculated erosion distance formula is illustrated conceptually in Figure 3-1 using an example beach profile. The *C1* term in the current study is the modelled short term erosion setback distance based on the volume eroded from the main pre-storm dune above the design water level. This is the primary short term erosion component to which the factor of safety is applied. The *C2* term is the distance between the seaward toe of the frontal dune and the location where the design water level intersects the pre-storm profile. This covers the short term erosion of the low foredune area to which the factor of safety is not applied. As outlined above, this minimises the potential overestimation of the total short term erosion component when using the standard formula on beaches with a broad low dune terrace. The approach for assessing short term erosion is discussed further in Section 3.5.

For the present study, the Department of Natural Resources and Mines (DNRM) state coastline definition has been used to estimate the frontal dune toe position along open coast beaches for erosion hazard area assessment and mapping purposes. The DNRM coastline was digitised manually, guided by several references including aerial imagery and HAT contours generated from LiDAR survey data. A review of the DNRM coastline definition along the beaches considered in this assessment indicates that digitised coastline is at an elevation above HAT and close to the seaward edge of dune vegetation.

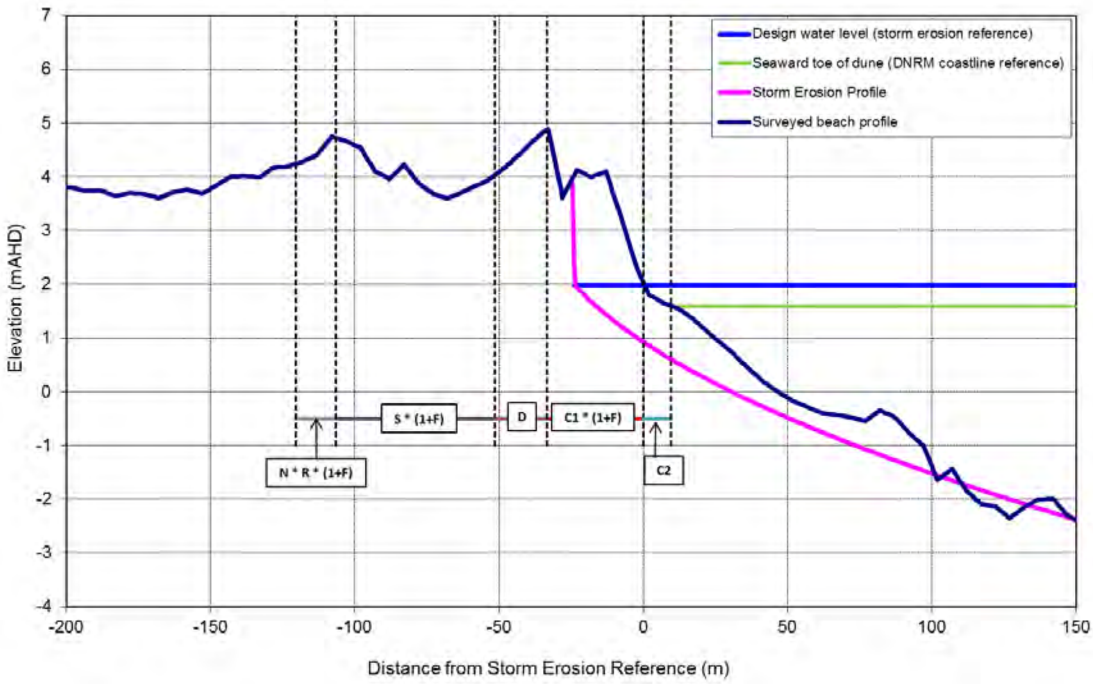
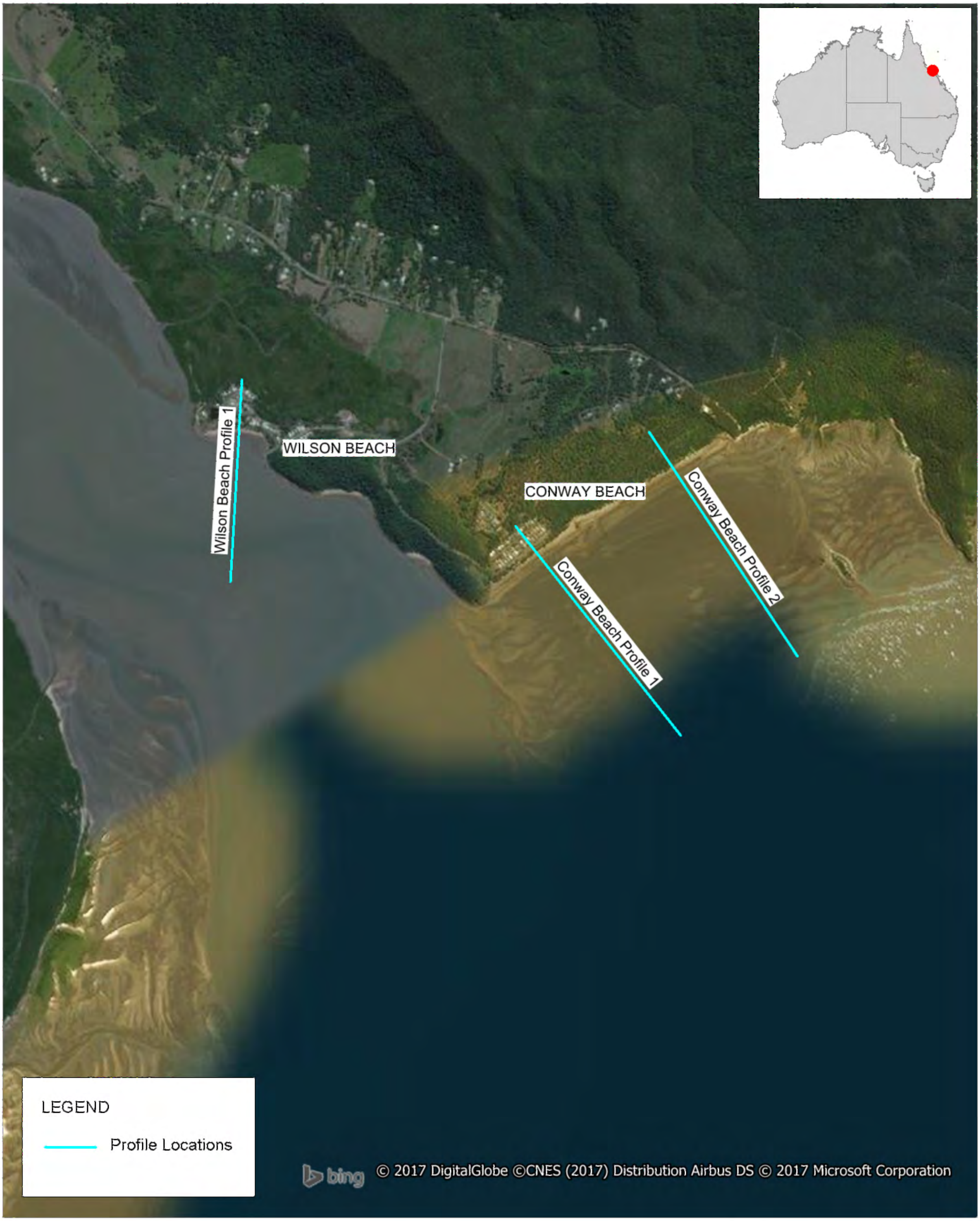


Figure 3-1 Conceptual Illustration of the Open Coast Calculated Erosion Distance Formula

Table 3-1 DEHP Plan WHR3A Calculated Erosion Distances for assessment locations

Beach name	Erosion Prone Area segment number(s)	Calculated Erosion Width (m)	Notes
Wilson Beach	WHR002	90	
Conway Beach	WHR004	105	
The Cove	WHR065	0	Constructed Beach
Airlie Beach	WHR066	75	Possible Bedrock
Cannonvale Beach	WHR070	90	
Dingo Beach	WHR145 / WHR144 / WHR143	80 / 135 / 130	
Hideaway Bay	WHR147	75	Possible Bedrock
Queens Beach	WHR193 / WHR192 / WHR191	140 / 90 / 140	



Title:

Erosion Assessment Locations: Wilson Beach & Conway Beach

Figure: 3-2

Rev: A

N

0 0.5 1km

Approx. Scale

BMT WBM

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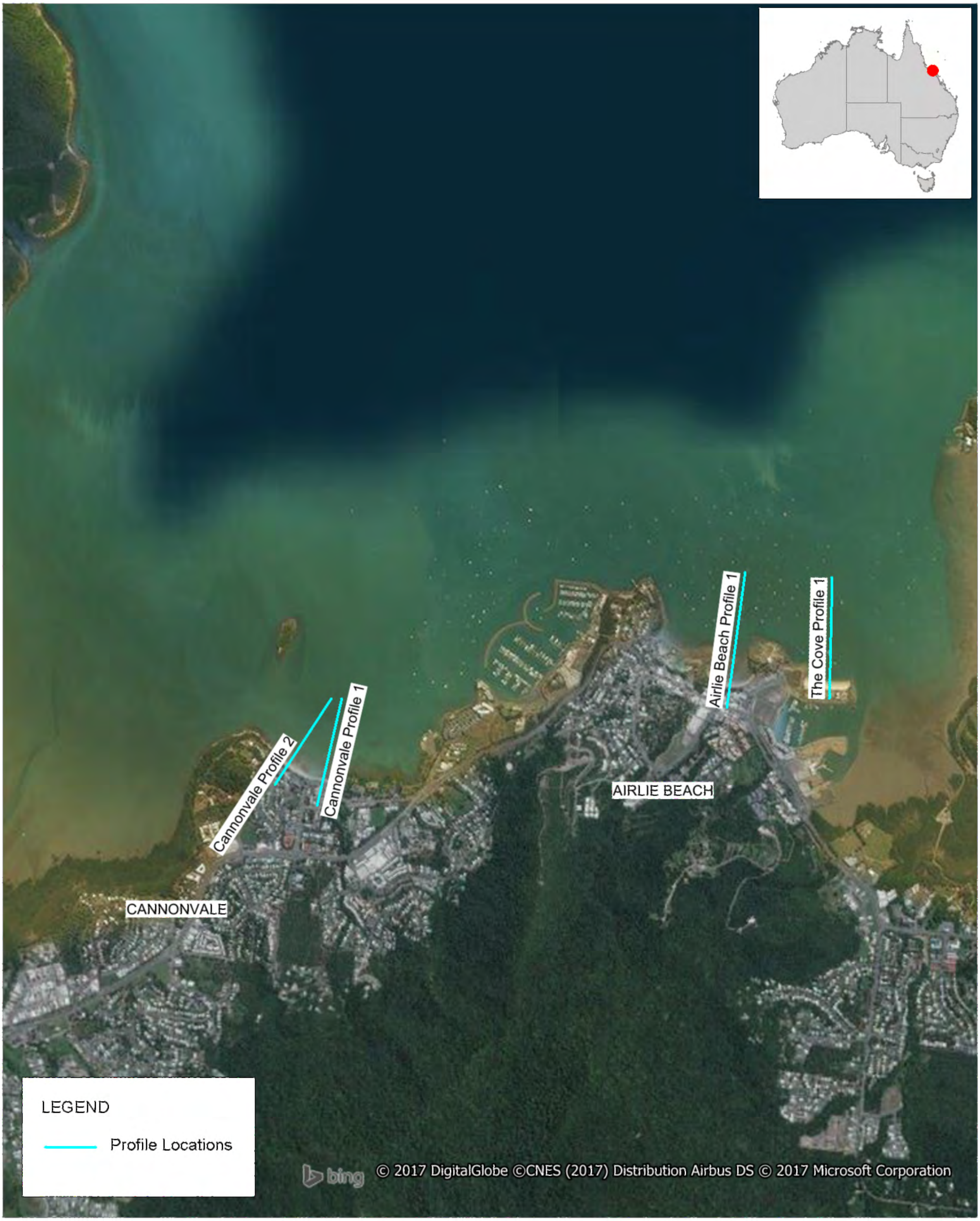

Title:
Erosion Assessment Locations: Cannonvale & Airlie Beach

Figure: 3-3

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BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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Title:
Erosion Assessment Locations: Queens Beach

Figure: **3-4**

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Title:
Erosion Assessment Locations: Hideaway Bay and Dingo Beach

Figure: 3-5

Rev: A

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Approx. Scale

BMT
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3.3 Planning Period (N)

The present-day, 2050 and 2100 planning horizons have been assessed. For each timeframe, it has been assumed that the storm erosion component (*C*), the rate of long term erosion (*R*) and the dune slumping component (*D*) remains consistent. For example, the linear erosion setback distance estimated for an extreme storm event under current conditions is representative of the linear setback distance for an extreme erosion event in 2050 or 2100.

3.4 Long Term Recession (R)

As noted in Section 3.2.1, the limited data and anecdotal evidence suggests that most beaches within the region are ‘dynamically stable’ and are not displaying trends of long term recession that can be linked to a deficit in sand supply. While management activities take place at some beaches these works are generally in response to minor storm erosion events rather than persistent long term processes.

The long term recession component (*R*) has been discussed with DES as part of these assessments and it was agreed that adopting an allowance of 10 m, the minimum allowance for (*R)* required by DEHP (2013), was appropriate given the apparent low rates of recession (S Sultmann 2018, pers. comm., 20 July). The one exception was for Queens Beach where periods of persistent recession trends have been observed. While these trends appear to have stabilised in more recent years, a more detailed analysis of the historical imagery has been completed.

The seaward extent of vegetation was digitised from aerial images at Queens Beach for 1985, 2002 and 2017, as shown in Figure 3-6. Recession rates vary along the length of the beach and over the time periods assessed. Erosion occurred at the northwest end of Queens Beach between 1985 and 2002 at a rate of approximately 1.5 m/year then stabilised between 2002 to 2017. The centre of the beach is either stable or accreting from 1985 to 2002 and receding at a rate of 0.5 – 0.7 m/year between 2002 and 2017. The southeast extent of the beach shows a steady recession trend of approximately 0.3 m/year from 1985 to 2017. Given these observed trends an allowance of 20 m was adopted for (*R)* at Queens Beach.

Title:

Queens Beach Coastline - North-west (Top) and South-east (Bottom)

Figure: **3-6**

Rev: **A**

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N

0 40 80m

Approx. Scale

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3.5 Storm Erosion (C)

Storm erosion occurs when increased wave heights and water levels result in the erosion of sand from the upper beach ridge. For the Whitsunday region, significant erosion events are typically associated with tropical cyclone activity.

The potential for short term storm erosion due to severe wave and elevated sea water levels (surge conditions) has been predicted using the simple cross-shore equilibrium profile model of Vellinga (1983). This empirical model calculates upper beach and dune erosion associated with the given storm induced extreme water level and wave conditions. The amount of shoreline recession is determined from the input parameters and the initial (pre-storm) beach profile shape. The model assumes the volume of material eroded from the upper beach/dune system and deposited offshore is balanced by a setback of the shoreline. This assessment approach is described further below.

3.5.1 Design Event Erosion Assessment

3.5.1.1 Background Information and Datasets

As described in Chapter 2 and BMT WBM & SEA (2017), water level and wave statistics have been recently updated throughout the Whitsunday region. The present-day 100 year ARI water levels and wave conditions at each assessment location have been adopted for the short term storm erosion assessments. The combined 100 year ARI water level and wave height conditions define the ‘design event’ for the short term storm erosion assessment. These key assessment input parameters are summarised in Table 3-3. It is noted that the likelihood of the 100 year ARI storm tide event coinciding with the 100 year ARI wave conditions throughout the Whitsunday region remains uncertain however is considered a rare event and appropriate for planning periods of at least 100 years.

Targeted sediment sampling and particle size distribution (PSD) analysis has been completed to establish the median grain size at the beaches of interest. Locations that are nourished with sand from the Don River were also considered. Table 3-2 provides a summary of the adopted values for the design event erosion assessment and PSD analysis results are provided in Appendix B. It is noted that the Vellinga model is relatively sensitive to the assumed sediment grain size with the erosion volume and setback distance increasing with decreasing grain size.

The pre-storm upper beach profiles for the assessments were obtained from topographic LiDAR survey acquired in 2016 and provided by Council or from the Geoscience Australia 5 m DEM (derived from LiDAR survey data captured in 2009). The upper beach profile data typically extended offshore to an elevation between 0 and -1.0 m Australian Height Datum (AHD). Below this elevation, the nearshore and offshore beach profile information used in this assessment was estimated from AusENC (Australian Electronic Navigational Charts) data[2] or acquired from historical beach profile survey data provided by DES (Queens Beach only).

[2] Previous experience with the Vellinga model, and sensitivity testing as part of this study, indicates that the pre-storm offshore slope influences the calculated post-storm slope but does not significantly alter the setback distance. More detailed offshore profile data is not expected to significantly modify the setback distance results.

Table 3-2 Summary of the Adopted Grain Size for Storm Erosion Assessment

Beach Compartment	Adopted Grain Size (mm)
Wilson Beach	0.60
Conway Beach	0.22
The Cove	0.60
Airlie Beach	0.60
Cannonvale Beach	0.60
Dingo Beach	0.60
Hideaway Bay	0.44
Queens Beach	0.60

3.5.1.2 Design Erosion Events Modelling Results

The pre-storm and predicted storm erosion profile at each assessment location is provided in Appendix B and the model inputs and assessment results are summarised in Table 3-3.

An example storm erosion modelling result at Queens Beach is presented in Figure 3-7. The position of the design water level and the DNRM coastline on the surveyed beach profile is also shown in Figure 3-7. As discussed in Section 3.2.1.1 and illustrated conceptually in Figure 3-1, the DNRM coastline definition has been used to estimate the dune frontal toe position and is the seaward reference for the storm erosion assessment and the overall open coast calculated erosion distance (*E* in Equation 3-2). Both the C1 and C2 components of the short term erosion are provided in Table 3-3.

The short term setback distances (C1 + C2) varied throughout the region, with a mean setback of 30 m (n = 14, SD = 8 m). The variation is primarily due to differences in the height and volume of the coastal barrier and the nearshore slope. Relatively subtle changes in the design storm characteristics also contribute to variation in the erosion estimates.

It is also important to note that the Vellinga storm erosion estimates do not account for erosion controls, such as the presence of bedrock behind the beach or man-made coastal erosion protection structures. Consideration of the seawalls and other features expected to influence the potential storm erosion limit are discussed further in Section 3.10.

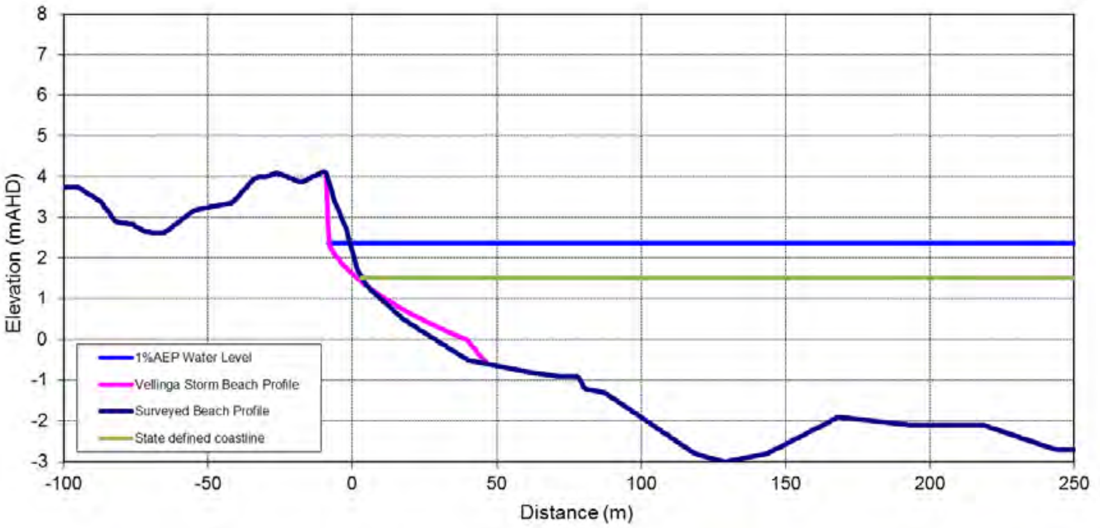

Figure 3-7 Example Design Erosion Setback at Queens Beach

Table 3-3 Summary of Design Storm Erosion Assessment Results

Beach Compartment	Profile Location	Input Peak Level (mAHD)	Input Peak Height, H_s (m)	Input Grain Size, D_{50} (mm)	Modelled Erosion Volume (m^3/m)	Modelled Landward Setback (m)	
						C1	C2
Wilson Beach	1	3.78	2.21	0.60	24	14	10
Conway Beach	1	3.78	2.21	0.22	49	24	15
Conway Beach	2	3.78	2.21	0.22	27	23	13
The Cove	1	2.69	2.44	0.60	7	5	8
Airlie Beach	1	2.69	2.44	0.60	11	8	8
Cannonvale Beach	1	2.67	2.39	0.60	14	10	3
Cannonvale Beach	2	2.67	2.39	0.60	9	4	6
Dingo Beach	1	2.54	2.80	0.60	7	6	14
Dingo Beach	2	2.54	2.80	0.60	7	5	6
Hideaway Bay	1	2.54	2.86	0.44	10	8	8
Hideaway Bay	2	2.54	2.86	0.44	17	11	10
Queens Beach	1	2.36	2.36	0.60	18	9	2
Queens Beach	2	2.36	2.36	0.60	13	8	4
Queens Beach	3	2.36	2.37	0.60	11	8	3

3.6 Dune Slumping (D)

Immediately following storm erosion events on sandy beaches, a near vertical erosion scarp of substantial height can be left in the dune or beach ridge. An area of reduced bearing capacity can exist on the landward side of sand escarpments. This can impact on structures founded on sand within this zone and the sand escarpments pose a hazard associated with sudden collapse.

Over time the near vertical erosion scarp will slump to the natural angle of repose of the sand. Nielsen et al. (1992) outlined the zones within and behind the erosion escarpment on a dune face that is expected to slump or become unstable following a storm erosion event (see Figure 3-8), namely:

- Zone of Slope Adjustment (ZSA): the area landward of the vertical erosion escarpment crest that may be expected to collapse after the storm event; and
- Zone of Reduced Foundation Capacity (ZRFC): the area landward of the zone of slope adjustment that is unstable being in proximity to the storm erosion and dune slumping.

Amongst other factors, the width of the dune slumping and reduced bearing capacity behind the top of an erosion escarpment is dependent upon the angle of repose of the dune sand and the height of the dune above mean sea level.

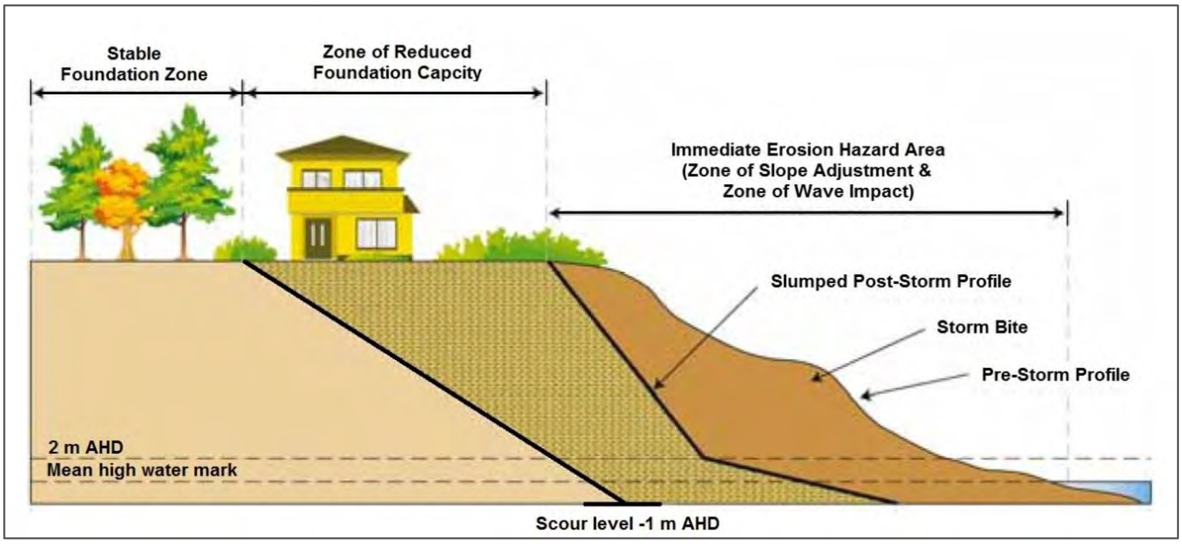

Figure 3-8 Schematic Beach/Dune Cross Section Showing Pre and Post Erosion Dune Face and Dune Stability Profiles (from DECCW, 2010; after Nielsen *et al.,* 1992)

For the current assessment, the dune slumping component is represented by ZSA and provides for the horizontal distance between the vertical erosion scarp and immediate erosion hazard area following a design erosion event. A typical angle of repose of 34 degrees for dune sands, and scour level of -1m AHD, was applied to the Nielsen et al (1992) schema, in addition to the post storm dune heights inferred from the storm erosion profiles and the available LiDAR topography data. The results of the assessment are summarised below in Table 3-4. The ZRFC is not included in the EPA formula but may be considered during risk assessment as part of the CHAS process.

Table 3-4 Summary of Dune Slumping Assessment Results

Beach Compartment	Profile Location	Dune Crest Elevation (mAHD)	Dune Slumping: ZSA* (m)	ZRFC (m)
Wilson Beach	1	4.6	2	13
Conway Beach	1	5.5	2	15
Conway Beach	2	4.1	1	12
The Cove	1	5.9	3	16
Airlie Beach	1	4.9	2	13
Cannonvale Beach	1	4.2	2	12
Cannonvale Beach	2	2.9	1	9
Dingo Beach	1	4.0	2	11
Dingo Beach	2	3.1	1	9
Hideaway Bay	1	3.5	1	10
Hideaway Bay	2	4.6	2	13
Queens Beach	1	4.1	2	11
Queens Beach	2	4.1	2	11
Queens Beach	3	4.4	2	12

* adopted dune slumping (D) component in the EPA formula

3.7 Shoreline Response to Sea Level Rise (S)

3.7.1 Background Information

As discussed in BMT WBM & SEA (2017), the Whitsunday Regional Council CHAS adopts the following SLR allowances (relative to present-day mean sea level[4]):

- 2050: 0.4 m
- 2100: 0.8 m

These allowances are based on consideration of the following key studies:

- IPCC (2014) suggest global mean increases to sea level of approximately 0.3 m by 2050 and 0.8 m by 2100;
- CSIRO & BOM (2015) suggest regional mean increases to sea level of approximately 0.14 m by 2030 and 0.65 m by 2090;
- Analysis of east coast Australia tide gauge data which suggests 3 mm/year increase in mean sea level (e.g. CSIRO/ACE CRC 2014); and
- State planning policy and guidelines that adopt 0.8 m by 2100.

It is noted that considerations for engineering design should follow best practice engineering guidelines (e.g. Harper 2012, 2017) and relevant standards and in some cases require consideration of different SLR allowances.

[4] present-day MSL is defined by MSQ (2017) and is based on the 1992 – 2011 tidal epoch

3.7.2 Equilibrium Profile (Bruun Rule) Concept

The mean sea level has remained at or near the present level for about 6,500 years. During this period the shoreline throughout the study area has evolved to a condition of ‘dynamic equilibrium’, noting that relatively short-term fluctuations in shoreline position occur (typically in response to storm events). In theory, the dynamic equilibrium shape will be maintained as the shoreline moves landward in response to SLR. This shoreline response assumes that no significant sediment sources or sinks emerge and that the landward migration of the shoreline is not obstructed by natural or man-made features.

The equilibrium profile concept can be simulated by the so-called Bruun Rule (Bruun 1962) which is illustrated in Figure 3-9. As SLR gradually occurs, wave, tide and wind related sand transport processes influence a higher position on the beach profile, with the shoreline evolving to a more landward position to return to equilibrium with the new sea level. There is an upward and landward translation of the profile to maintain equilibrium with the prevailing condition at the new SLR position.

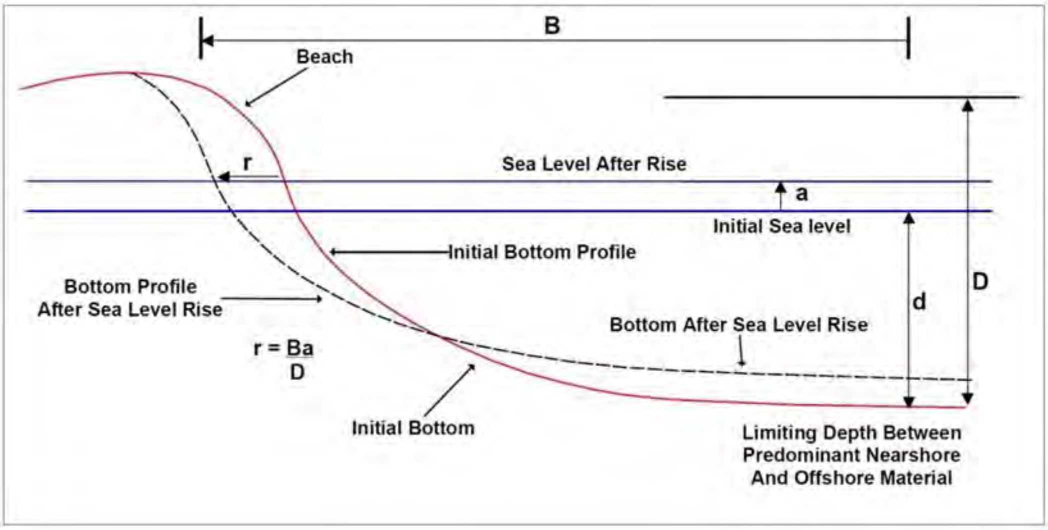

Figure 3-9 Bruun (1962) Concept of Recession due to Sea Level Rise

It is noted that application of the Bruun Rule has been highly contested within the coastal science community (e.g. Ranasinghe et al., 2007), often relating to the method for estimating the depth of closure. The depth of closure is the theoretical depth limit at which there is little or no potential for significant cross-shore exchanges of sand. Recession estimates can vary by around 500% depending on the method used to calculate the depth of closure (Ranasinghe and Stive, 2009). This compounds the already high level of uncertainty associated with the future rate of SLR and highlights the appropriateness of a risk-based approach to future climate shoreline recession assessments.

As noted by Woodroffe et al. (2012), the wide application of the Bruun Rule probably reflects its simplicity rather than its proven accuracy and recession rate estimates based on the method should be considered as only broadly indicative. More robust numerical methods to assess future climate shoreline recession exist; however, such methods require extensive historical datasets to underpin the modelling assumptions and, despite significant additional effort, will not always reduce the level of uncertainty for decision makers over long planning periods.

The 'Standard' Bruun Rule Approach

The simplified Bruun Rule as shown in Figure 3-9 for the linear recession distance *r* (in metres) is:

$$r = \frac{Ba}{D}$$

Equation 3-3

Where: *B* = horizontal distance offshore from the top of the dune to the depth of closure (*d*); *a* = the rise in sea level, and *D* = the vertical distance (height) from the top of the dune to the depth of closure (d).

Depth of Closure

Hallermeier (1981) divides the nearshore zone into three zones, namely:

- The littoral zone, which "extends to the seaward limit of intense bed activity";
- The shoal zone, which "extends from the seaward edge of the littoral zone to a water depth where expected surface waves are likely to cause little sand transport" and "waves have neither strong nor negligible effects on the sand bed"; and
- The offshore zone, which is seaward of the shoal zone and water depths are relatively deep with respect to surface wave effects on the sea bed.

Hallermeier (1981) stresses that sediment motion can and does occur seaward of the shoal zone, however the seaward boundary (d_i) defined by Hallermeier (1981) aims to provide "a physically meaningful seaward limit to the usual wave-constructed shoreface".

Hallermeier (1981) then identifies two depths that define the landward and seaward boundaries of the shoal zone:

- Depth d_l which is the "maximum water depth for sand erosion and seaward transport by an extreme yearly wave condition"; and seaward of this
- Depth d_i which is the "maximum water depth for sand motion by the median wave condition", corresponding to the seaward limit of the usual wave-constructed profile.

Patterson (2012; 2013) identified that the time-scale of profile response, the time required for the profile to achieve equilibrium, increases with depth and needs to be considered in determining closure depth. Nicholls et al. (1996, 1998) and Cowell et al. (2001) both refer to the closure depth in terms of the time scale considered. That is, they note that profile "closure" occurs at greater depth as the time scale increases. Nicholls et al. (1998) adopt a version of the Hallermeier (1977; 1981) relationship for depth of closure of the form:

$$d_{l,t} = 2.28\, H_{e,t} - 68.5\, ({H_{e,t}}^2 \,/\, g{T_{e,t}}^2)$$

Equation 3-4

Where $d_{l,t}$ = the predicted depth of closure over t years, referenced to Mean Low Water; $H_{e,t}$ = non-breaking significant wave height exceeded 12 hours per t years; and $T_{e,t}$ = associated wave period.

Following Equation 3-4, the depth of closure to cater for SLR over a planning period of 100 years will be greater than that adopted for shorter durations. Adopting a representative regional 100 year ARI design wave height of 3 m and an associated wave period of 9 seconds in Equation 3-4 suggests a 100 year planning period depth of closure around 6 m for Whitsunday region beaches. However, it should be noted that this does not provide for the concept of accumulation at the lower part of the equilibrium profile translation to balance upper profile erosion on which the Bruun Rule is based.

Considering the above, the horizontal distance offshore to the depth of closure varies between approximately 335 m and 600 m throughout the study area. Considering the variation in dune heights and offshore bathymetry, the measured Bruun Rule slope factor ranges from 1:36 to 1:73.

3.7.3 Shoreline Response to Sea Level Rise Assessment Results

The shoreline response to SLR assessment results are presented in Table 3-5. It must be recognised that the Bruun Rule does not account for the influences of longshore sand transport processes on the profile response to sea level, nor does it consider the potential changes to sediment sinks and sources (e.g. rivers and creeks) that may influence the future sediment budget. As noted by DEHP (2013), SLR projections are expected to be refined and updated in line with future IPCC publications. Should this refinement occur, Whitsunday Regional Council may wish to consider a review of the assumptions that underpin the SLR assessments described in this report.

Table 3-5 Summary of Response to Sea Level Rise Assessment Results

Beach Compartment	Profile Location	Profile Width (m)	Profile Slope (1V: XH)	Bruun Rule Recession Estimate (m)	
				2050 (0.5m SLR)	2100 (0.8m SLR)
Wilson Beach	1	600	69	28	56
Conway Beach	1	600	63	25	51
Conway Beach	2	600	73	29	59
The Cove	1	600	55	22	44
Airlie Beach	1	600	61	24	49
Cannonvale Beach	1	560	62	25	50
Cannonvale Beach	2	465	60	24	48
Dingo Beach	1	600	62	25	50
Dingo Beach	2	600	69	28	55
Hideaway Bay	1	600	65	26	52
Hideaway Bay	2	415	40	16	32
Queens Beach	1	600	68	27	54
Queens Beach	2	600	68	27	54
Queens Beach	3	600	65	26	52

3.8 Factor of Safety (F)

In accordance with DEHP (2013), a 40% factor of safety has been applied to the erosion hazard area calculations for this study, as a conservative provision to acknowledge the uncertainties and limitations of the available datasets, adopted methods and assumptions.

3.9 Assessment Results

The open coast erosion hazard distances have been calculated following the methodology and formula described in Section 3.2.1 and 3.2.1.1 for locations throughout the study area where sufficient data is available. A summary of the calculated widths at each assessment location is provided in Table 3-6. The State-declared calculated distance is also listed in Table 3-6 (taken from DEHP Plan WHR3A, refer Section 3.1.1). For beach compartments with multiple assessment locations, the compartment average has been adopted for comparison and calculated erosion width mapping purposes. Other assumptions relating the calculated erosion distance mapping are discussed in Section 3.10.

As noted in Section 3.2.1, it is not possible to estimate a long term trend in shoreline recession (*R*) from the limited historical datasets but it is assumed to be very low and/or mitigated through ongoing management activities. This component is simply accounted for by adopting an allowance of 10 m (the minimum allowance for *R* required by DEHP 2013) and represents approximately 10% of the total calculated erosion distance.

The short term erosion component (*C1* + *C2*, see Section 3.5) has an average setback distance of 30 m, and a standard deviation of 8 m (*n* = 14). This variability is due to the differences in the cross shore profile and design storm characteristics between locations. The short term erosion component accounts for approximately 30% of the coastal erosion hazard area under the 2100 timeframe.

The calculated erosion distance also considers slumping of the dune scarp (*D*, see Section 3.6) and this component accounts for approximately 10% of the total erosion prone area under the 2100 timeframe.

Considering the SLR projection of 0.8 m by the year 2100 adopted by the Queensland Government for planning purposes (DEHP 2015), the shoreline response to SLR (*S*, see Section 3.7) component accounts for approximately 50% of the coastal erosion hazard area.

Regarding the calculated and State-declared calculated erosion widths (DEHP WHR3A) the following is noted:

- Except for Queens Beach and Dingo Beach, the calculated widths in 2100 are greater than the State-declared widths.
- Despite The Cove being a constructed beach bounded by groyne structures, the State-declared width of zero is considered too low for strategic planning purposes. However, it is acknowledged that the standard open coast formula (Equation 3-1) is not well suited to this location. The present-day calculated erosion width is therefore considered an appropriate hazard area definition at this location.

Other considerations for erosion hazard area definition and mapping include:

- Similar to The Cove, Airlie Beach is a highly modified beach compartment bounded by coastal structures and is not well suited to the standard calculated erosion distance formula. At this location, the present-day erosion width is expected to capture the key assets and values relevant to the CHAS.
- The seawall at Cannonvale Beach is expected to limit the landward extent of gradual erosion processes associated with SLR and/or long term recession. However, the design standard of the wall is uncertain and may not withstand a severe storm event. The present-day erosion distance, measured landward from the seawall crest, is considered the appropriate maximum width at this location. This assumes that the seawall is maintained to a standard suitable to limit gradual erosion processes (but not necessarily withstand a severe storm).

3.10 Calculated Erosion Distance Mapping

The calculated erosion widths summarised in Table 3-6 have been mapped and are presented in Appendix D (the data is also available in digital format). This mapping has been produced specifically for the CHAS and to assist in the identification of potentially exposed assets and values. Further site-based data collection and assessments may be required to support the design of proposed coastal hazard risk mitigation measures.

As discussed above, the mapping includes some qualitative assumptions at locations where coastal structures are expected to limit the landward extent of erosion and/or the open coast erosion formula is not well suited. It is noted that these locations contain existing development (including roads, public and private assets) with a high likelihood of protection.

Table 3-6 Summary of Erosion Hazard Area Assessment Results (including 40% Factor of Safety)

Beach Compartment	Long term recession component	Short term storm erosion component		Dune slumping component	Shoreline response to sea level rise S x F (m)		Calculated erosion distance[1] E (m)			Declared EPA Width WHR3A (m)	Notes
	(N x R) x F (m)	C1 x F (m)	C2 (m)	D (m)	2050 (0.4m SLR)	2100 (0.8m SLR)	Present -day[2]	2050	2100		
Wilson Beach	14	20	10	2	39	78	32	85	123	90	
Conway Beach	14	33	14	1	38	77	48	100	138	105	
The Cove	14	7	8	3	31	62	17	62	93	0	constructed or highly modified beach
Airlie Beach	14	11	8	2	34	68	21	69	103	75	constructed or highly modified beach
Cannonvale Beach	14	10	5	1	34	69	16	64	98	90	some seawall controls present; uncertain design standard
Dingo Beach	14	7	10	1	37	74	18	69	106	115[3]	
Hideaway Bay	14	13	9	2	30	59	23	67	96	75	possible bedrock
Queens Beach	28	12	3	2	37	75	17	82	120	123[3]	some seawall controls present; uncertain design standard

[1] The above calculated erosion distances do not consider local erosion controls where present (i.e. bedrock or engineered coastal protection structures). They also do not apply to coastal waterway entrances.

[2] Short term erosion and dune slumping components only

[3] Average for beach compartment (refer Table 3-1)

4 Permanent Inundation due to Sea Level Rise

4.1 Hazard Assessment Approach

As discussed in Section 3.1.1, the State EPA mapping defines permanent tidal inundation due to SLR at 2100 as:

- Present-day Highest Astronomical Tide (HAT) plus 0.8 m SLR.

The hazard area is then obtained by extrapolating the water level across land. Areas adjacent to tidal waters where the ground elevation falls below the threshold water level are deemed to be within the hazard area.

The SLR hazard information provided by the State is useful for ‘first-pass risk screening’ but does not provide sufficient information regarding likelihood and consequence to undertake a more detailed risk assessment and develop risk mitigation options. To address this issue, SLR hazard mapping including depth classification has been developed for the Whitsunday Regional Council CHAS planning horizons. The adopted approach generally follows the State definition, whereby a threshold water level (mAHD) is defined by consideration of HAT plus an appropriate SLR allowance. Present-day HAT was estimated at 445 unique locations throughout the region as part of the Bowen Water Hazards Study (BMT WBM & SEA 2017) and the extension of this work described in Chapter 2 of this report. The water level mapping assumptions at key locations throughout the study area are summarised in Table 4-1. The published HAT tidal plane (MSQ 2017) at Abbot Point, Bowen and Shute Harbour is also indicated in Table 4-1. This comparison suggests that HAT estimated using the numerical modelling tools (the so-called HAT Proxy) is within ±0.05 m of the published tidal planes at these locations.

4.2 Permanent Inundation due to Sea Level Rise Mapping

Broad scale mapping showing the projected impact of permanent inundation due to SLR at 2050 and 2100 is presented in Appendix E. This data is also available in digital format.

Table 4-1 Permanent inundation due to Sea Level Rise mapping assumptions at key locations

Location	Present-day HAT Proxy (mAHD)	2050 (0.4m SLR)	2100 (0.8m SLR)
Molongle Creek	2.03	2.43	2.83
Abbot Point	1.92 (1.97*)	2.30	2.70
Queens Bay	1.92	2.32	2.72
Horseshoe Bay	1.92	2.32	2.72
Kings Beach	1.94	2.34	2.74
Bowen	1.98 (1.95*)	2.38	2.78
Heronvale	1.98	2.38	2.78
Brisk Bay	1.99	2.39	2.79
Edgecumbe Bay	2.01	2.41	2.81
Sinclair Bay	2.01	2.41	2.81
Cape Gloucester	1.99	2.39	2.79
Gloucester Island	1.96	2.36	2.76
Hideaway Bay	2.05	2.45	2.85
Dingo Beach	2.05	2.45	2.85
Cannonvale Beach	2.20	2.60	3.00
Airlie Beach	2.20	2.60	3.00
Shute Harbour	2.46 (2.42*)	2.86	3.26
Conway Beach	3.31	3.71	4.11
Wilson Beach	3.31	3.71	4.11

*MSQ (2017) published HAT tidal plane

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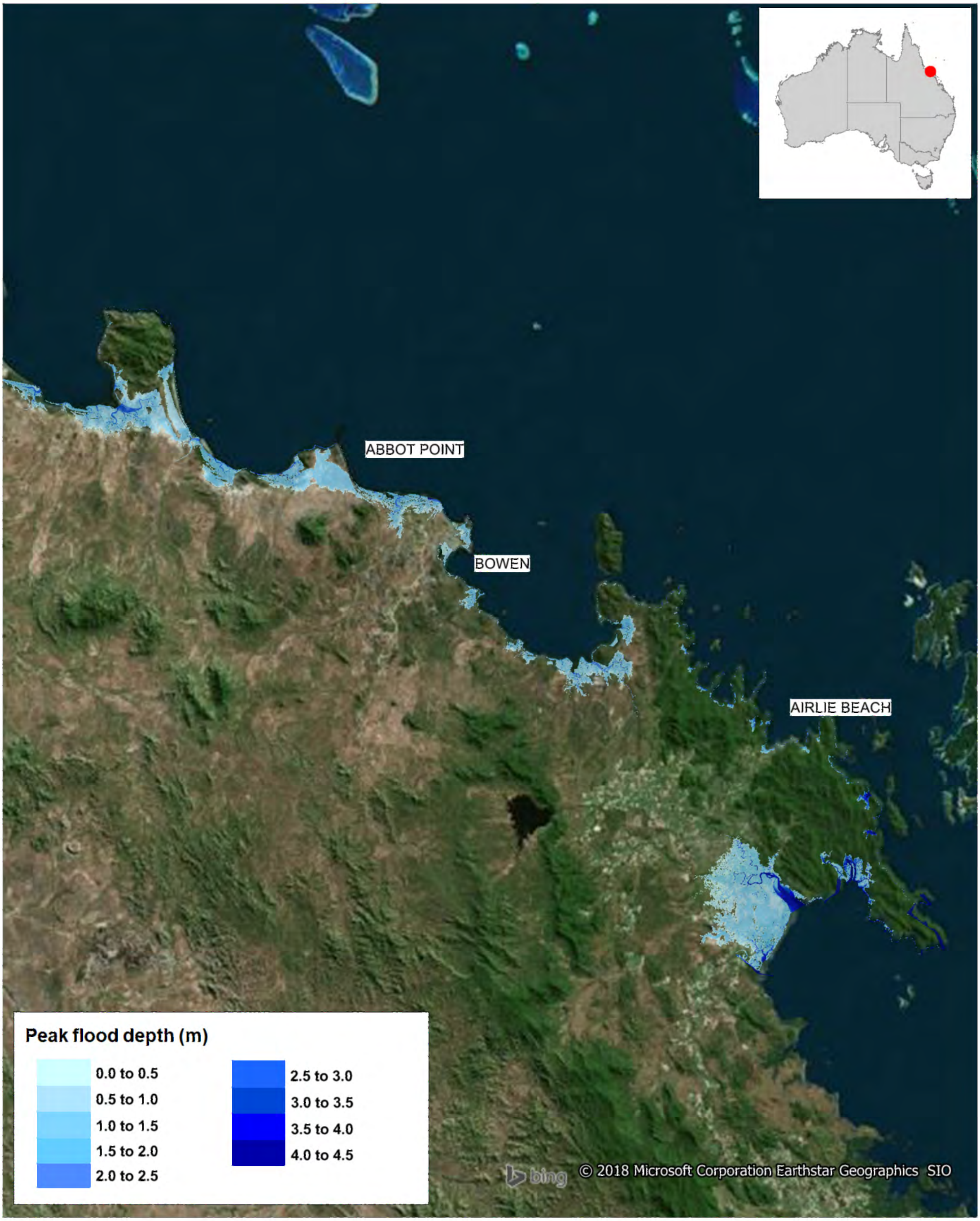
Appendix A Current & Future Climate Storm Tide Inundation Mapping



Title:

Current Climate 100 year ARI Storm Tide Inundation Peak Depth

Figure: **A-1**

Rev: **A**

N

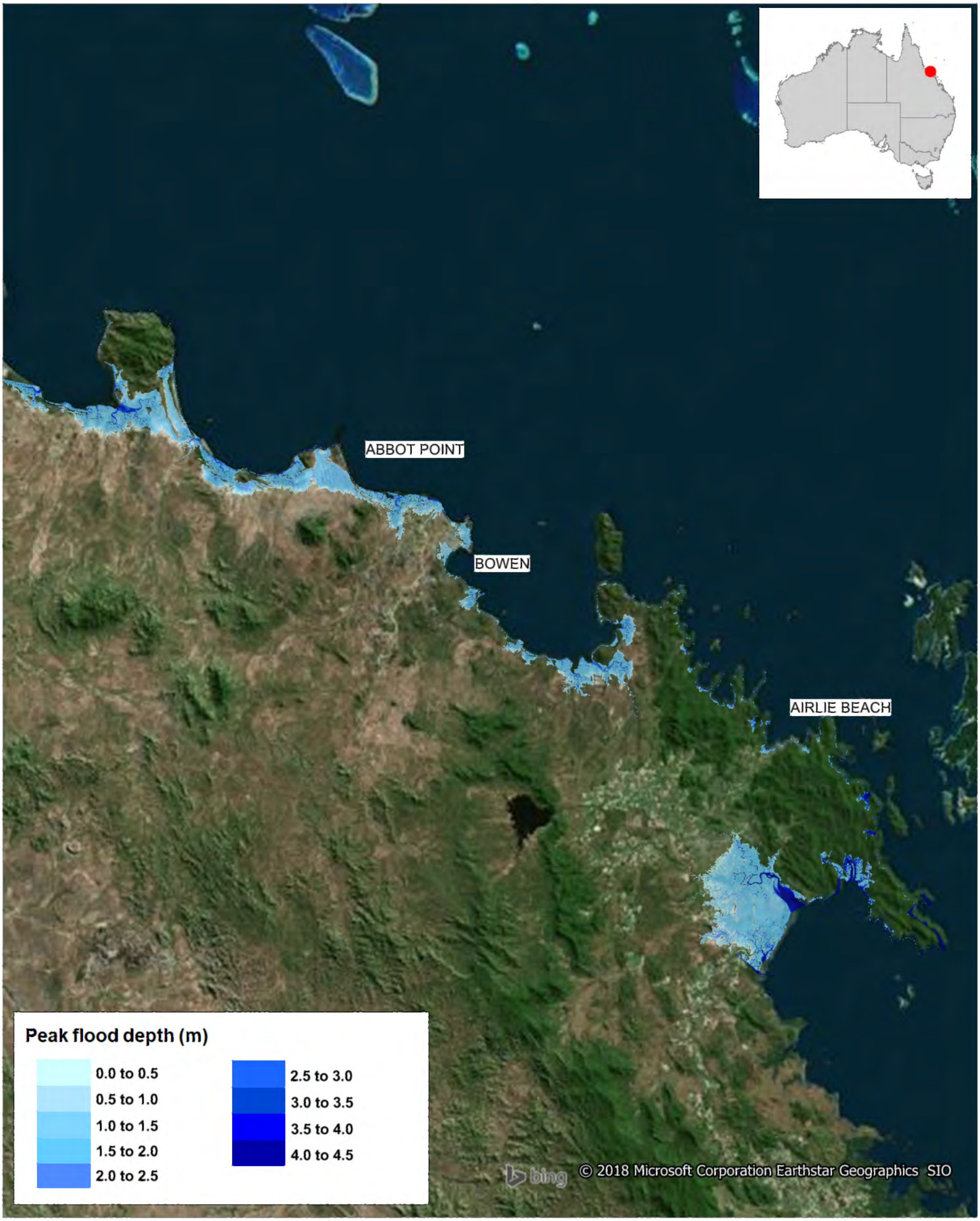
0 15 30km

Approx. Scale

BMT

www.bmt.org

Filepath: I:\B22589_I_JLB Bowen Water Hazards Study MB\DRG\COA_072_WRC_LGA_2017_100yearARI.wor



Title:

Future Climate 2050 100 year ARI Storm Tide Inundation Peak Depth

Figure: **A-2**

Rev: **A**

N

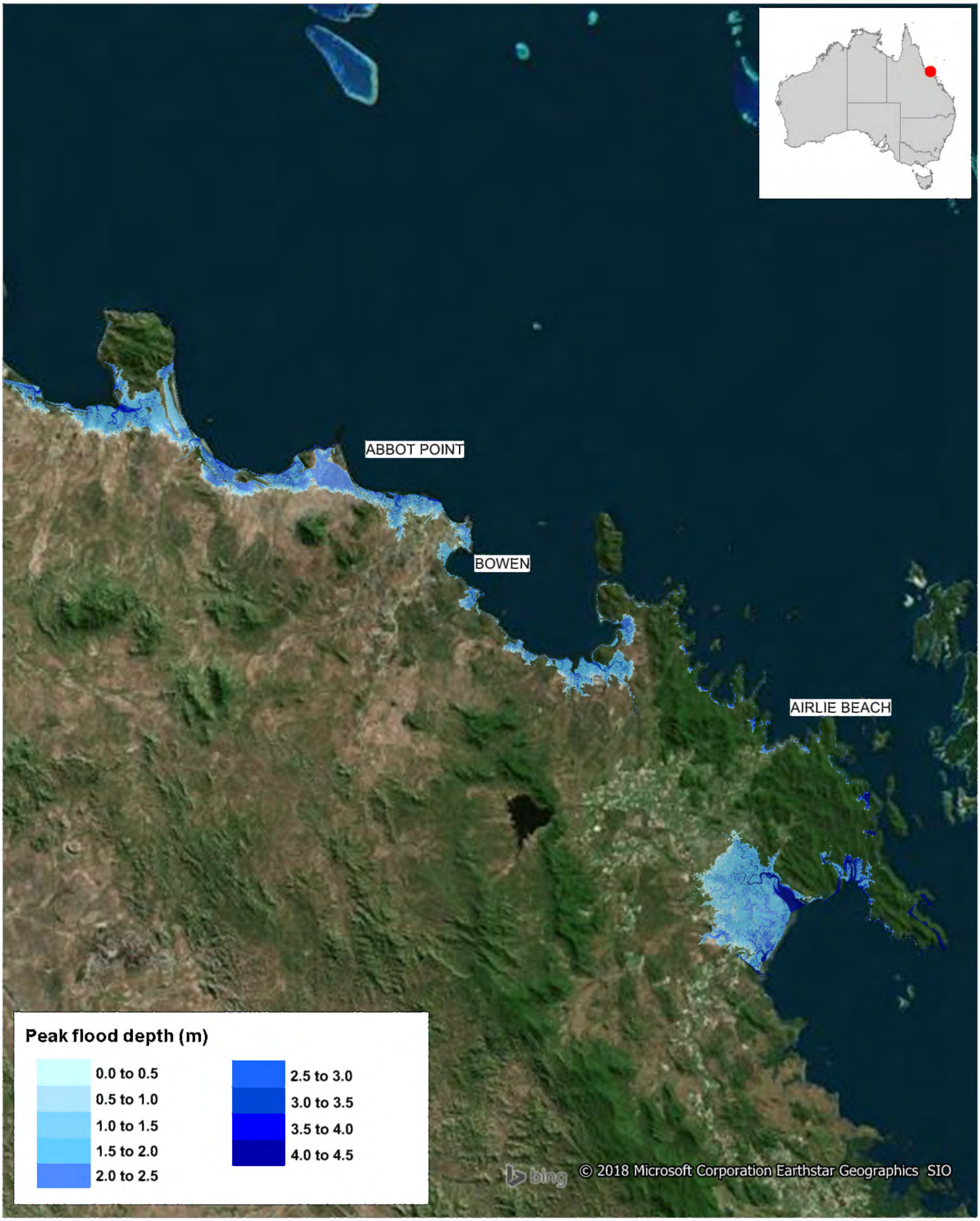
0 15 30km

Approx. Scale

BMT

www.bmt.org

Filepath: I:\B22589_I_JLB Bowen Water Hazards Study MB\DRG\COA_071_WRC_LGA_2050_100yearARI.wor



Title:

Future Climate 2100 100 year ARI Storm Tide Inundation Peak Depth

Figure: **A-3**

Rev: **A**

N

0 15 30km

Approx. Scale

www.bmt.org

Filepath: I:\B22589_I_JLB Bowen Water Hazards Study MB\DRG\COA_070_WRC_LGA_2100_100yearARI.wor

Appendix B Particle Size Distribution Analysis Result

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Cover Aggregate Report

Test Methods Q103B, Q201, Q202, Q215, Q216, Q217

Report Number	18-03
Senders Number	01
Road	Conway Beach #1
Sample Location	Sampled By Others
Aggregate Size (mm)	N/A

Client	Whitsunday Regional Council
Job	Beach Replenishment
Job Number	4684.1056.0401
Date Received	1/03/18
Date Tested	20/03/18

TEST		SPECIFICATIONS		RESULT
	Sieve Size (mm)	Min	Max	% Passing
Particle Size Distribution	6.7			100
	4.75			100
	2.36			100
	1.18			100
	0.600			100
	0.425			99
	0.300			90
	0.150			7.3
	0.075			0.1
Flakiness Index (%)				N/A
Average Least Dimension (mm)				N/A
Crushed Particles (%)				N/A
Degree of Aggregate Precoat (%)				N/A
Weak Particles (%)				N/A

Signatory	M.Moody.	M.M.
Title	Senior Soil Technician	
Date	20/03/18	
Accreditation Number	5298	

Comments	Conway Beach #1

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Test Methods Q103B, Q201, Q202, Q215, Q216, Q217

Report Number	18-03	Client	Whitsunday Regional Council
Senders Number	02	Job	Beach Replenishment
Road	Conway Beach #2	Job Number	4684.1056.0401
Sample Location	Sampled By Others	Date Received	1/03/18
Aggregate Size (mm)	N/A	Date Tested	20/03/18

TEST		SPECIFICATIONS		RESULT
	Sieve Size (mm)	Min	Max	% Passing
Particle Size Distribution	6.7			100
	4.75			100
	2.36			100
	1.18			99
	0.600			99
	0.425			97
	0.300			89
	0.150			22
	0.075			0.2
Flakiness Index (%)				N/A
Average Least Dimension (mm)				N/A
Crushed Particles (%)				N/A
Degree of Aggregate Precoat (%)				N/A
Weak Particles (%)				N/A

Signatory	M.Moody.	M.M.
Title	Senior Soil Technician	
Date	20/03/18	
Accreditation Number	5298	

Comments	Conway Beach #2

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Report Number	18-03
Senders Number	03
Road	Conway Beach #3
Sample Location	Sampled By Others
Aggregate Size (mm)	N/A

Client	Whitsunday Regional Council
Job	Beach Replenishment
Job Number	4684.1056.0401
Date Received	1/03/18
Date Tested	20/03/18

TEST		SPECIFICATIONS		RESULT
	Sieve Size (mm)	Min	Max	% Passing
Particle Size Distribution	6.7			100
	4.75			100
	2.36			99
	1.18			99
	0.600			98
	0.425			96
	0.300			84
	0.150			13
	0.075			0.2
Flakiness Index (%)				N/A
Average Least Dimension (mm)				N/A
Crushed Particles (%)				N/A
Degree of Aggregate Precoat (%)				N/A
Weak Particles (%)				N/A

Signatory	M.Moody.	M.M.
Title	Senior Soil Technician	
Date	20/03/18	
Accreditation Number	5298	

Comments	Conway Beach #3

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Report Number	18-03
Senders Number	04
Road	Bowen #1
Sample Location	Sampled By Others
Aggregate Size (mm)	N/A

Client	Whitsunday Regional Council
Job	Beach Replenishment
Job Number	4684.1056.0401
Date Received	1/03/18
Date Tested	20/03/18

TEST		SPECIFICATIONS		RESULT
	Sieve Size (mm)	Min	Max	% Passing
Particle Size Distribution	6.7			100
	4.75			100
	2.36			100
	1.18			96
	0.600			83
	0.425			72
	0.300			54
	0.150			18
	0.075			0.9
Flakiness Index (%)				N/A
Average Least Dimension (mm)				N/A
Crushed Particles (%)				N/A
Degree of Aggregate Precoat (%)				N/A
Weak Particles (%)				N/A

Signatory	M.Moody.	M.M.
Title	Senior Soil Technician	
Date	20/03/18	
Accreditation Number	5298	

Comments	Bowen #1

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Report Number	18-03
Senders Number	05
Road	Bowen #2
Sample Location	Sampled By Others
Aggregate Size (mm)	N/A

Client	Whitsunday Regional Council
Job	Beach Replenishment
Job Number	4684.1056.0401
Date Received	1/03/18
Date Tested	20/03/18

TEST		SPECIFICATIONS		RESULT
	Sieve Size (mm)	Min	Max	% Passing
Particle Size Distribution	6.7			100
	4.75			100
	2.36			99
	1.18			91
	0.600			57
	0.425			37
	0.300			23
	0.150			6.7
	0.075			0.3
Flakiness Index (%)				N/A
Average Least Dimension (mm)				N/A
Crushed Particles (%)				N/A
Degree of Aggregate Precoat (%)				N/A
Weak Particles (%)				N/A

Signatory	M.Moody.
Title	Senior Soil Technician
Date	20/03/18
Accreditation Number	5298

Comments	Bowen #2

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Test Methods Q103B, Q201, Q202, Q215, Q216, Q217

Report Number	18-03
Senders Number	06
Road	Bowen #3
Sample Location	Sampled By Others
Aggregate Size (mm)	N/A

Client	Whitsunday Regional Council
Job	Beach Replenishment
Job Number	4684.1056.0401
Date Received	1/03/18
Date Tested	20/03/18

TEST		SPECIFICATIONS		RESULT
	Sieve Size (mm)	Min	Max	% Passing
Particle Size Distribution	6.7			100
	4.75			100
	2.36			94
	1.18			73
	0.600			40
	0.425			22
	0.300			9.7
	0.150			2
	0.075			0.7
Flakiness Index (%)				N/A
Average Least Dimension (mm)				N/A
Crushed Particles (%)				N/A
Degree of Aggregate Precoat (%)				N/A
Weak Particles (%)				N/A

Signatory	M.Moody.
Title	Senior Soil Technician
Date	20/03/18
Accreditation Number	5298

Comments	Bowen #3

Nov-17

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Particle Size Distribution Report
Test Methods - Q103A

Report Number	17-40
Senders Number	05
Road	Gladston Park Road
Sample Location	River
Proposed Use	Sand

Client	WRC
Job	Beach Rehabilitation
Job Number	4687.2616
Date Received	27/10/17
Date Tested	14/11/17

Sieve Size (mm)	% Passing
16.0	100
13.2	99.8
9.5	99.5
6.7	99.3
4.75	98.4
2.36	92.0
1.18	72.8
0.600	26.0
0.425	9.0
0.300	3.6
0.150	1.1
0.075	0.6

Signatory	M.Moody.
Title	Senior Soil Technician
Date	15/11/17
Accreditation	5298

M.M.

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Cover Aggregate Report

Test Methods Q103B, Q201, Q202, Q215, Q216, Q217

Report Number	18-32
Senders Number	Point 1 Sample A
Road	N/A
Sample Location	Sampled By Others
Aggregate Size (mm)	N/A

Client	Whitsunday Regional Council
Job	Hydeaway Beach Samples
Job Number	W000046.74.2021.401
Date Received	17/07/18
Date Tested	2/08/18

TEST		SPECIFICATIONS		RESULT
	Sieve Size (mm)	Min	Max	% Passing
Particle Size Distribution	6.7			100
	4.8			100
	2.36			100
	1.18			100
	0.600			98
	0.425			84
	0.300			29
	0.150			1.1
	0.075			0
Flakiness Index (%)		35		N/A
Average Least Dimension (mm)				N/A
Crushed Particles (%)				N/A
Degree of Aggregate Precoat (%)				N/A
Weak Particles (%)				N/A

Signatory	M.Moody.	M.M. -
Title	Senior Soil Technician	
Date	2/08/18	
Accreditation Number	5298	

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Test Methods Q103B, Q201, Q202, Q215, Q216, Q217

Report Number	18-32
Senders Number	Point 1 Sample B
Road	N/A
Sample Location	Sampled By Others
Aggregate Size (mm)	N/A

Client	Whitsunday Regional Council
Job	Hydeaway Beach Samples
Job Number	W000046.74.2021.401
Date Received	17/07/18
Date Tested	2/08/18

TEST		SPECIFICATIONS		RESULT
	Sieve Size (mm)	Min	Max	% Passing
Particle Size Distribution	6.7			100
	4.8			99
	2.36			97
	1.18			91
	0.600			78
	0.425			57
	0.300			14
	0.150			0.7
	0.075			0
Flakiness Index (%)		35		N/A
Average Least Dimension (mm)				N/A
Crushed Particles (%)				N/A
Degree of Aggregate Precoat (%)				N/A
Weak Particles (%)				N/A

Signatory	M.Moody.
Title	Senior Soil Technician
Date	2/08/18
Accreditation Number	5298

M.M.

Comments	

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Test Methods Q103B, Q201, Q202, Q215, Q216, Q217

Report Number	18-32
Senders Number	Point 2 Sample A
Road	N/A
Sample Location	Sampled By Others
Aggregate Size (mm)	N/A

Client	Whitsunday Regional Council
Job	Hydeaway Beach Samples
Job Number	W000046.74.2021.401
Date Received	17/07/18
Date Tested	2/08/18

TEST		SPECIFICATIONS		RESULT
	Sieve Size (mm)	Min	Max	% Passing
Particle Size Distribution	6.7			100
	4.8			100
	2.36			100
	1.18			98
	0.600			90
	0.425			44
	0.300			7.9
	0.150			0.3
	0.075			0
Flakiness Index (%)		35		N/A
Average Least Dimension (mm)				N/A
Crushed Particles (%)				N/A
Degree of Aggregate Precoat (%)				N/A
Weak Particles (%)				N/A

Signatory	M.Moody.	M.M.
Title	Senior Soil Technician	
Date	2/08/18	
Accreditation Number	5298	
Comments		

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Cover Aggregate Report

Test Methods Q103B, Q201, Q202, Q215, Q216, Q217

Report Number	18-32
Senders Number	Point 2 Sample B
Road	N/A
Sample Location	Sampled By Others
Aggregate Size (mm)	N/A

Client	Whitsunday Regional Council
Job	Hydeaway Beach Samples
Job Number	W000046.74.2021.401
Date Received	17/07/18
Date Tested	2/08/18

TEST		SPECIFICATIONS		RESULT
	Sieve Size (mm)	Min	Max	% Passing
Particle Size Distribution	6.7			100
	4.8			100
	2.36			100
	1.18			99
	0.600			92
	0.425			47
	0.300			7.8
	0.150			0.2
	0.075			0
Flakiness Index (%)		35		N/A
Average Least Dimension (mm)				N/A
Crushed Particles (%)				N/A
Degree of Aggregate Precoat (%)				N/A
Weak Particles (%)				N/A

Signatory	M.Moody.	M.M.
Title	Senior Soil Technician	
Date	2/08/18	
Accreditation Number	5298	

Comments	

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Test Methods Q103B, Q201, Q202, Q215, Q216, Q217

Report Number	18-32
Senders Number	Point 3 Sample A
Road	N/A
Sample Location	Sampled By Others
Aggregate Size (mm)	N/A

Client	Whitsunday Regional Council
Job	Hydeaway Beach Samples
Job Number	W000046.74.2021.401
Date Received	17/07/18
Date Tested	2/08/18

TEST		SPECIFICATIONS		RESULT
	Sieve Size (mm)	Min	Max	% Passing
Particle Size Distribution	6.7			99
	4.8			98
	2.36			92
	1.18			67
	0.600			7.1
	0.425			0.3
	0.300			0.1
	0.150			0.1
	0.075			0
Flakiness Index (%)		35		N/A
Average Least Dimension (mm)				N/A
Crushed Particles (%)				N/A
Degree of Aggregate Precoat (%)				N/A
Weak Particles (%)				N/A

Signatory	M.Moody.	M.M.
Title	Senior Soil Technician	
Date	2/08/18	
Accreditation Number	5298	

Comments	

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Test Methods Q103B, Q201, Q202, Q215, Q216, Q217

Report Number	18-32
Senders Number	Point 3 Sample B
Road	N/A
Sample Location	Sampled By Others
Aggregate Size (mm)	N/A

Client	Whitsunday Regional Council
Job	Hydeaway Beach Samples
Job Number	W000046.74.2021.401
Date Received	17/07/18
Date Tested	2/08/18

TEST		SPECIFICATIONS		RESULT
	Sieve Size (mm)	Min	Max	% Passing
Particle Size Distribution	6.7			98
	4.8			96
	2.36			91
	1.18			63
	0.600			5.6
	0.425			0.2
	0.300			0.1
	0.150			0
	0.075			0
Flakiness Index (%)		35		N/A
Average Least Dimension (mm)				N/A
Crushed Particles (%)				N/A
Degree of Aggregate Precoat (%)				N/A
Weak Particles (%)				N/A

Signatory	M.Moody.
Title	Senior Soil Technician
Date	2/08/18
Accreditation Number	5298

M.M.

Comments	

Appendix C Storm Erosion Estimates

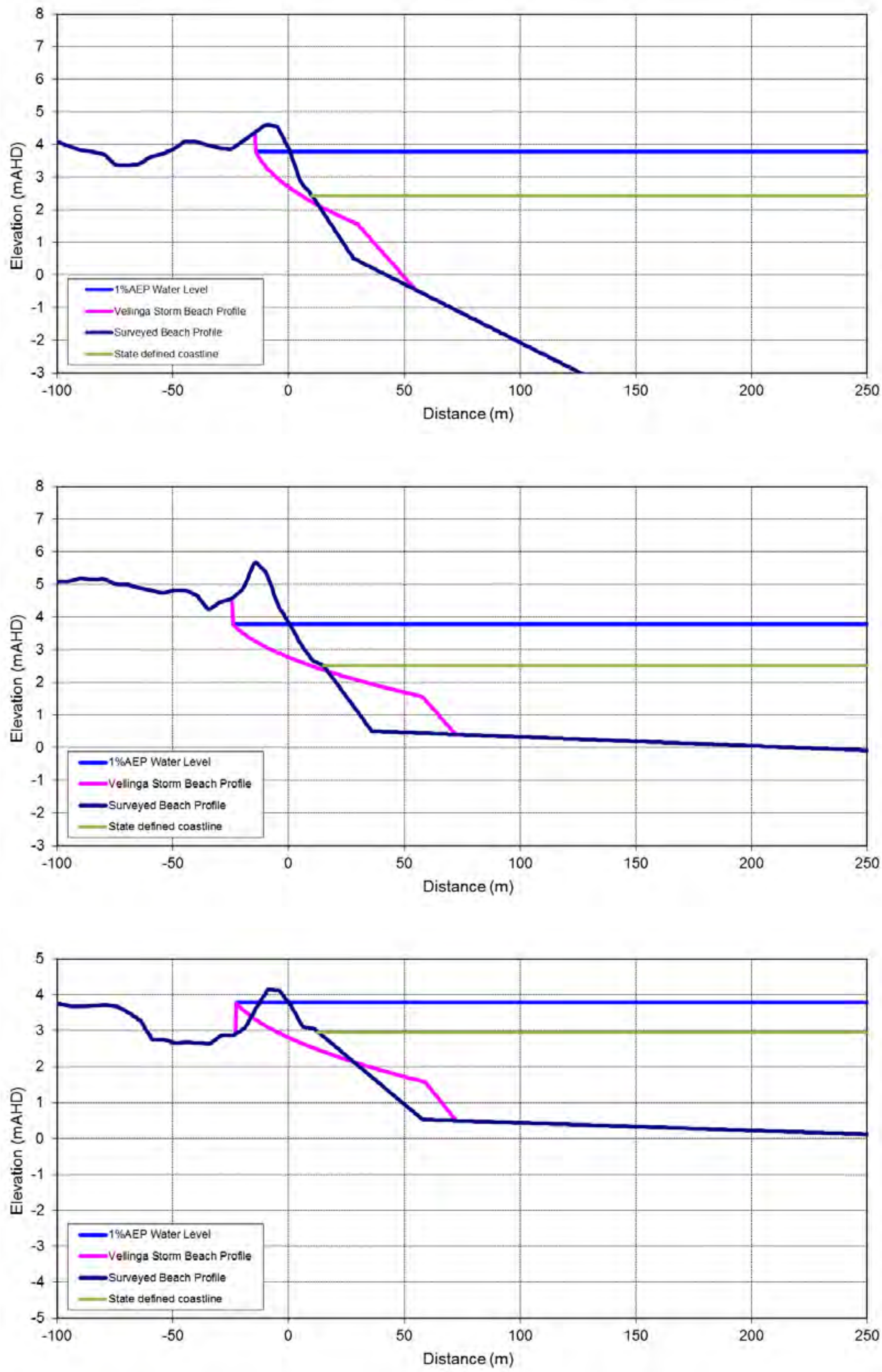

Figure C-1 Storm Erosion Estimate: Wilsons Beach (top), Conway Beach 1 (middle) and Conway Beach 2 (bottom)

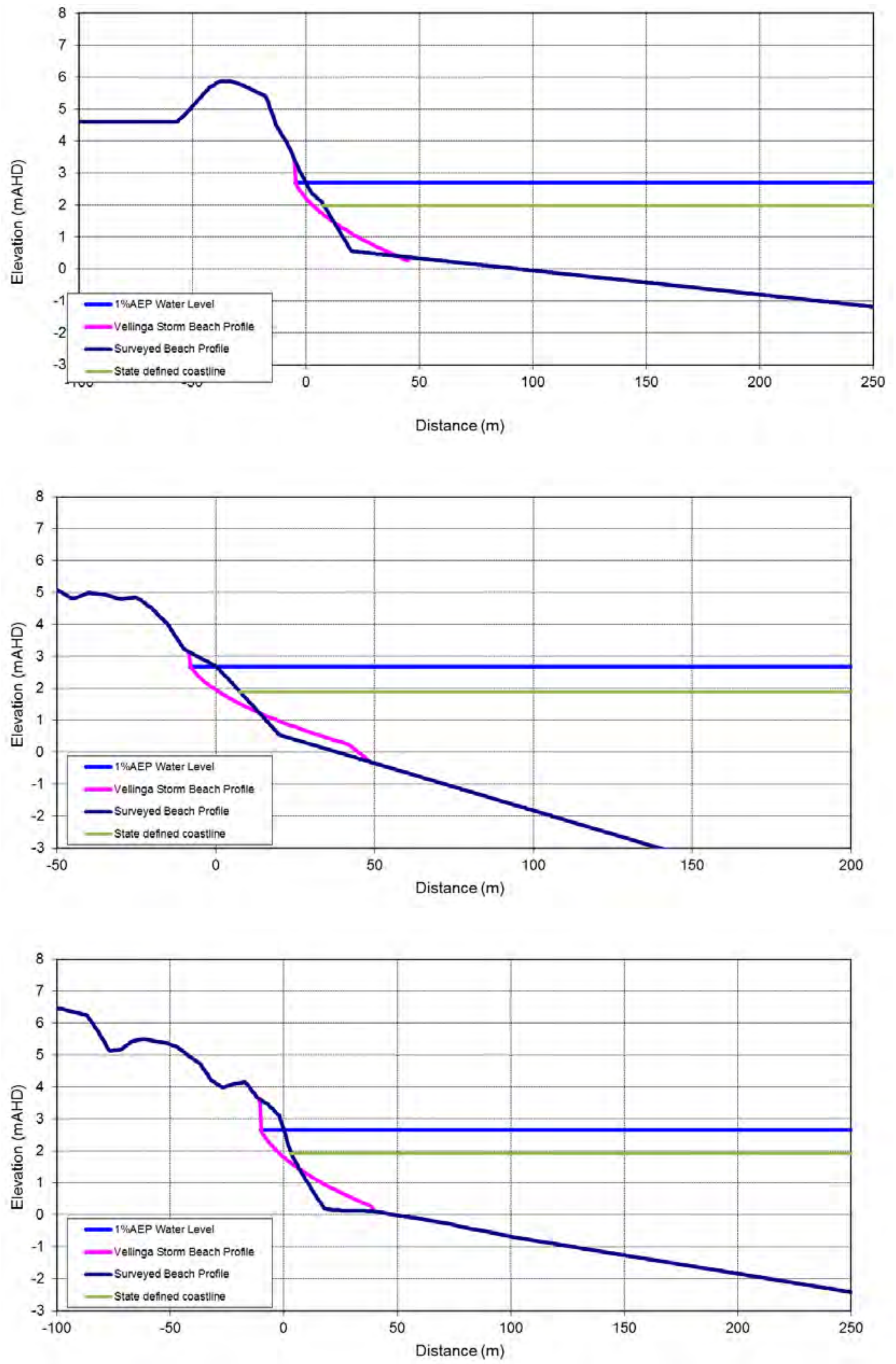

Figure C-2 Storm Erosion Estimate: The Cove (top), Airlie Beach (middle) and Cannonvale Beach 1 (bottom)

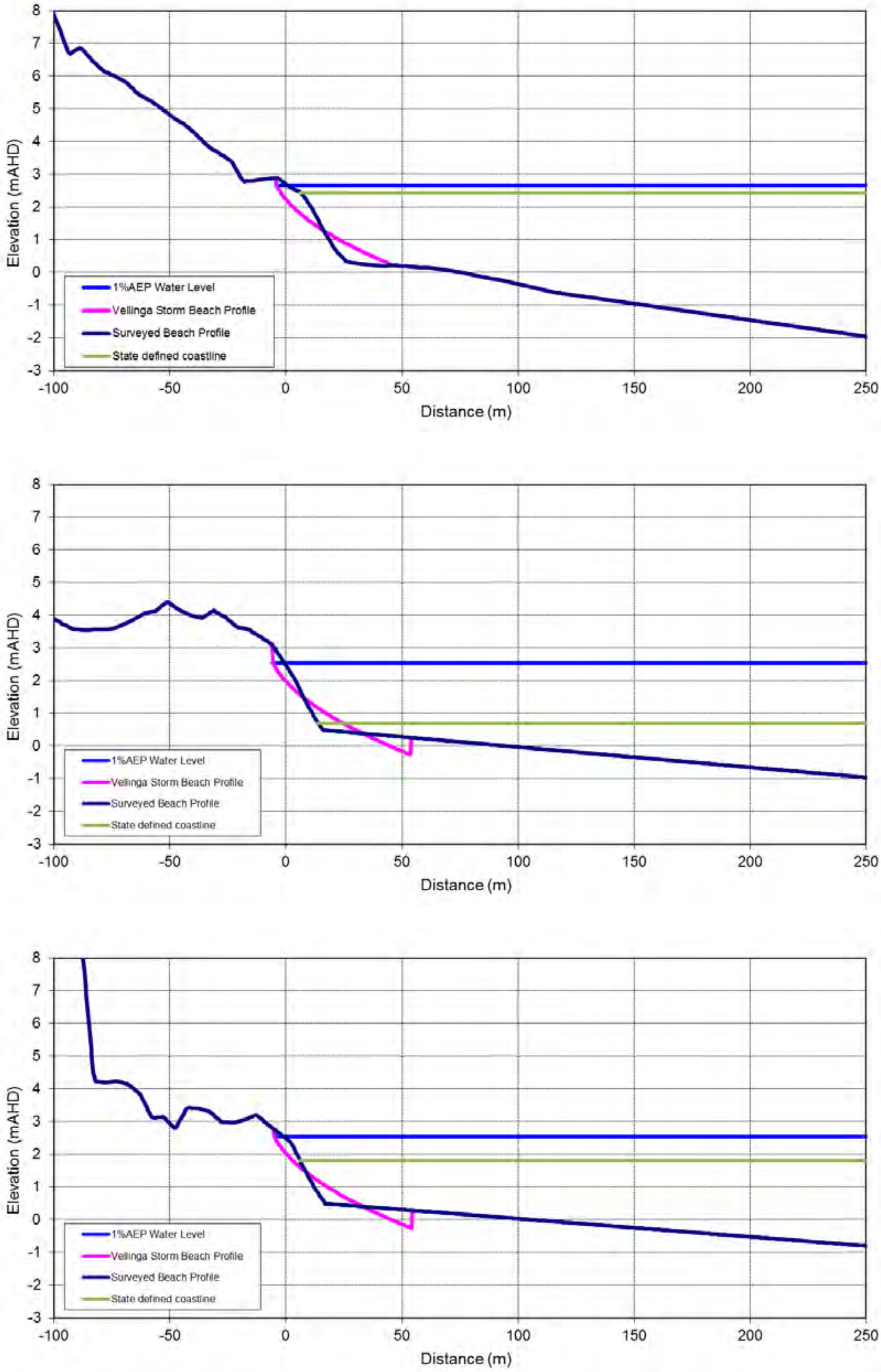

Figure C-3 Storm Erosion Estimate: Cannonvale 2 (top), Dingo Beach 1 (middle) and Dingo Beach 2 (bottom)

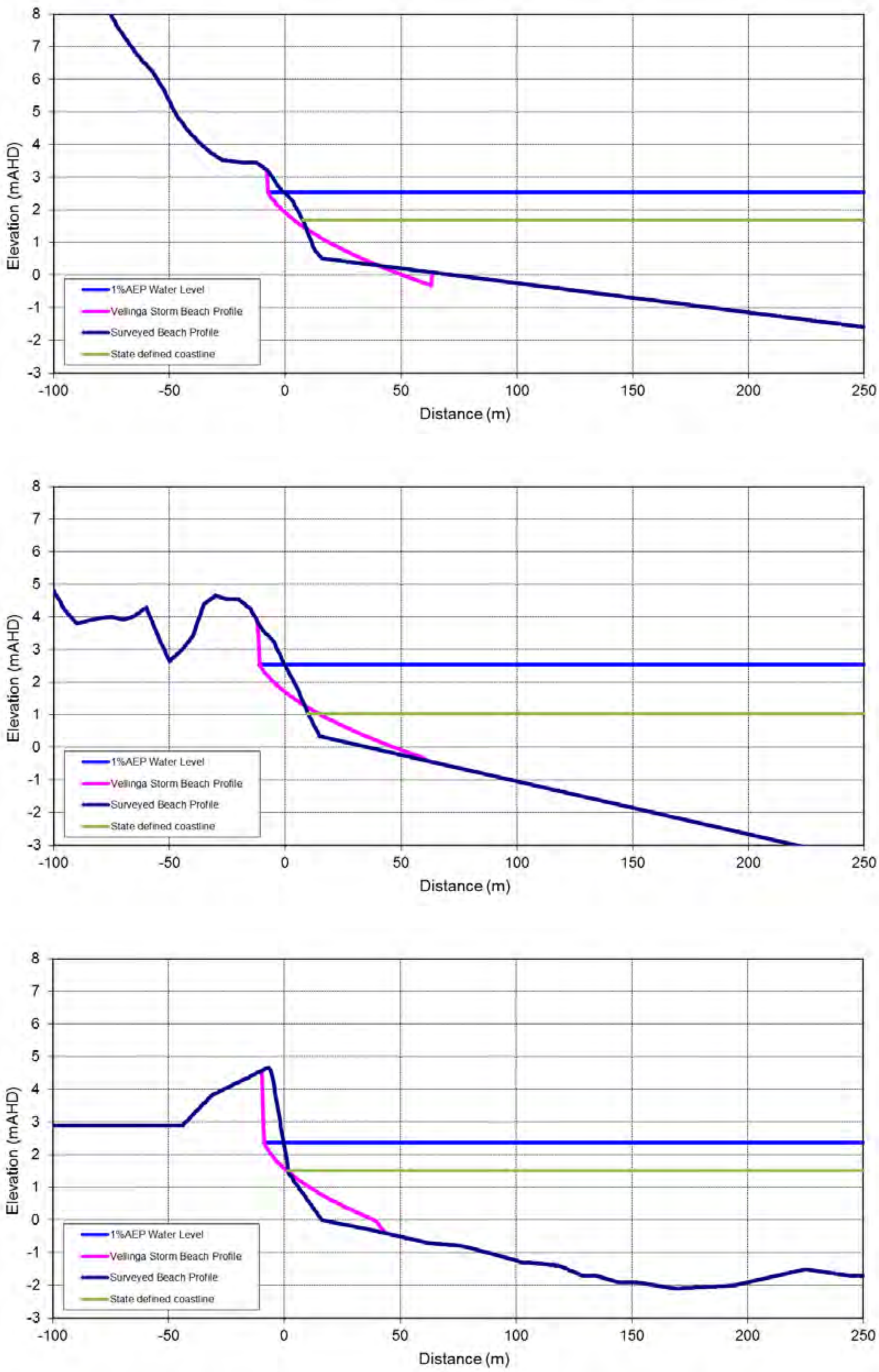

Figure C-4 Storm Erosion Estimate: Hideaway Bay 1 (top), Hideaway Bay 2 (middle) and Queens Beach 1 (bottom)

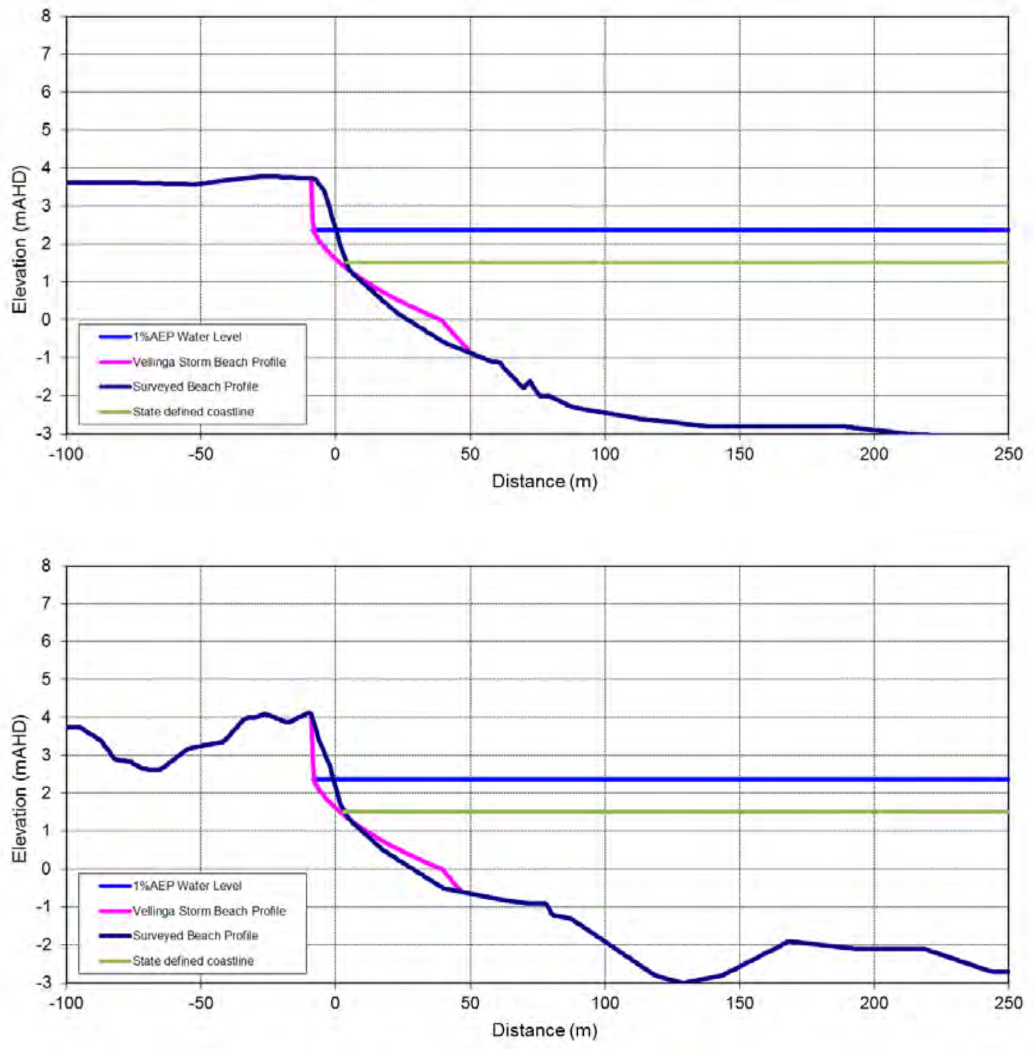

Figure C-5 Storm Erosion Estimate: Queens Beach 2 (top) and Queens Beach 3 (bottom)

Appendix D Calculated Erosion Prone Area Width Mapping

Title:

Erosion Prone Areas: Wilson Beach & Conway Beach

Figure: D-1

Rev: B

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N

0 0.5 1km

Approx. Scale

BMT

www.bmt.org

Filepath: I:\B22454_i_iat_KIPT\DRG\COA_060_Erosion_Prone_Areas_Conway_Wilson.wor

Title:

Erosion Prone Areas: Cannonvale & Airlie Beach

Figure: D-2

Rev: B

N

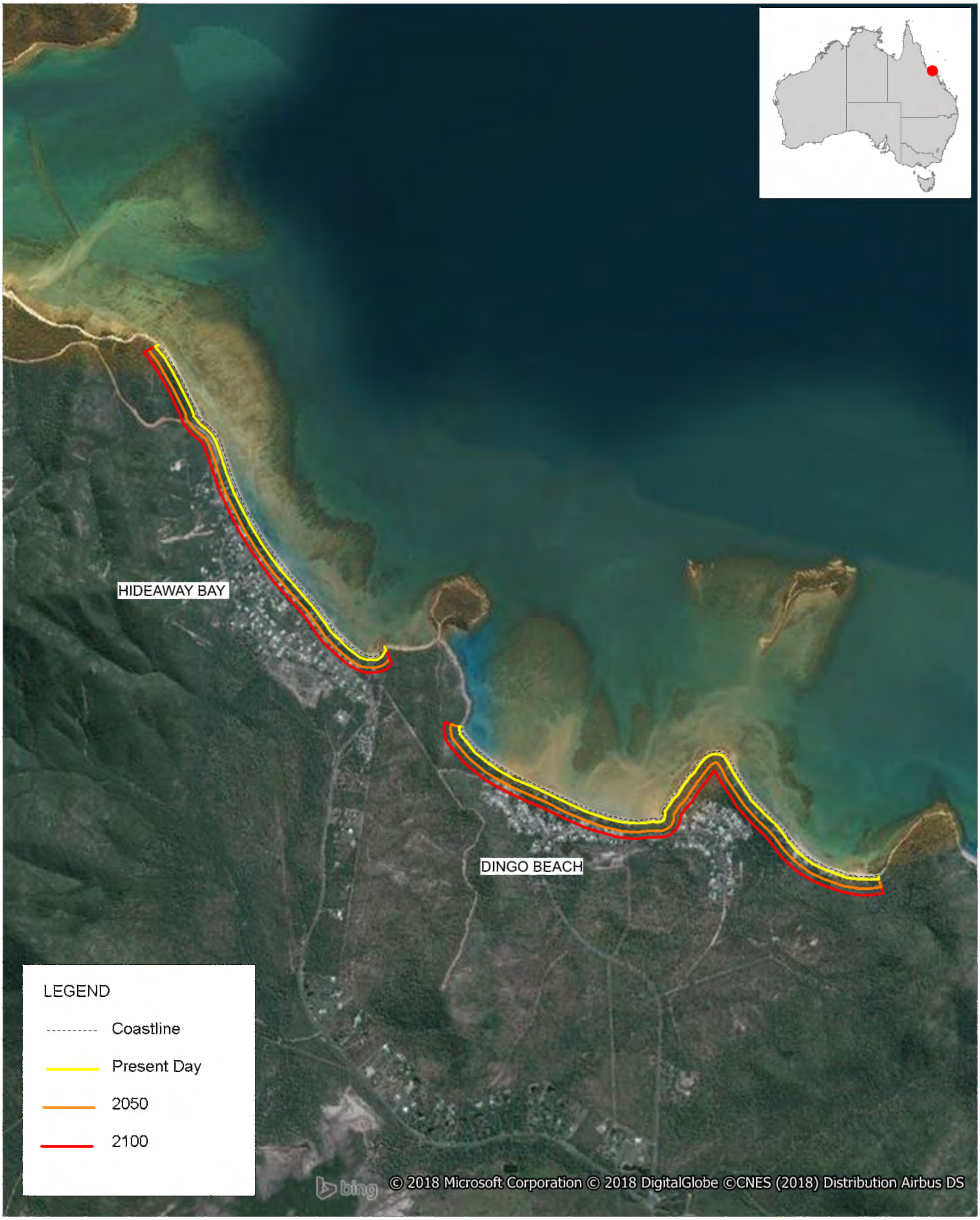
0 0.5 1km

Approx. Scale

BMT

www.bmt.org

Filepath: I:\B22454_i_iat_KIPT\DRG\COA_061_Erosion_Prone_Areas_Cannonvale_Airlie.wor



Title:
Erosion Prone Areas: Hideaway Bay and Dingo Beach

Figure: D-3

Rev: B

N

0 0.5 1km
Approx. Scale

BMT
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Filepath: I:\B22589_I_JLB Bowen Water Hazards Study MB\DRG\COA_058_Erosion_Prone_Area_Hideaway_Dingo.WOR

Title:

Erosion Prone Areas: Queens Beach

Figure: D-4

Rev: B

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N

0 0.5 1km

Approx. Scale

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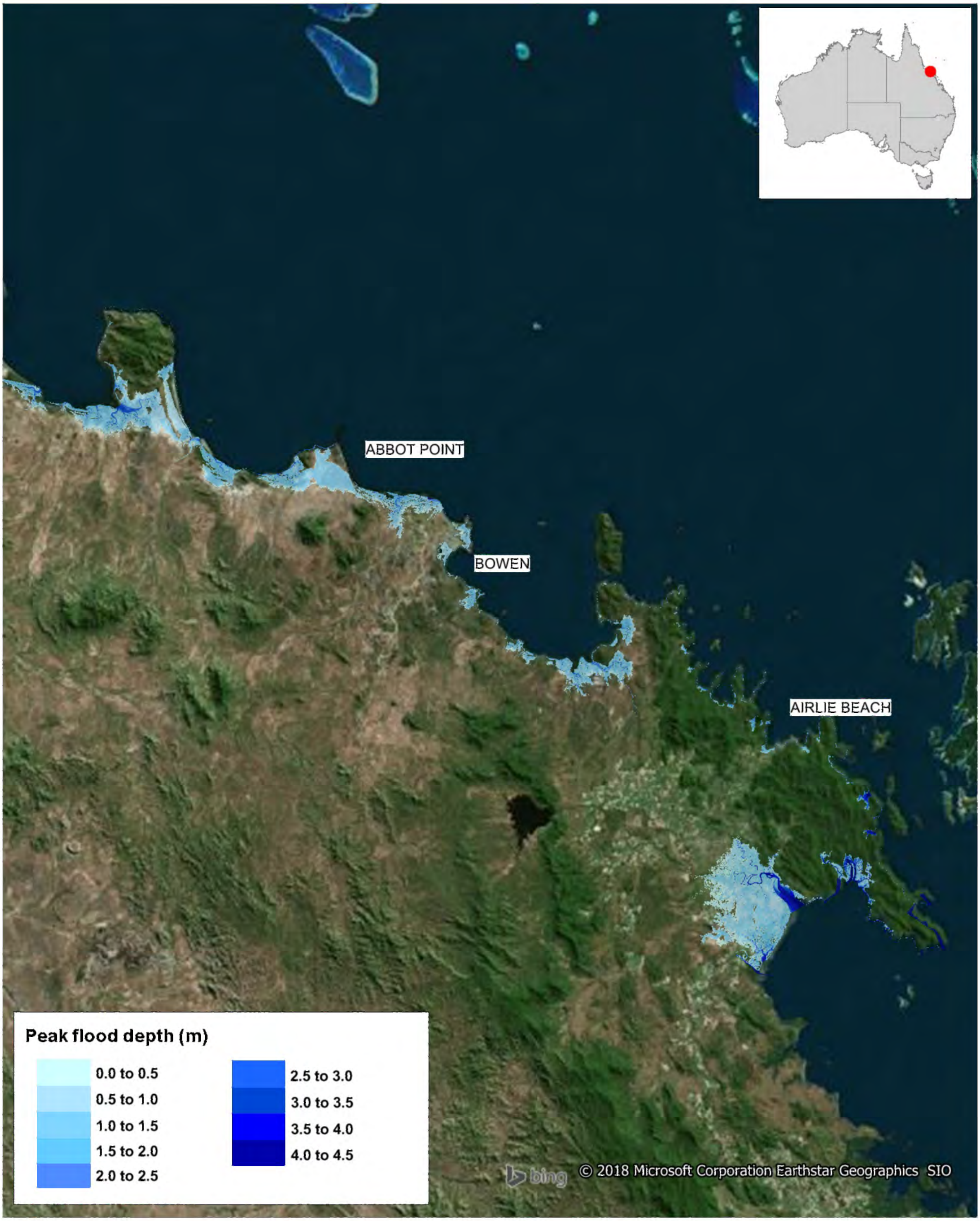
Filepath: I:\B22589_I_JLB Bowen Water Hazards Study MB\DRG\COA_059_Erosion_Prone_Areas_Queens.wor

Appendix E Permanent Inundation Due to Sea-level Rise Mapping



Title:

2050 Permanent Inundation due to Sea Level Rise

Figure: E-1

Rev: A

N

0 15 30km

Approx. Scale

BMT

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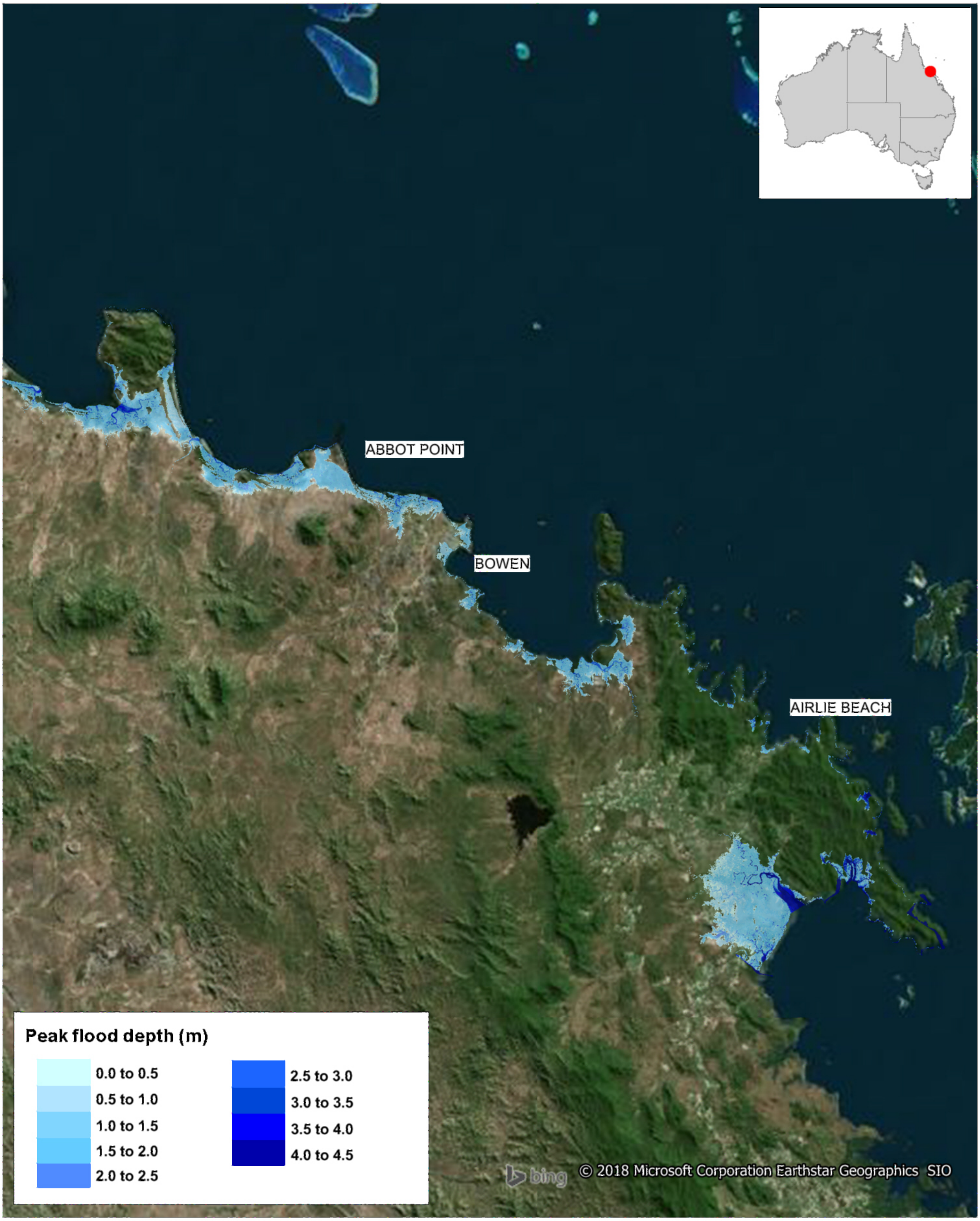
Filepath: I:\B22589_I_JLB Bowen Water Hazards Study MB\DRG\COA_068_WRC_LGA_2050_SLR.wor



Title:

2100 Permanent Inundation due to Sea Level Rise

Figure: E-2

Rev: A

N

0 15 30km

Approx. Scale

BMT

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Filepath: I:\B22589_I_JLB Bowen Water Hazards Study MB\DRG\COA_069_WRC_LGA_2100_SLR.wor

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