SUNDAY ISLAND BAY – DIRK HARTOG ISLAND

Coastal Setback Allowances

Damara WA Pty Ltd

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1. Introduction

The owners of Lot 304 Sunday Island Bay, Dirk Hartog Island are considering the development of 33 individual accommodation units (Figure 1; Figure 2). The proximity of the site to the coast requires consideration of appropriate evaluation of coastal hazards, including inundation and erosion. Damara WA has been commissioned to provide a simple site-specific assessment of these hazards for use in adaptation planning. The lot is located in an area where the State Coastal Planning Policy SPP 2.6 (WAPC 2013) is relevant for setting a coastal reserve and hazard mitigation.

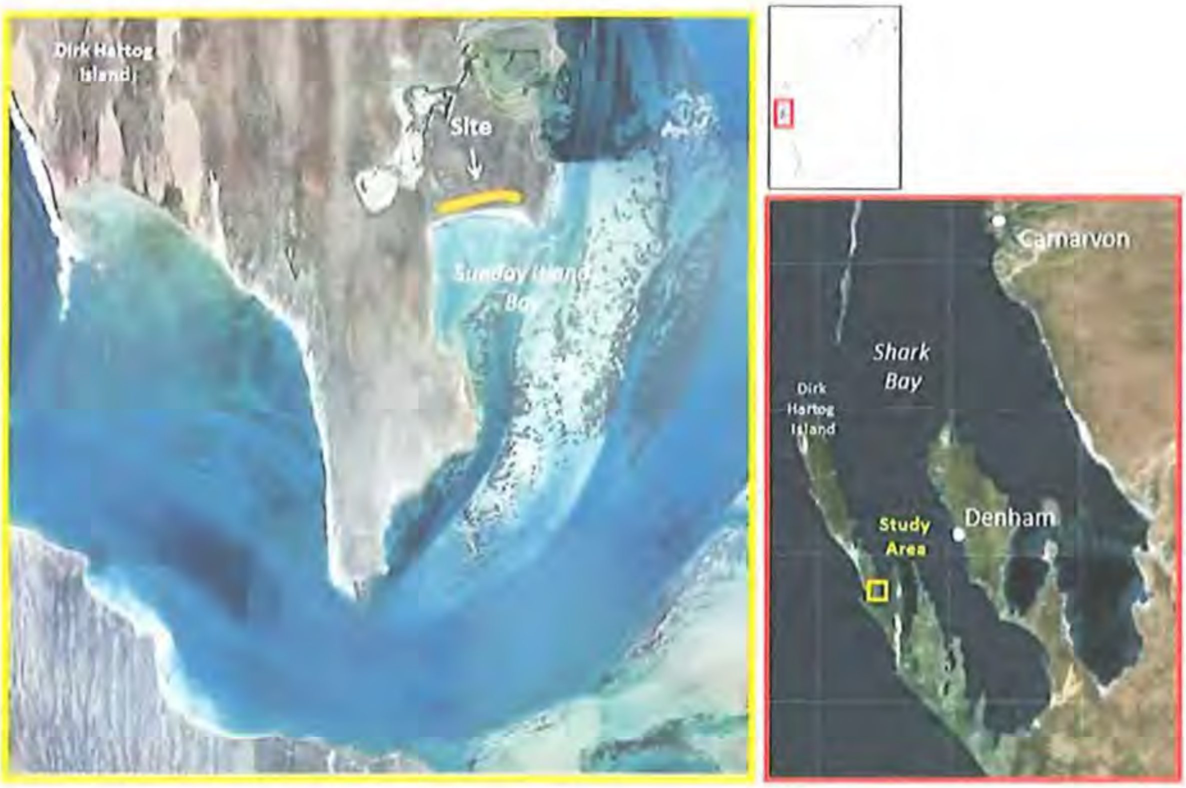

Figure 1: Sunday Island Bay Site (Image: Landgate 2007)

Distances between the coast and the site are relevant to the management of coastal erosion hazard and site elevations are relevant to management of inundation hazard. The site is 90-120m wide and is located between 55m and 210m from the +2m AHD contour, with elevations ranging between+3m AHD and +20m AHD (Figure 2). The proponent is considering 33 individual building envelopes on the site (red on Figure 2), with 22 alternate building envelopes (blue on Figure 2). The most seaward building envelope is 66m landward of the +2m AHD contour at envelope 3, with an alternate location identified 20m further landward. The majority of building envelopes are located landward of the +6m AHD contour, except for six envelopes (building sites 1-5, 8).

This report provides a site-specific assessment of coastal hazards that may be used to support strategies for coastal hazard risk mitigation, in accordance with SPP2.6. A simple assessment using default allowances for coastal setback (Section 3) is followed by a refined assessment (Section 5).

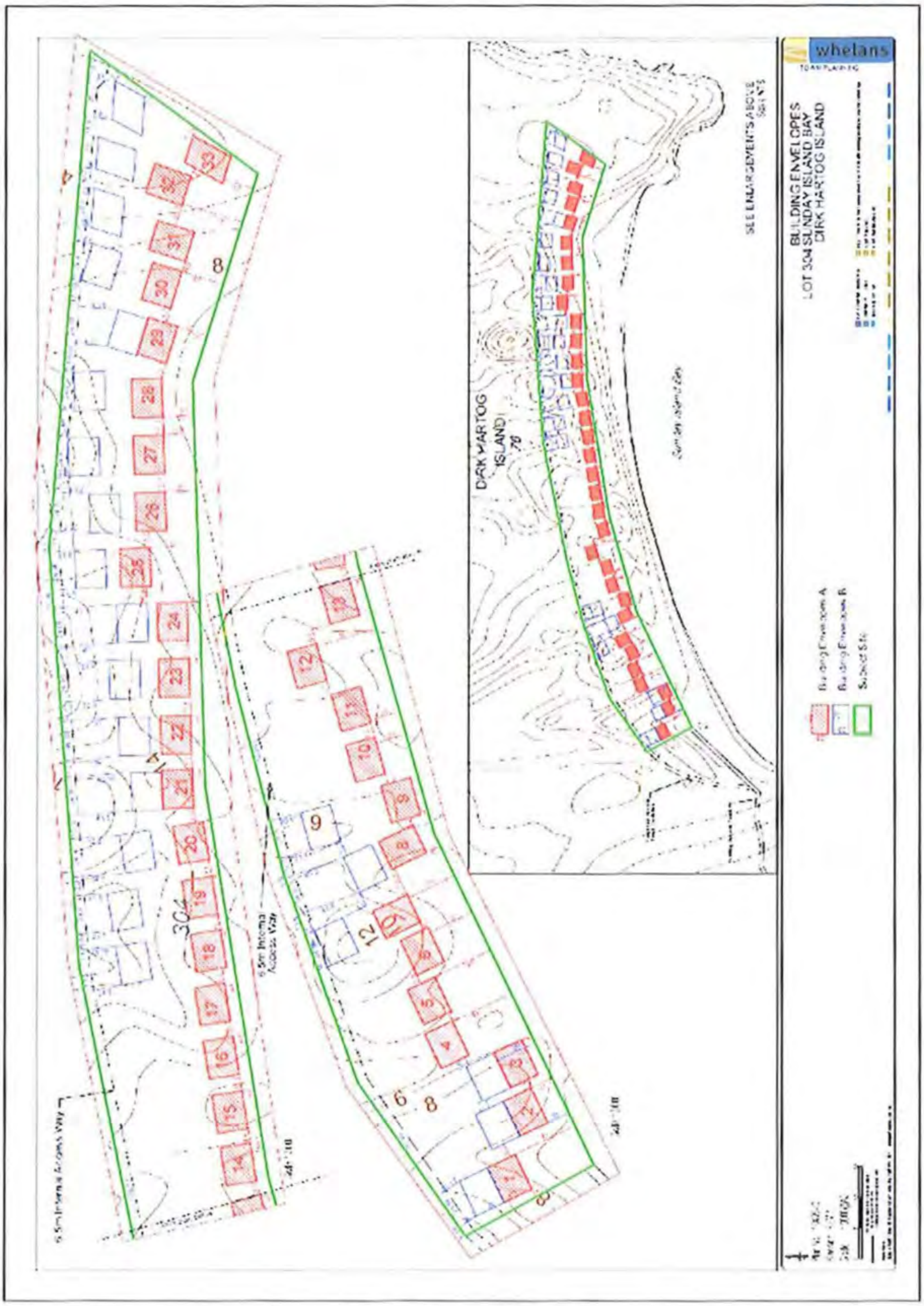

Figure 2: Initial Site Layout

2. Setback Policy

Coastal setbacks have been identified as one of the most effective forms of coastal hazard mitigation on slowly varying coastlines, as the setback provides a buffer against short-term coastal fluctuations. The approach acknowledges the natural tendency for erosion-recovery cycles and aims to avoid expensive coastal protection works.

Guidance for development along the Western Australian coast is provided by relevant 'infrastructure objectives' in the *Coastal Zone Management Policy* (WAPC 2001), including:

- Recognition of the dynamic nature of coastal environments and the consequences for coastal development and use.
- Avoidance or mitigation of the impacts of natural hazards through intelligent siting and design of infrastructure, based on ongoing scientific research.

The recommended approach towards achieving these objectives was outlined in the *State Coastal Planning Policy* SPP No. 2.6 (WAPC 2013), which identified setbacks as a primary technique for the mitigation of coastal hazards. The focus of the policy is coastal hazard assessment, management and adaptation planning. The SPP 2.6 provided guidelines for the assessment of development setbacks and gave a suggested method of assessment for multiple shore types. The shore type most relevant for Sunday Island Bay is discontinuous rocky coasts (Clause 4.6.3 of Schedule One).

SPP2.6 provides a simple technique in Schedule One for the evaluation of setback allowances for physical processes, includes:

- HSD Horizontal Shoreline Datum: active limit of shoreline under storm activity, which for 'Area 2' (WAPC 2013 Figure 1) is the peak steady water level (no runup) for the 100-year recurrence interval storm.
- S1 Acute Erosion Allowance: cross-shore erosion associated with impact of a severe storm sequence, with consideration of longshore erosion.
- S2 Chronic Erosion Allowance: horizontal erosion due to progressive loss of coastal sediment, within 100 years. Projected using aerial photography with 1972 the earliest available at Sunday Island Bay. Calculated as 100 times the historic annual rate of erosion.
- S3 Sea Level Allowance: coastal recession associated with climate change induced sea level rise (Figure 16 of DoT 2010). On a sandy coast this should be 100 times the adopted sea level rise value of 0.9m over a 100-year timeframe or 90 metres.
- Uncertainty: an additional 0.2m per year allowance for uncertainty on sandy coasts.
- S4 Storm Surge Inundation Allowance: peak stead water level plus wave runup for a tropical cyclone storm with a one-in-five hundred probability of being equalled or exceeded in any given year.

A general case for calculation of an allowance for coastal processes is described by SPP 2.6 Schedule One, which is applicable to sandy coasts. This method of calculation is formulaic rather than process-based or landform-based, and in most cases is dominated by S3, with the application of a Bruun ratio of 100:1 to sea level projections (Bruun 1962). The policy allows for consideration of adaptation planning for sites located within the erosion or inundation hazard areas. Adaptation planning requires an understanding of both likely and possible future scenarios, which may be separately assessed using realistic and conservative models for coastal change.

3. Default Assessment of Schedule One

A simple assessment of setbacks for coastal hazards is based on existing datasets, default or assumed values in Schedule One of SPP2.6 (WAPC 2013; Section 2), to determine the feasibility of development on the site. Default values for S1, S2, S3 and uncertainty have been applied (Table 1).

The HSD should represent the active limit of shoreline activity under a storm with a 100-year ARI water level, excluding runup. For adjacent areas of Denham (Wallace & Boreham 1990) and Monkey Mia (MP Rogers & Associates 2004) the 100 year ARI event peak steady water level has been estimated at +2.5m AHD. This value has been used for this simple assessment as it was the only available value for the area. It was estimated through comparison of short water level datasets collected simultaneously at Carnarvon and Denham in the 1980s, noting that data from Tropical Cyclone Herbie (1988) was not captured. This level is based on the assumption that water levels at Denham are 1.3 times larger than at Carnarvon. Refining the analysis of water levels during tropical cyclones may change the HSD value, based on estimates of central pressure, track curvature and speed, radius of maximum winds and coincidence with high tides (Damara WA 2009; Section 5.1).

Table 1: Components of SPP2.6 Schedule One and possible refinements

		Default (m)	Refinement
HSD	Horizontal shoreline datum, limit of shoreline in storm activity	+2.5m AHD (Wallace & Boreham 1990)	Estimate site-specific 100-year inundation peak steady water levels (no runup).
S1	Acute storm response	40	Relatively sheltered area for waves. Estimate local wave forcing and water level conditions, and simulate storm response in the numerical model SBEACH.
S2	Long-term response	20	Split into sections to account for rotation at the bay extents with minimal movement in the centre. The extent is considered in terms of the rock control and is likely to be tending to 0 as it fluctuates around a mean.
S3	Sea-level rise response for 100 years	90	Site does not require 100-year planning timeframe as units are designed for retreat or removal (2070 is 0.4m, or 40m).
Uncertainty	0.2m/year which is 20m over 100 years.	20	Determine if this is necessary on a site-specific assessment. Could be removed based on providing more certainty through landform analysis.
S4	500-yr ARI inundation event. Peak steady water level + runup.	+4m AHD	Estimate site-specific 500-year inundation levels (PSWL + runup). No properties are at an elevation <+4m AHD.
Set-back	HSD + S1 + S2 + S3 + uncertainty	170m from +2.5m AHD	

The allowance for inundation considers a 500-year recurrence interval tropical cyclone water level, including runup and projected sea level rise. A simple estimate of +4m AHD is used to incorporate an additional 0.3m water level compared to the 100-year water level, 0.5m for extra sea level rise and a 0.7m wave runup. This value provides a simple initial estimate to determine extent of site susceptible to inundation hazard.

Using these assumptions and default values, the erosion allowance for a 100-year planning timeframe is 170m horizontal setback from the +2.5m AHD with the inundation allowance defined by the +4m AHD contour (Figure 3). None of the proposed sites would be susceptible to inundation hazard if this assumed S4 value was correct. The majority of the lot is located within the coastal erosion hazard zone using default values for a 100-year time period. Therefore, the site should be managed through a Coastal Hazard Risk and Adaptation Management Plan (CHRMAP), with refined evaluation of coastal change appropriate to assess coastal hazard and risk management measures. Methods for refinement of coastal hazard components are summarised in Table 1.

Figure 3: Simple Measure of Distances on Site Layout

4. Site Context

Sunday Island Bay is a south-facing bay on the south-east of Dirk Hartog Island in western Shark Bay (Figure 1; Figure 4). The geomorphology and bathymetry of western Shark Bay and Dirk Hartog Island play a significant role in the coastal dynamics of the area and are important for the definition of coastal setbacks and management of coastal risk. At all scales in western Shark Bay there are controls and feedback between the mobile sedimentary features, older (inherited) landforms and the rock structures. Considerations of erosion hazard require consideration of the coast as a mixture of rock and sand, with control by inherited features.

Limited geologic and geomorphologic information is included for outside the Sunday Island Bay area. Previous reading by the authors has identified information relevant to the wider Shark Bay is available from Logan & Cebulski (1970), Read (1974), Butcher *et al.* (1984), Payne *et al.* (1987), Playford (1990), Richardson *et al.* (2005), Eliot *et al.* (2012) and Gozzard (2012). Dirk Hartog Island is a mixed rock and sand island with a SSE-NNW alignment, forming the western boundary of Shark Bay (Figure 4). Southern Dirk Hartog Island is largely quaternary Tamala limestone with landforms according to the Edel Land System description (Box 1; Figure 5). The material varies from unconsolidated sediments to strongly lithified locally quartzose calcerinite. Longitudinal dunes and dune-like sandy crests are present over limestone ridges, with some supratidal sediment deposits.

Box 1: Edel Land System description (Ed)
(Source: Payne *et al.* 1987)

Undulating sandy plains with occasional dunes, limestone ridges and saline flats supporting low acacia shrublands with some saltbush and heath communities.

Geology: Quaternary Tamala Limestone with minor areas of mixed supra-tidal deposits and calcareous sand.

Geomorphology: Undulating plains of eolian calcareous sands with minor longitudinal dunes, small areas of outcropping limestone and saline plains; no drainage features.

Landforms: Longitudinal dunes and dune-like sandy crests over limestone ridges; relief up to 15 m; soils are light reddish brown calcareous sands.

Restricted limestone plains and stony rises densely mantled with pebbles, cobbles and boulders; soils are red, reddish brown or yellowish brown shallow sand, loamy sand or clayey sands.

Swales and undulating plains sparsely to moderately mantled with limestone gravels; soils are yellowish red or reddish brown sands or loamy sands, calcareous throughout.

Low-lying saline plains, lightly to moderately mantled with limestone pebbles or cobbles; soils are very shallow grey loamy sands with calcareous inclusions.

A bathymetric context for the site is required for predicting wave and water level response during tropical cyclones, interpretation of coastal landforms and estimation of response to oceanographic forcing. From north to south through Shark Bay the bathymetry shallows through Naturaliste Passage to 50m depths in Denham Sound to the 2m depth shallow flats within Blind Strait, with connection seaward through South Passage between Dirk Hartog Island and Steep Point (Figure 4; Figure 6). Denham Sound is connected to Blind Strait and also to Freycinet Reach, which is separated from Blind Strait by Bar Flats Sill. The nearest water level recording station is at Useless Loop, with water levels differing to Sunday Island Bay due to the influence of Bar Flats Sill, the dynamics of Blind Strait and different bay aspect, affecting surge response to winds. Storm surges at Sunday Island Bay are lower than adjacent areas due to aspect, dispersal of surge in Blind Strait and proximity to Freycinet Reach. The site is further sheltered from erosion during tropical cyclones as it is unlikely that high waves would occur with peak storm surge, given the required wind directions.

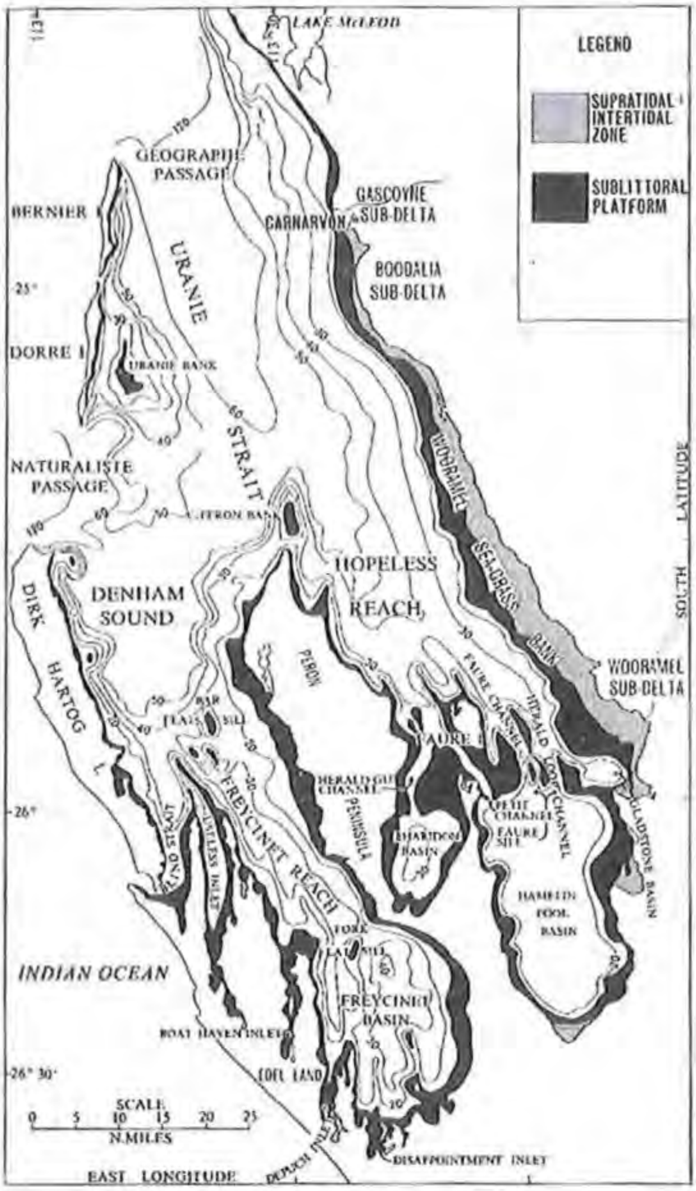

Figure 4: Bathymetry (Logan & Cebulski 1970)

The broader behaviour of the Sunday Island Bay coast has been considered in a wider sediment cell context incorporating the controls of the banks either side of the channel (Figure 7; white dots). At this scale, the longer-term sediment dynamics within Blind Strait and the adjacent banks have been considered. However, for this setback assessment and adaptation planning the discussion is focused on a finer scale sediment cell between the two headlands (Figure 7; yellow dots). The coast is topographically controlled on a broad scale by the peninsulas, islands, broader bathymetric structure and the sand flats within Blind Strait; and on a local scale by rock features either side of the bay, foredunes, relict longitudinal dunes, local bathymetry including terraces and platforms, and subtidal rock outcrops (Figure 7; Figure 8).

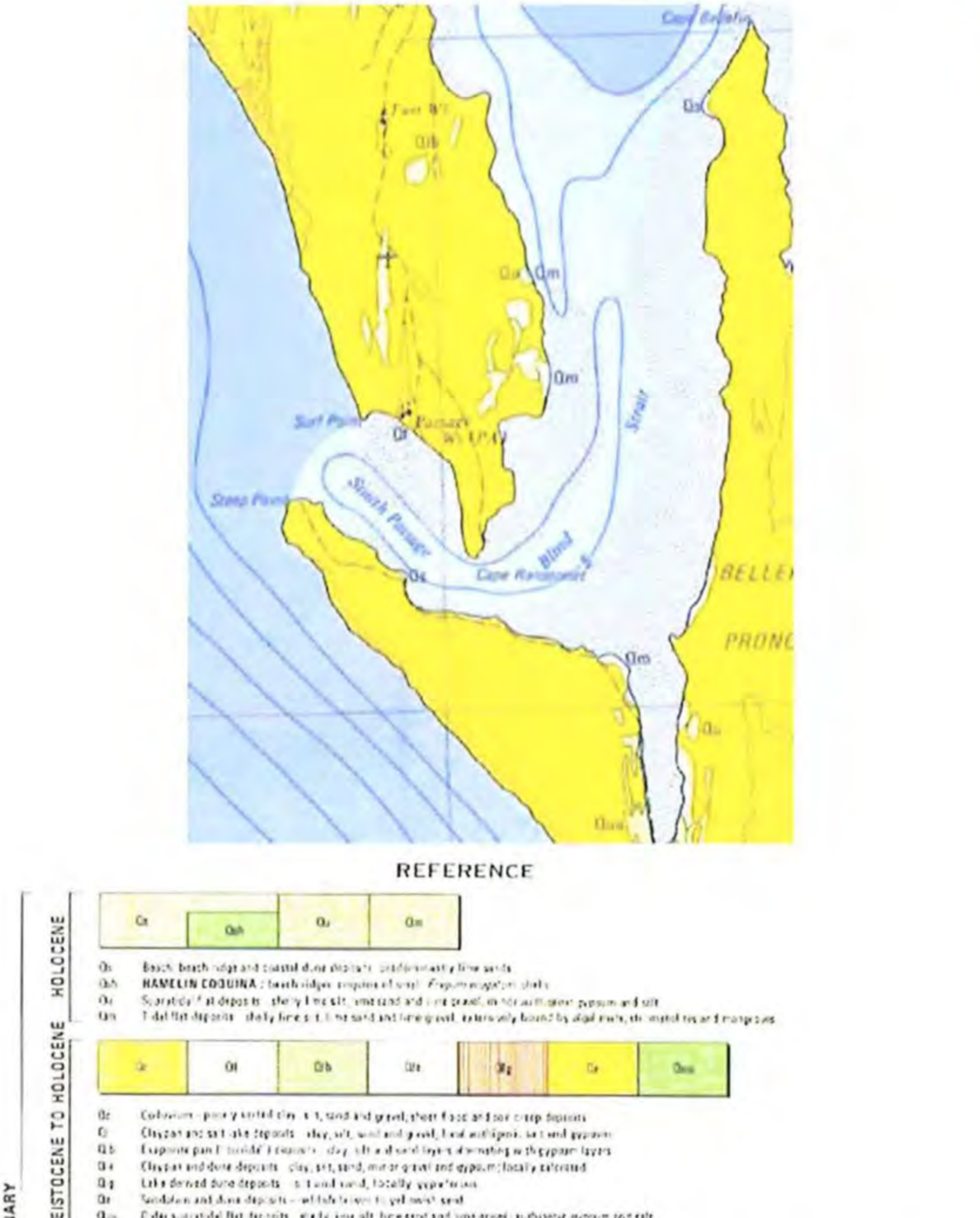

Figure 5: Site Geology (Butcher *et al.* 1984)

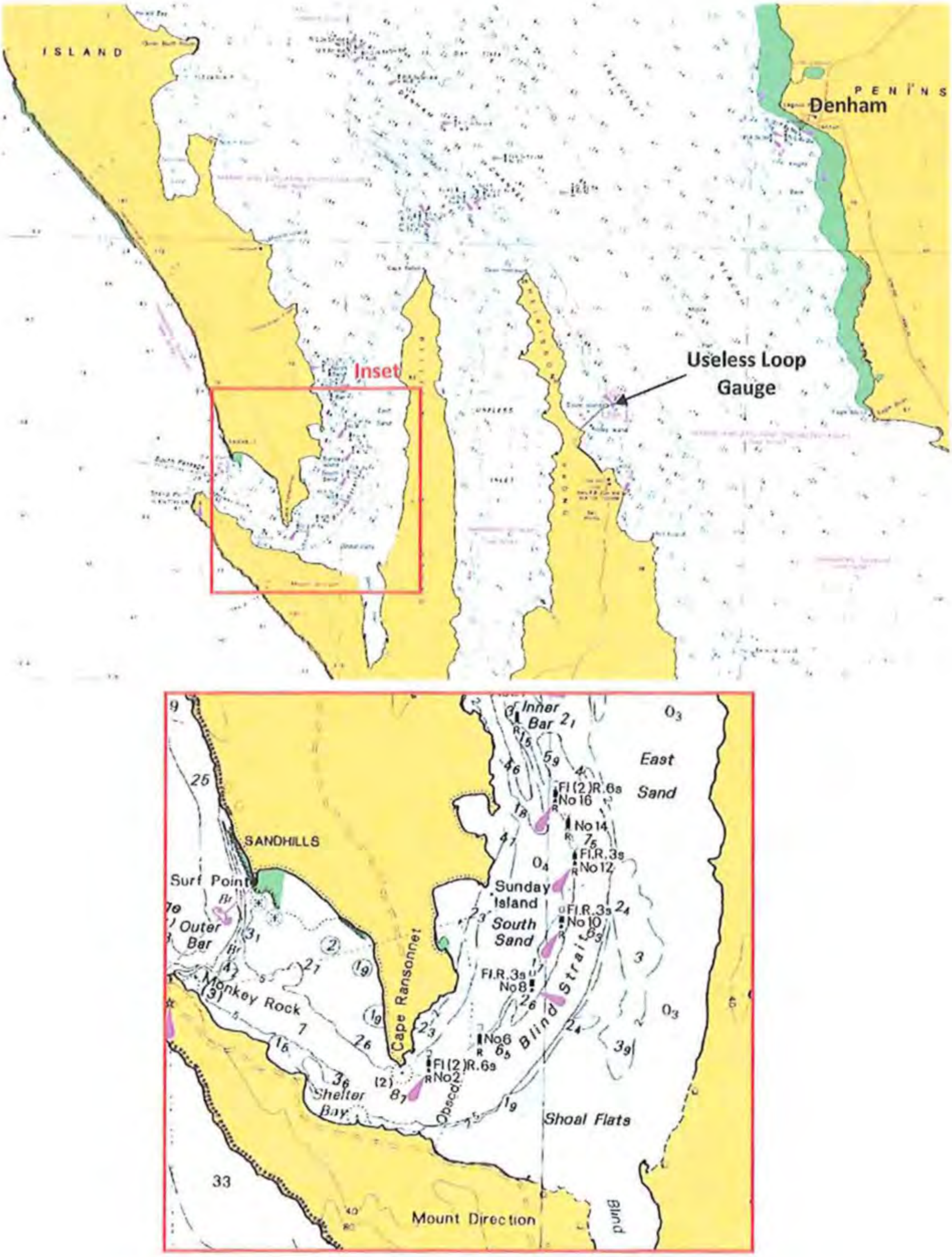

Figure 6: Broad-Scale Bathymetry
(RAN Hydrographic Office Chart 749 Shark Bay South Western Sheet 1993)

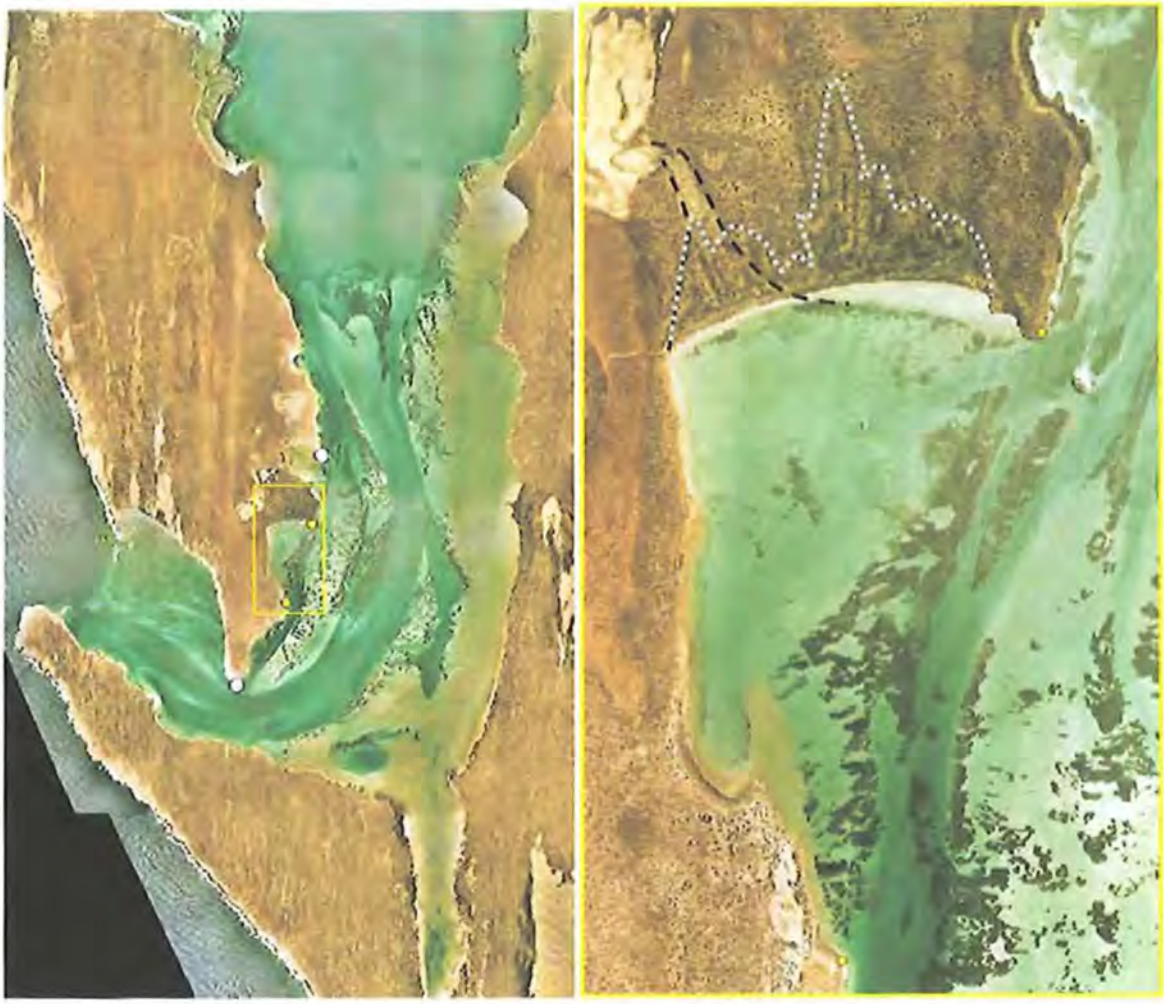

Figure 7: Focal Sediment Cells for Investigation (Source: Landgate 2002)
Broader cell between white dots for longer time-scales and focal cell for investigation in yellow dots. The right image shows relict channel (black line) connected to terrace and with flood tide shoal in the lagoon. Longitudinal dunes (grey dotted line) subsequently activated and shifted sediment landward.

Interpretation of landforms suggests a traditional approach to predicting coastal response to sea level rise may not apply at this site. There is a disconnection from the onshore landforms to the dynamics of the channel and adjacent banks in Blind Strait. Coastal response to sea level rise may incorporate sediment movement onto the banks adjacent to the channel, changing levels on the terrace, beach rotation and potential accretion in longitudinal dunes. . In a previous time period sediment was moved onshore demonstrated by infill of the relict channel connected to the terrace, with a flood tide delta within the inlet (Figure 7); with subsequent movement of material onshore via the longitudinal dunes. It is anticipated these changes would have occurred during the previous sea level highstand (around 2,000 years ago). The existing longitudinal dunes presently restrict the capacity for coastal retreat at the site, with historic movement only occurring in the foredune plain to seaward (Figure 8; Figure 9).

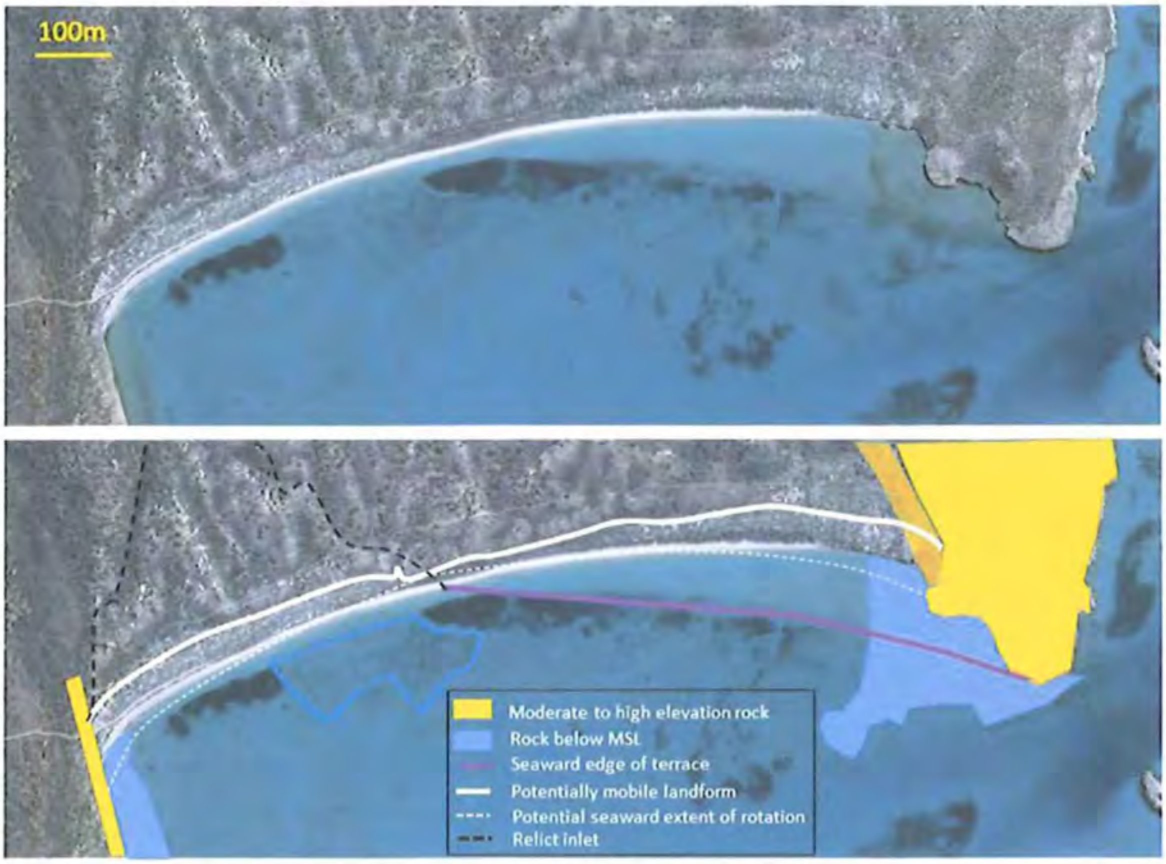

Figure 8: Rock and Terrace Controls (Image: Google Earth 2013)
Potentially mobile foredunes are located seaward of the older longitudinal dunes (see Figure 7).

Figure 9: Site Photo of Eastern Headland
Lower foredunes are located seaward of older dune features, constrained by rock ridges

Contemporary coastal response, excluding projected sea level rise, is likely to be restricted to erosion and rotation within the existing foredune plain, as demonstrated by the white lines in Figure 8. This is hypothesised due to the reworked nature of the foredune plains seaward of the longitudinal dunes; and the controls provided by the rock headlands, rock below mean sea level and the terrace. If a sequence of erosive storm events were to occur, causing wholescale cross-shore retreat, it may result in minor reworking of the longitudinal dunes to landward. Post-event recovery would see the foredune plain reform (in a different configuration) due to sediment storage on the terrace and local sediment production.

Landforms also support the assumption that inundation hazard is less significant in Sunday Island Bay than north facing coasts within Denham Sound and Freycinet Reach. This is because there are no distinct landforms formed by overwash within the bay.

5. Revised Schedule One for Adaptive Hazard Assessment

The components of Schedule One of SPP2.6 have been revised from default setback allowances, to provide a more locally-relevant assessment of coastal change that may support adaptive decision-making. Several key assumptions were required to compensate for data limitations.

5.1. STORM EVENT (HSD, S1 AND S4)

Locally relevant assessments of the HSD, acute storm allowance (S1) and inundation allowance (S4) require consideration of a tropical cyclone event and the associated extreme waves and water levels. The evaluation of extreme water levels for Sunday Island Bay has used information developed for *Selection of Design Cyclones for Coastal Development Approval Assessments* (Damara WA 2009) regarding tropical cyclone intensity, scale and coincidence with tidal conditions. This analysis suggests characteristics for 'direct hit' design storms, coincident with a tidal level of Mean Higher High Water, which is 1.0m CD[1] (RAN Hydrographic Office Chart 749).

Table 2: Characteristics of 'Direct Hit' Design Storms

Design Storm Recurrence	>100 yr ARI	>500 yr ARI
Central Pressure	955 hPa	933 hPa
Radius of Maximum Winds	38 km	70 km
Peak Wind Speed	157 km/h	185 km/h
Maximum Pressure Surge	0.6m	0.8m
'Critical Speed' Pressure Surge	1.2m	1.6m
Pressure Surge @ Rmax	0.15m	0.3m
'Open Coast' Max Surge	2.9m	4.2m

The high 'open coast' maximum surges are significantly reduced by characteristics of the Sunday Island Bay site, particularly its aspect on the southeast side of Dirk Hartog Island, the influence of Blind Strait to disperse surge and the site's position relative to Freycinet Reach (Figure 4; Figure 6). The influence of these factors has been evaluated relative to three different surge scenarios, including a northerly storm directed down Freycinet Reach, or westerly storms which either peak on the east side of Denham Sound, or the western side of Dirk Hartog Island (Table 3).

Local factors affecting the surge suggest that there is relatively little between the three scenarios. However, they also indicate that the damped surge response is comparable to both the 'critical speed' pressure surge, based on Proudman Resonance and the historically observed shelf waves generated by TC Glynis and TC Hazel (Fandry *et al.* 1984). For the purpose of adaptive hazard assessment, the recommended surge levels are +1.5m for 100-year ARI (westerly event) and +2.6m for 500-year ARI (northerly event) (Table 3).

Recommended peak water levels are to add the design surge to MHWS (+1m CD), plus a 0.4m allowance for sea level rise for the short-term and 0.9m allowance for the longer-term (Table 4). Site capacity should facilitate adaption to a sea level rise of 0.9m.

[1] The conversion between Chart Datum (CD) and Australian Height Datum (AHD) is provided by DoT. Useless Loop CD is equal to Lowest Astronomical Tide (LAT) which corresponds to -0.755m AHD. Carnarvon CD is equal to LAT which corresponds to -0.956m AHD.

Table 3: Evaluation of Local Storm Surge Scenarios

Scenario	Northerly Event	Westerly Event – A	Westerly Event – B
Peak Surge Location	Freycinet Reach	Denham	Dirk Hartog Island
Coast Shape Factor	2.0	1.0	1.0
Required Fetch	140 km	70 km	Rmax
500yr Peak Surge	5.5m	3.8m	4.2m
100yr Peak Surge	2.8m	2.4m	2.9m
SIB Position	60 km	33km	60% of Blind Strait
SIB Factor (wind setup)	0.43	0.47	0.40
500yr SIB Surge	2.6m	2.1m	2.2m
100yr SIB Surge	1.3m	1.3m	1.5m

Table 4: Water Levels associated with a Tropical Cyclone Event

		100-yr ARI		500-yr ARI	
		m CD	m AHD	m CD	m AHD
Required Capacity	Short-term	2.9	2.1	4.0	3.2
	Long-term	3.4	2.6	4.5	3.7

5.1.1. Horizontal Shoreline Datum (HSD)

Using this information, the HSD is +2.1m AHD representative of the 100-yr ARI water level with a 0.4m vertical sea level rise component and no wave runup. This is represented by the +2m AHD contour on the available topographic contours, with the horizontal discrepancy of the 0.1m vertical difference likely to be in the same order as the accuracy of the contours themselves.

This value is 0.5m lower elevation than the estimate included in Section 3.

5.1.2. Inundation Allowance (S4 + SLR)

The allowance for inundation is the sum of the present risk of storm surge inundation (S4) and the predicted extent of sea level rise. The potential for dune breaching was not considered at this site because the dunes do not demonstrate a decrease in elevation to landward, and therefore exceed $100m^3$ cross-section area. The long-term 500-yr ARI value of +3.7m AHD in Table 4 represents the peak steady water level plus predicted extent of sea level rise (0.9m), but excludes wave run-up.

Wave run-up is estimated using analytical formulae (Mase 1989) and standard values due to the limited datasets available. Wave run-up formulae on beaches require input information on beach slope, wave height and wave period. Wave conditions have been estimated using a local wind hindcast across the effective fetch (Figure 10), giving conservative significant wave heights (H_s) of 2.1m and wave periods (T_p) of 3.2s. These values are conservative as they were generated using a 100-year ARI wind of 72.6 ms^{-1} extracted from AS1170.2 for region D (p.13, Section 3, Regional Winds) including a 1.1 factor of safety multiplier (Standards Australia 2002). For comparison, the highest wind speed recorded at Denham station was 20.1 ms^{-1} for the period 1988 to 2010 (Bureau of Meteorology datasets), suggesting the design wind used significantly exceeds the highest measured wind speed.

Design wave conditions for the site were assessed using a fetch-limited wave hindcast (USACE 1984), using the design wind from AS1170.2. Effective fetches along the critical directions for extreme wind-wave generation was determined based on the directional distribution of extreme winds and according to methods described in FWERI (2005) which takes into account the shape of the terraces and flats along the fetch within Blind Strait (Figure 10). As wind-wave generation is also dependent on water depth, depths along the effective fetch have been characterised using available bathymetric information (RAN Chart 749), with an allowance for elevated water levels during the design conditions. For the purpose of wave hindcasting, it has been assumed that elevated water levels and extreme waves occur at the same time, which is unlikely to occur at Sunday Island Bay.

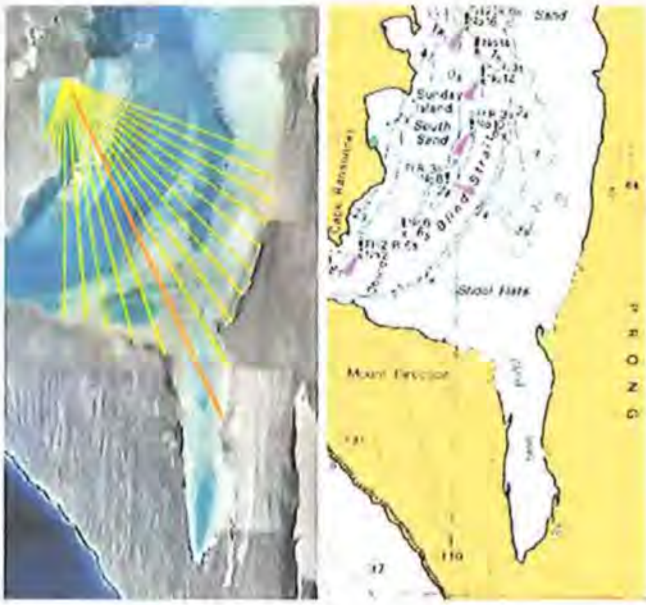

Figure 10: Determining the Effective Fetch for Sunday Island Bay

The calculated wave height and wave period were converted to a wave run-up (R) on a beach using the formulae by Mase (1989) as included in the *Coastal Engineering Manual* (USACE 2006; Part II-4). Run-up is the maximum elevation of wave uprush above still-water level. This is calculated using the three formulae below with offshore wave conditions represented by the subscript 0, and it is assumed the beach slope (tan β) is 1:20. The run-up calculated is the run-up exceeded by 2 percent of the run-up crests ($R_{2\%}$). For this site the run-up is estimated as 0.95m, which is included in calculations of S4 as 1m.

$$\frac{R_{2\%}}{H_o} = 1.86\, \xi_o^{0.71}$$

$$\xi_o = \tan\beta\, (H_o/L_o)^{-1/2}$$

$$L_o = g\, T^2/(2\pi)$$

The S4 allowance for inundation hazard is +4.7 mAHD, calculated as a sum of the 500-yr ARI peak steady water level (+2.8m AHD), sea level rise component (0.9m) and wave run-up (1.0m). This value is 0.7m higher elevation than the estimate included in Section 3.

5.1.3. Acute Erosion (S1)

Setback allowance for storm erosion is based on calculating maximum cross-shore storm erosion with consideration of the maximum longshore storm erosion. A high allowance for cross-shore storm erosion is not anticipated due to the relative sheltering from high surges and a restricted fetch length for wind-wave generation (Section 4). Sheltering from large surge events is further confirmed by an absence of overwash features, as compared to north facing bays on eastern Dirk Hartog Island.

Cross-shore erosion has been determined using the SBEACH numerical sediment transport model (Larson & Kraus 1989). The S1 allowance is the maximum distance landward of the HSD, at which the SBEACH model predicted erosion to occur. A beach profile (Figure 11) was extrapolated from the topographic contours and bathymetry (RAN Chart 749), which was artificially extrapolated beyond the terrace to allow the SBEACH model to converge. The model was run for a synthetic storm condition that was a combination of the 500-year water level and 100-year wind and wave conditions. A storm of constant wave height, wave period and water level (+2.1m, 3.2s, +3.2m AHD) was run for 6 hours to model extreme storm erosion for an event that could not occur in reality. The 6 hours is several times longer than a typical storm peak to satisfy the requirement to model three successive storms. The S1 allowance for setback is a highly conservative measure using this storm. The maximum cross-shore retreat would be more accurately represented by 7-15m for the most significant storm event, with 15m selected for use in adaptation planning (Figure 12).

Figure 11: Selected profile for use in SBEACH Modelling

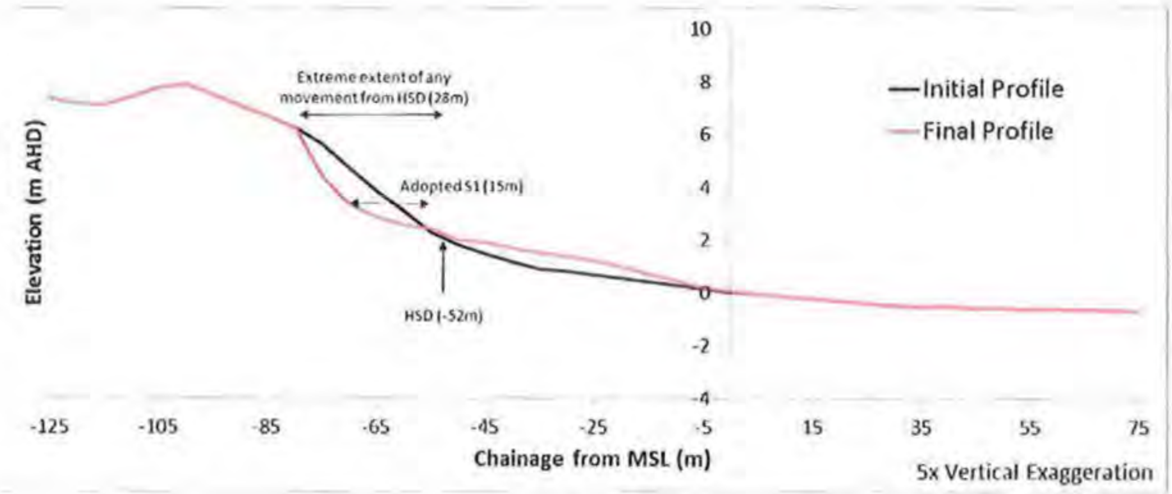

Figure 12: SBEACH Output for Artificial Extreme Event

This synthetic event could never occur due to the impossibility of the coincidence of high waves and high surge at the site from a tropical cyclone.

The longshore response to a storm would cause apparent beach rotation within the bay. The magnitude of this longshore response is not included in the S1 allowance as it is incorporated within the S2 allowance below through consideration of potential landform response.

5.2. CHRONIC EROSION (S2)

The allowance for historic shoreline movement trends is recommended to be based on the review of available shoreline records, preferably at five-yearly intervals. The earliest aerial photograph available from Landgate was 1972, with no detailed historic bathymetry available for comparison.

The traditional approach for determining the S2 setback allowance is based on analysis of vegetation line movements over the time period of available aerial photography. Vegetation lines are a proxy for coastal profile change and therefore should be interpreted with care (Camfield & Morang 1996; Boak & Turner 2005). In many approaches it depends on the length of the photographic record, condition of the first vegetation line from the most recent extreme storm and on the time of year of the aerial photography. The time of the year of aerial photography within a semi-enclosed bay may not capture the seasonal fluctuations in beach position. It was considered that vegetation line mapping for this site may be unnecessary given the small changes observed, with most changes observed in beach width which is dependent on the water level at the time of the photography.

Long-term shoreline change was interpreted from four aerial photographs including the most recent (2013) and earliest (1972-georectified), as well as two other years where orthophotographs were available (2002, 2007) with further visual checks of GoogleEarth historic imagery (Figure 13). This analysis suggested a relatively stable coast, with variation in vegetation line and beach width at the eastern extent of the site, to a total of 6m across the time-period. The total beach width has reduced by approximately 3-4m, with losses of 12m beach width at the eastern extent of the bay.

Some of the recent rotation observed in the bay may be attributed to a local surge of ~30cm associated with a strong La Niña from 2009-2013 (Figure 14). The inter-annual relationship between mean sea level and climate fluctuations is suggested by a strong correlation between annual average water level and SOI - the Southern Oscillation Index (Pattiaratchi & Buchan 1991; Figure 14). The SOI is determined by the barometric pressure difference between Darwin and Hawaii, and has been demonstrated as a reasonable indicator of El Niño or La Niña climatic conditions. The sea level relationship to SOI indicated by Figure 14 occurs along the entire Western Australian coast (Pariwono *et al.* 1986; Pattiaratchi & Buchan 1991; Feng *et al.* 2004). High mean sea levels in Shark Bay also occur due to thermal expansion of warmer water which accumulates within the bay. The response in Shark Bay to higher sea surface temperatures is larger than in south-west WA. Beach recovery is anticipated as the SOI returns to El Niño conditions and lower sea surface temperatures. Sediment on the terrace can be migrated onshore during lower mean sea level conditions.

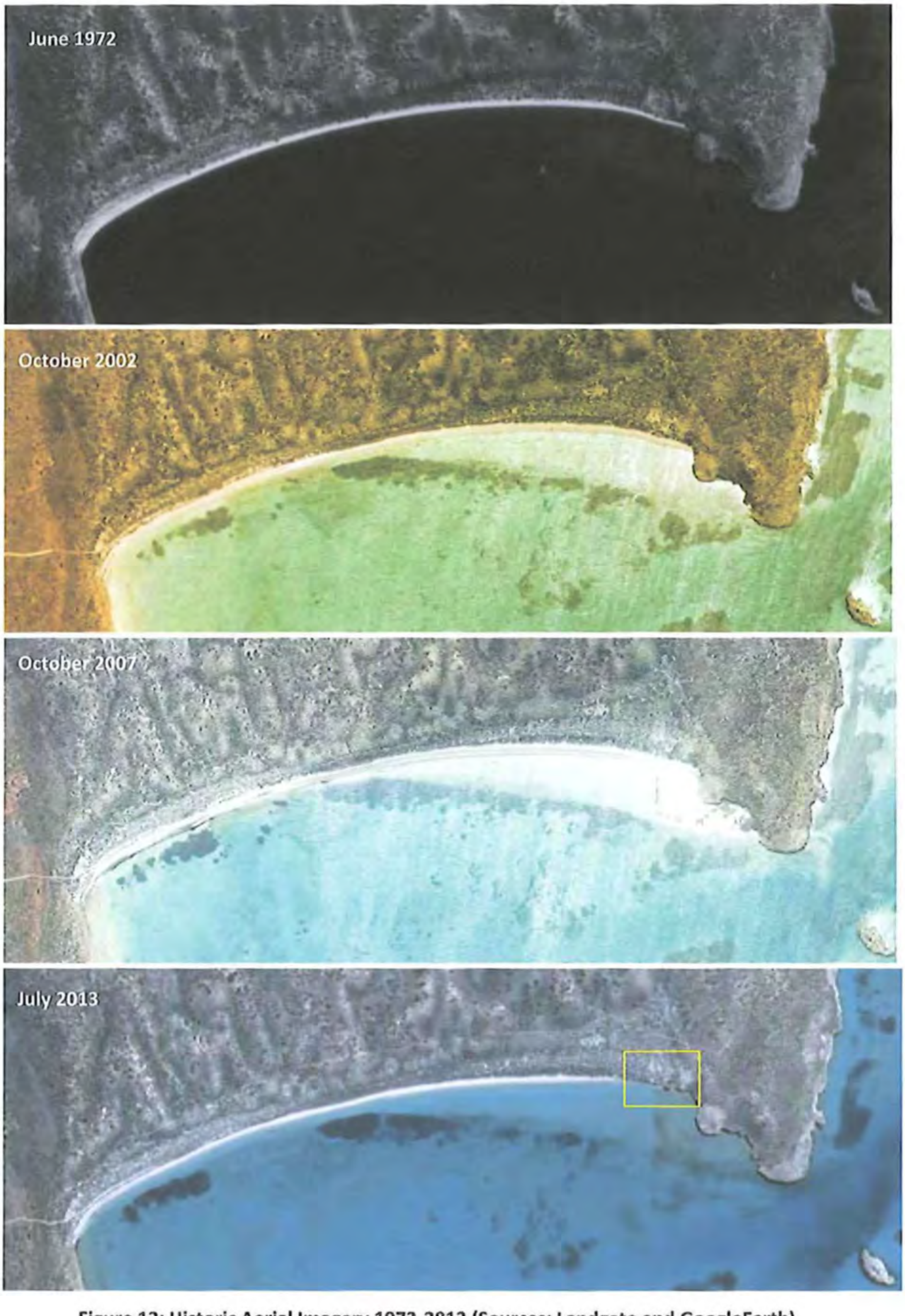

Figure 13: Historic Aerial Imagery 1972-2013 (Sources: Landgate and GoogleEarth)

The S2 allowance is recommended as 100 times the historic annual rate of erosion. The only section of the bay with any historic rate of erosion is the eastern section of the bay shown in a yellow box in Figure 13. The total erosion in this area of the vegetation line is <6m in 41 years. Using the traditional assumption the allowance for S2 should be 0m for the majority of the bay with 14.6m in the eastern extent (100 x 6m/41 years). It is likely a significant proportion of this change is attributed to changing climate conditions associated with higher water levels and altered wind patterns due to the la Niña and warmer sea surface temperatures in Shark Bay.

The landward limit of rotation is constrained by rock controls, the terrace and higher dunes to landward (Figure 8).

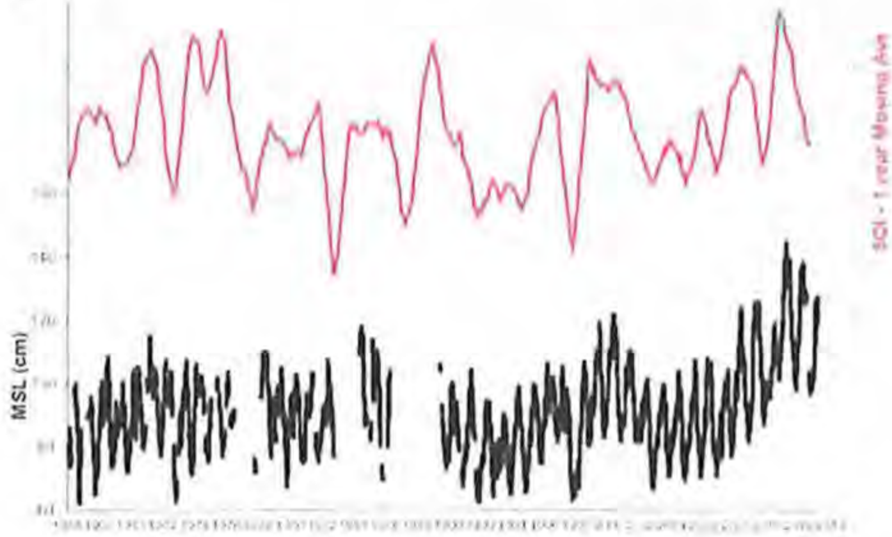

Figure 14: Mean Sea Level for Carnarvon and Southern Oscillation Index (SOI)

5.3. RESPONSE TO SEA LEVEL RISE (S3)

Setback allowance for erosion caused by future sea level rise on a sandy coast is recommended as 100 times the adopted sea level rise value 0.9m over a 100-year timeframe or 90 metres. The 0.9m sea level rise is recognised as toward the upper limit of IPCC projections (Department of Transport 2010). SPP2.6 recommends further increasing the allowance where obstacles may reduce updrift longshore sediment transport. This increase is not required for Sunday Island Bay as the interaction of the beach with the terrace and sediment exchange across the South Sand area would provide sufficient sediment supply.

The Bruun ratio is the basis for the 100:1 response to projected sea level rise (Bruun 1962, 1988). This is based on an unconstrained sandy beach in cross-shore equilibrium exposed to regular wave action, with direct connection between offshore and onshore to allow a consistent coastal response. Landward and upward movement of an exponential-shaped profile is assumed to balance erosion of the beach and dune with infilling of the deeper section, down to the limit of wave action, termed the depth of closure. All eroded sediment is assumed to be transported offshore. This results in a simple formula, which has the form $\Delta X = S * W_* / (h_c + B)$, where ΔX is the horizontal recession, h_C is the depth of closure (<4.5m at this site), B is the berm height, W_* is the width from most landward extent of change to the closure depth and S is the sea level rise. The sum of the depth of closure and the berm height is termed the active height. Typically W_* divided by active height is in the order of

50-100, which results in common application of the further simplified formula $\Delta X = 100\ S$. The model relies upon a balance of seaward sediment transport during storm events against landward transport under ambient conditions. An equivalent Bruun model at the site is 65:1 based on depth of closure of -4.5m[2], berm height attributed as +2m AHD (HSD) and width of active zone from the HSD to the first channel of 480m.

The Bruun conceptual model has reduced validity in Shark Bay, where the presence of lithified former shorelines provides considerable control on coastal response to changing environmental conditions. At Sunday Island Bay the coast is perched upon a rock platform, constrained between two rock shorelines, adjacent to a broad terrace and is disconnected to traditional offshore features. The sandbanks and the low energy beach terraces are characteristic of non-equilibrium conditions, although the previously presence of seagrass beds suggests change is gradual. The underlying rock, and higher elevation rock at the bay extents, limits the extent of retreat that can occur with losses distributed across the bay and the terrace. Coasts with segmented structures, with a flat seabed in front of a steeper beach face, typically respond geometrically (Komar *et al.* 1995) to increased water levels and waves by raising the beach berm level and landward movement of the beach face. This gives small ratios of coastal response to sea level change, often in the order of 30:1 or less. This is particularly relevant to Sunday Island Bay with a likely ongoing sediment supply from seagrass banks, eroding Tamala limestone and from transport along the banks.

The beach will respond through rotation and retreat of low-elevation landforms. It is anticipated that in periods of rapid sea level rise, such as the 30cm surge that has occurred between 2008 and 2012 (Figure 14), sediment will be eroded from the beachface and distributed on the terrace.

As noted above, the S3 allowance is likely to represent a conservative estimate of both the magnitude of sea level rise and the relative coastal response to such change. Applying realistic estimates of these factors, the response to sea level rise may be as little as 26m by 2100, although if higher values of these factors occur, then 26m erosion could occur by 2055. In order to provide a minimal time frame of >50 years before the need for adaptation may be possible, then a 40m setback allowance is recommended, based upon a 0.4m sea level rise (by 2070) and 100:1 ratio for coastal response (Figure 15, Table 5). It is proposed to provide further adaptive capacity to subsequent sea level rise and erosion by designing the buildings for ease of relocation, and definition of alternative building envelopes further landward. Relocation of buildings would be based upon coastal retreat to a trigger level, as specified in Section 5.5.

Table 5: Coastal Response to Sea Level Rise

Time Frame	Sea Level Rise	Response Ratio	Coastal Retreat	Likelihood
2070	0.2m	65:1	13m	High
2070	0.4m	65:1	26m	Moderate
2070	0.4m	100:1	40m	Low
2100	0.4m	65:1	26m	High
2100	0.9m	65:1	58m	Moderate
2100	0.9m	100:1	90m	Low

[2] Using Hallermeier (1981) with extreme wind speeds >100 year ARI, which would generate a wave height greater than that exceeded for 12 hours in any one year, and therefore a larger closure depth than reality.

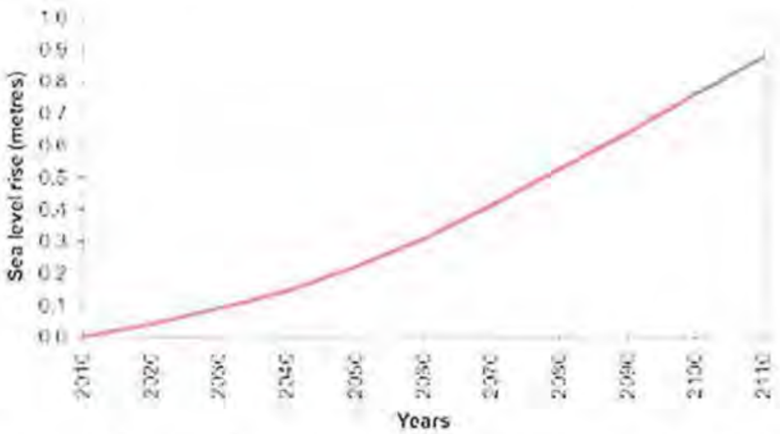

Figure 15: Sea Level Rise Allowance Time Series (Source: DoT 2010)

It is possible increased sediment mobilisation under an increased sea level, in combination with dune destabilisation, could result in activation of longitudinal dunes on the site (Figure 7). There are numerous examples of these dunes on Dirk Hartog Island and in Shark Bay. Any beach access should avoid a north-south alignment to avoid activating these dunes.

5.4. UNCERTAINTY

An allowance for uncertainty is recommended as 0.2m/yr, or 20m total, to be added to the other erosion allowances when developing a setback (WAPC 2013). However, because the focus for this section is to obtain an accurate predictor for adaptation planning, this allowance has been neglected. Reasons for doing so include the rock control at the site, evidence of landform behaviour, the sheltered location from combined high surge and wave conditions, as well as fetch restricted conditions for wave forcing (Sections 4 and 5.1). A minimum setback to the landward extent of the landforms exhibiting rotation behaviour accounts for uncertainty.

5.5. REVISED ALLOWANCES FOR EROSION AND INUNDATION

A formulaic application of Schedule One in SPP2.6 with S1 allowance of 15m and projected sea level rise to 2070 would produce erosion hazard setbacks to 2070 of 55 to 70m from the HSD of +2.0m AHD, with local higher setback at the western extent to the +4.7m AHD for inundation hazards (Table 6; Figure 16; Figure 17). The areas potentially susceptible to inundation hazard have been inferred from interpolation of the 2m contours of +4m AHD and +6m AHD (Figure 16). One envelope should be moved to avoid being located within the erosion or inundation hazard lines according to this policy (Figure 17). No sites are located in an erosion hazard area, with Sites 2, 3 and 4 requiring confirmation that they are outside the inundation hazard area. Site 4 requires a new alternate envelope to be developed if it is located at an elevation less than +4.7m AHD.

The setback allowance to 2110 would be 105 to 120m from the +2.0m AHD contour using S1 of 15m. This zone is used as the basis for considering any required adaptation sequencing in a CHRMAP.

This approach does not use the existing landform information to determine setback. A revised approach incorporating landforms with a buffer is therefore considered.

Table 6: Revised Components of SPP2.6 Schedule One

		Value	Notes
HSD	Horizontal shoreline datum, active limit of shoreline under storm activity	+2.0m AHD	The +2m AHD contour has been used in lieu of the +2.1m AHD due to the limitations of the survey data at 2m intervals. Representative of highest storm added to MHWS, but excluding local wave runup.
S1	Acute storm response	15m	Conservative estimate of wave heights and periods using strong winds. Unlikely high waves and water levels would occur coincidentally.
S2	Long-term response	0m centre and west. 15m for the E	Relatively stable foreshore. The bay was separated into separate sections to account for rotation with minimal movement at the centre. Greatest rotation could occur at the eastern extent as the control point for rotation occurs closer to the west of the bay and due to higher exposure.
S3	Sea-level rise response for 55-years (2070)	40m	2070 level of sea level rise of 0.4m. If mean sea level shift occurs more rapidly due to sea level rise the trigger for landward retreat may occur sooner.
Uncert-ainty	Uncertainty allowance of 0.2m/year.	0	Selected as 0 because of the sheltered location of the bay, rock and terrace control, as well as the evidence of landforms controlling historic coastal movement.
S4	500-yr ARI inundation event	+4.7m AHD	Site-specific analysis of 500-year water level, plus sea level rise component of 0.9m and wave run-up of 1m.
Setback for erosion to 2070	HSD + S1 + S2 + S3 + uncertainty	55-70m from +2.0m AHD	Consideration to be included of locations where the inundation allowance (S4) is landward of the setback for erosion. A minimum setback is also applied to the landward extent of landforms exhibiting rotation.

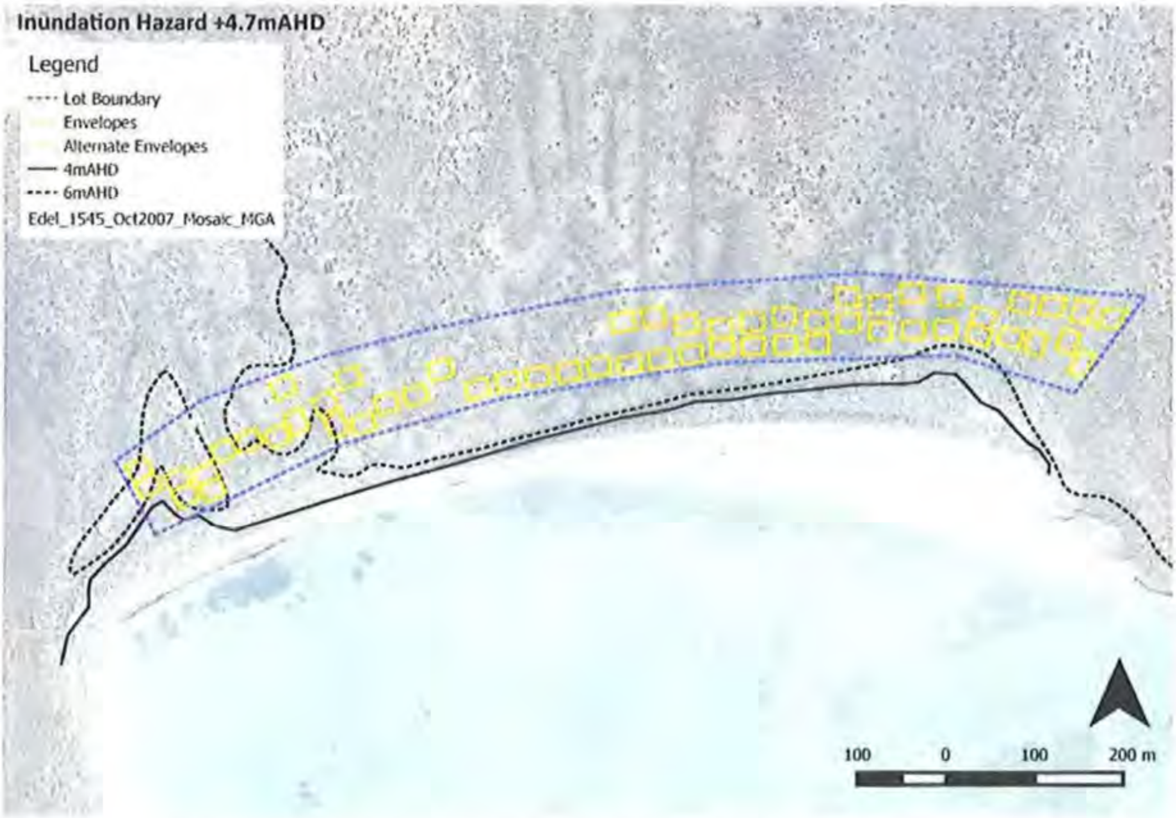

Figure 16: Inundation Hazard of +4.7m AHD Inferred from 2m Contours

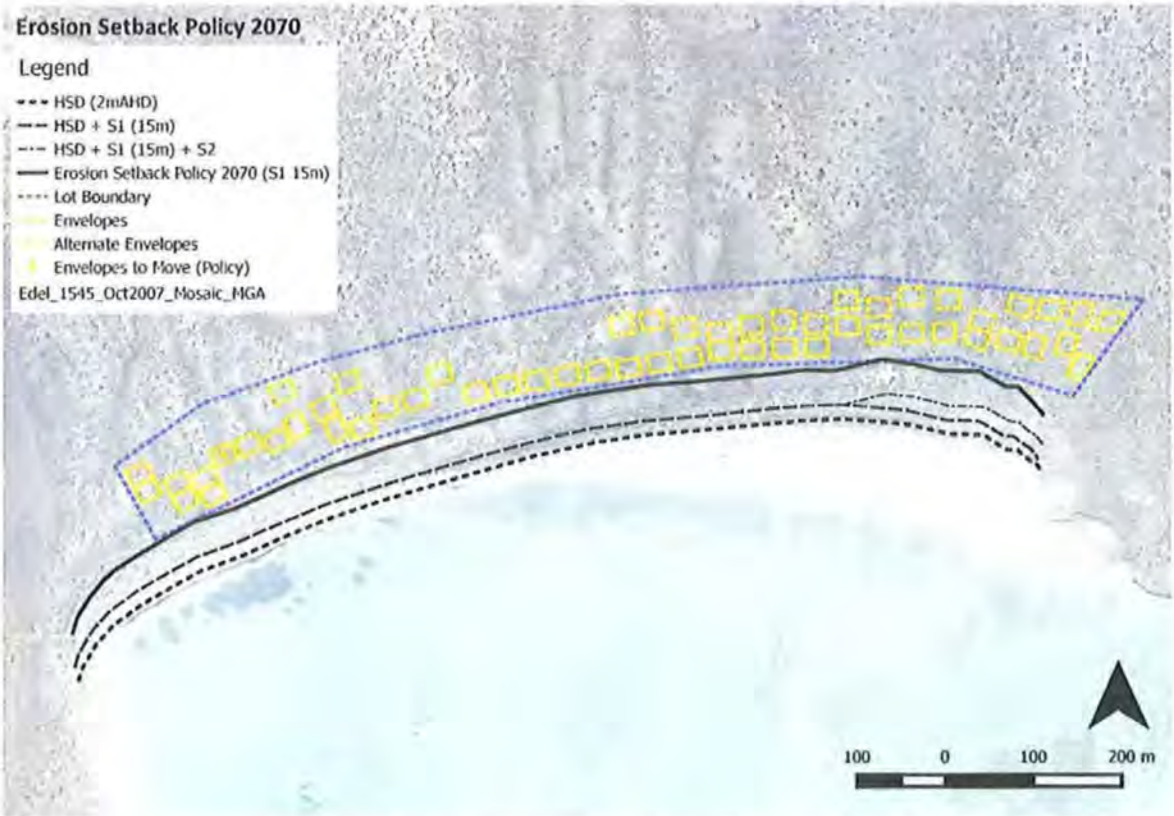

Figure 17: Erosion Setback According to Policy to 2070
Site envelopes within the erosion or inundation setback to 2070 are marked with a yellow dot

The further conditional setback allowance proposed to ensure the unstable landforms associated with coastal rotation and retreat with changes in metocean forcing and climate are included. The unstable landforms are incorporated as the most landward of the (Figure 18):

- Sum of S1 and S2 allowances (varies from 15m to 30m) from HSD (black dashed lines).
- Limit of unstable landforms (blue line).

The limit of unstable landforms is the most landward of the two lines using an S1 of 15m. This reduces the need for the uncertainty parameter as the 40m S3 component is essentially an uncertainty allowance for coastal response to sea level rise. The 40m is added to the most landward extent of anticipated change to produce a landform based erosion setback to 2070 (Figure 19). It is recommended 10 of the envelopes should be moved to avoid being located within the erosion or hazard inundation lines according to this landform approach (Figure 17). Sites 2, 3, 8, 9 18, 19, 20, 23 and 24 already had alternate envelopes selected, with site 4 requiring a new alternate envelope to be developed. Lastly, the alternate envelope for site 3 will also require moving as it is located within the erosion hazard limit.

Following SPP 2.6 (WAPC 2013), the implications of uncertainty in setbacks have been assessed in Section 6, considering the Avoid-Retreat-Accommodate-Protect hierarchy.

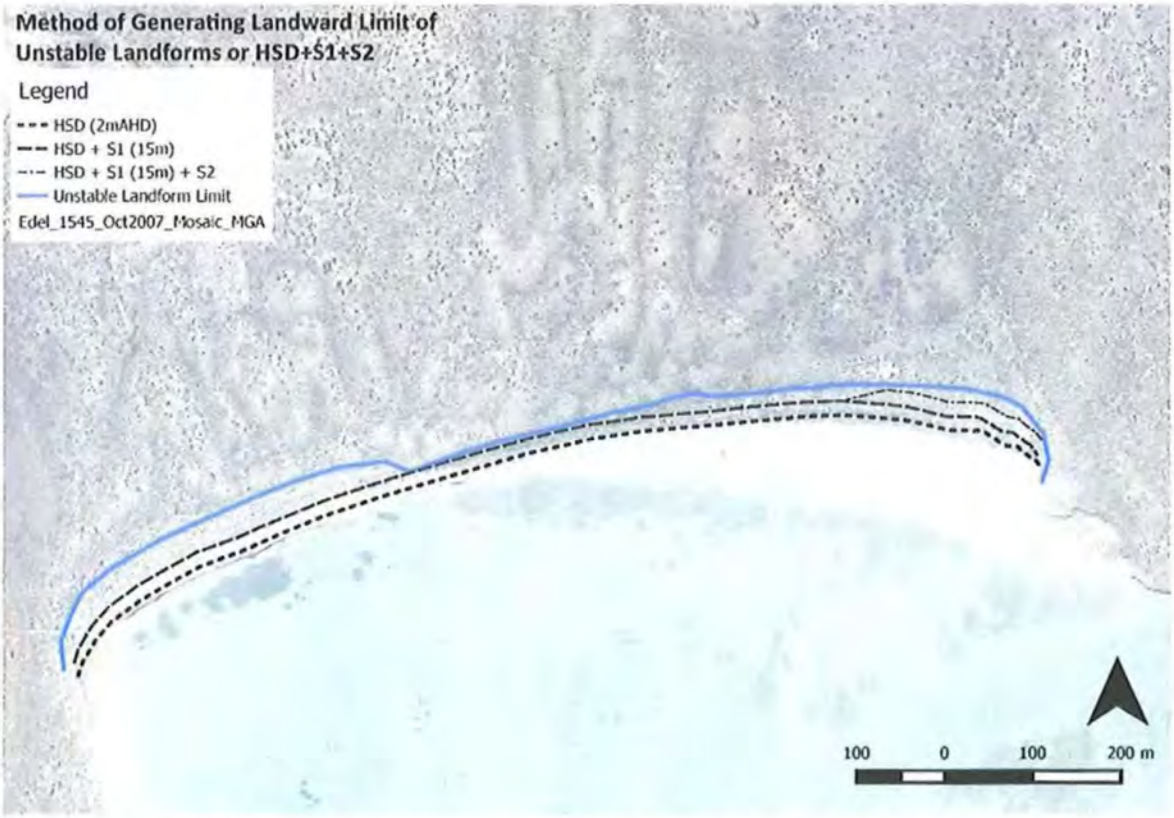

Figure 18: Method of Generating Landward Limit of Landforms or HSD+S1+S2

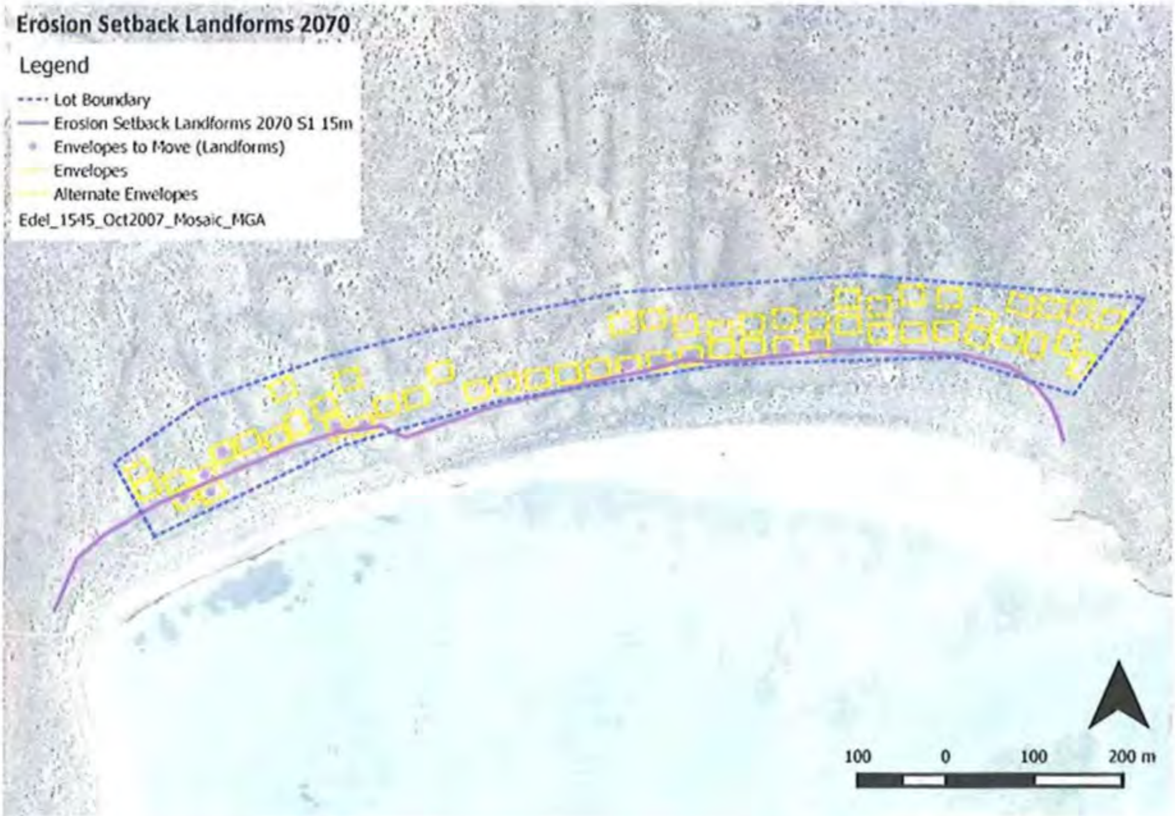

Figure 19: Recommended Erosion Setback Based on Landforms to 2070

6. Recommendations

A major part of Lot 304 freehold area is located seaward of a demarcation line derived from Schedule One of SPP 2.6 (WAPC 2013). This line distinguishes between areas that may be considered wholly avoiding coastal hazard over the next 100 years (landward of the line) and those areas that may possibly be affected by coastal hazards (seaward of the line). The Schedule One calculation is a simple method, with limited consideration of coastal processes, and therefore indicates allowances for a conservative coastal setback, rather than an estimate of anticipated coastal response. Development seaward of the demarcation line is not prohibited, but SPP 2.6 recommends that such developments be managed through a Coastal Hazard Risk Management and Adaptation Plan (CHRMAP), which acknowledges the potential risk and identifies pathways for their management.

Guidelines for the application of a CHRMAP have been developed by the Department of Planning, which indicate the need to distinguish between likely and possible coastal hazard outcomes. Further, SPP 2.6 acknowledges the constraints of applying setback allowances derived from projected sea level rise to existing freehold land. To this end, the policy allows consideration of adaptation to sea level rise as a variation to the general case. A preferential hierarchy is defined, following the sequence of *Avoid-Retreat-Accommodate-Protect*.

Evaluation of possible coastal hazards corresponding to the Schedule One setback allowance indicates that the site effectively avoids coastal hazards to 2070 (Figure 17). Due to the narrow nature of the Lot 304 freehold area, it is not possible to wholly *Avoid* coastal hazard to 2110, without purchasing additional land area. Instead, the proposed approach is to *Avoid* moderate or high likelihood hazards, and mitigate low likelihood hazard through *Planned Retreat*.

The strategy of *Planned Retreat* requires an estimate of the time frame or conditions under which the retreat would be required, which therefore should consider the difference between best estimates of coastal change and the conservative estimate developed through application of SPP 2.6 Schedule One.

Based upon realistic estimates of coastal change due to sea level rise, a setback of 71m from the +2m AHD contour acts to *Avoid* coastal hazards with high or moderate likelihood to beyond 2110. This corresponds to 56m of coastal retreat and 15m buffer for storm erosion.

Under higher scenarios of sea level rise and coastal response, 56m of coastal retreat could occur by 2084. However, evaluation of retreat practicalities of would need to occur prior to this, including recognition of the likely effectiveness of building relocation. The recommended trigger for this evaluation is coastal retreat of 41m, which gives allowance for two severe storm sequences, and is not projected to occur until 2070 under high response scenarios.

Any beach access should avoid a north-south alignment to avoid activating any dunes.

Modify Layout

It is recommended the layout be modified according to the erosion and inundation hazard assessment. If the landform erosion setback allowance to 2070 was incorporated the site layout should be altered by:

- Moving sites 2, 8, 9, 18, 19, 20, 23 and 24 to the alternate envelope already mapped.
- Creating a new alternate envelope for site 3 that is further landward of the landform-based erosion hazard line to 2070.
- Either moving site 4 further landward or confirming the elevations are >5m AHD at that location.

This is a total of 10 site envelopes that require moving.

This is dependent on acceptance of 1) the landform approach; 2) neglecting the uncertainty allowance; and 2) apply a sea level rise component only to 2070 (40m rather than 90m). Triggers for coastal retreat are included in the text above as part of a CHRMAP approach.

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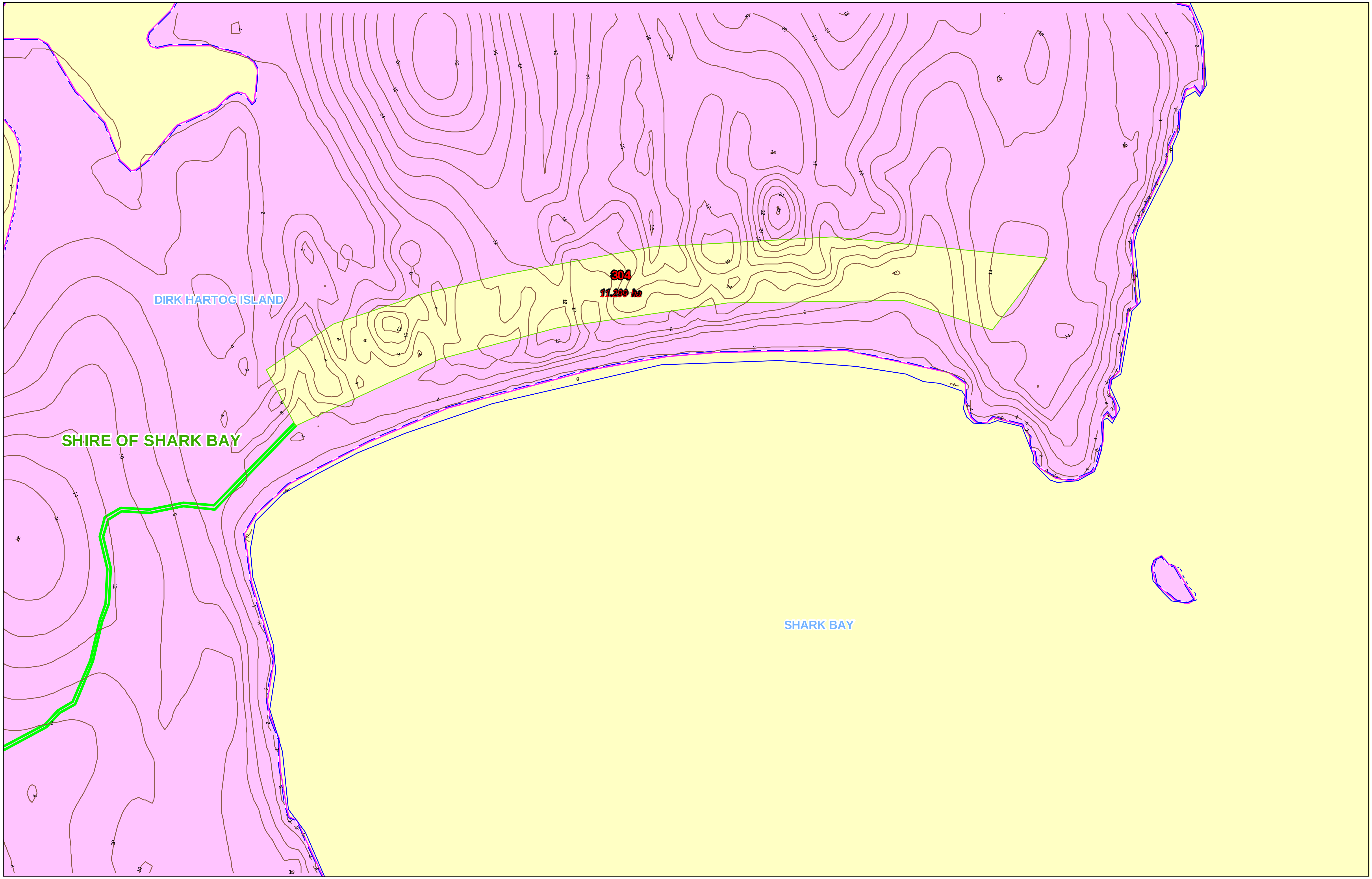

MAP USER INFORMATION

PROJECTION Universal Transverse Mercator.

DIMENSION DATUMS Horizontal: Geographical - Geocentric Datum of Australia 1994 (GDA94) Grid - Map Grid Australia 1994 (MGA94) Zone XX
Vertical: Australian Height Datum 1971.

GEODETIC CONTROL Gesmar using Western Australian Primary Trigonometric Traverses, Standard Surveys and Levelling.

HORIZONTAL ACCURACY +/- 1.0 millimetre at map scale for areas/boundaries that have not been spatially upgraded (this translates to 2 metres at 1:2000 and 250 metres at 1:250 000).
+/- 0.2 metres in spatially upgraded urban areas.
+/- 2.0 metres in spatially upgraded rural areas.
+/- 10.0 metres in spatially upgraded pastoral/remote areas.

COMPILATION On the Spatial Cadastral Database (SCDB) from Landgate Public Plans and Topographic Datasets at scales varying from 1:1000 to 1:500 000.

GRATICULE VALUES Latitude and longitude are shown in degrees, minutes and seconds.

GRID VALUES Map Grid of Australia (MGA94) coordinates are shown in metres

DATA SOURCES Cadastral and Tenure information sourced from the Spatial Cadastral Database (SCDB).
Administrative boundaries are sourced from the Landgate Administrative Boundaries Dataset.
Topographical data sourced from the PSMA Data set.
Road Names sourced from Landgate Road Centre line Dataset.
Coastlines and shorelines are interpreted from aerial photography or recorded from ground surveys.
Local Authorities terminate at Low Water Mark unless otherwise specified.
Pastoral Leases terminate 40 metres above High Water Mark unless otherwise specified.
Islands shown are Unallocated Crown Land (UCL) unless otherwise specified.

GDA

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Hydrographic features shown may not necessarily depict exact cadastral boundaries.

Roads and tracks shown may not necessarily imply public right of way.

100 0 100 200 300 400 Metres

Scale: 1:5,000

CADASTRAL BOUNDARIES
Surveyed Boundary
Unsurveyed Boundary
Grouped Lot Boundary
Road Frontage
Unsurveyed Road Frontage
Surveyed Water Mark
Unsurveyed Water Mark

ADMINISTRATION BOUNDARIES
Land District — SWAN DISTRICT
Locality — SUBIACO LOCALITY
Townsite — PERTH TOWNSITE
Local Government Authority (LGA) — SHIRE OF MOUNT MAGNET

TENURE
Lot on Survey — 64
Crown Allotment — 1372
Crown Reserve — R33853
Unallocated Crown Land — UCL
Lease — L3114/1194
Marine Park — MARINE PARK 4

Closed Road — CLOSED ROAD
State Forest — F14
Timber Reserve — O148/25
Road — SUES RD OR SUES RD

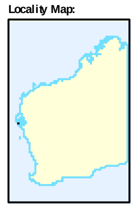
SURVEY INFORMATION
Area — *1012m² or 2.1457ha*

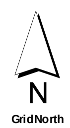
Interests
Types of Interests
E = Easement; Int = Interest;
TP = Tree Plantation;
PP = Profit A Prende;
CR = Carbon Right;
CC burden = Carbon Covenant burden;
CC benefit = Carbon Covenant benefit

CULTURE
Airport/Landing Ground
Bridge or Crossing
Railway Line
Railway Station

HYDROGRAPHIC
River or Watercourse
Lake or Dam

Locality Map:





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Heading

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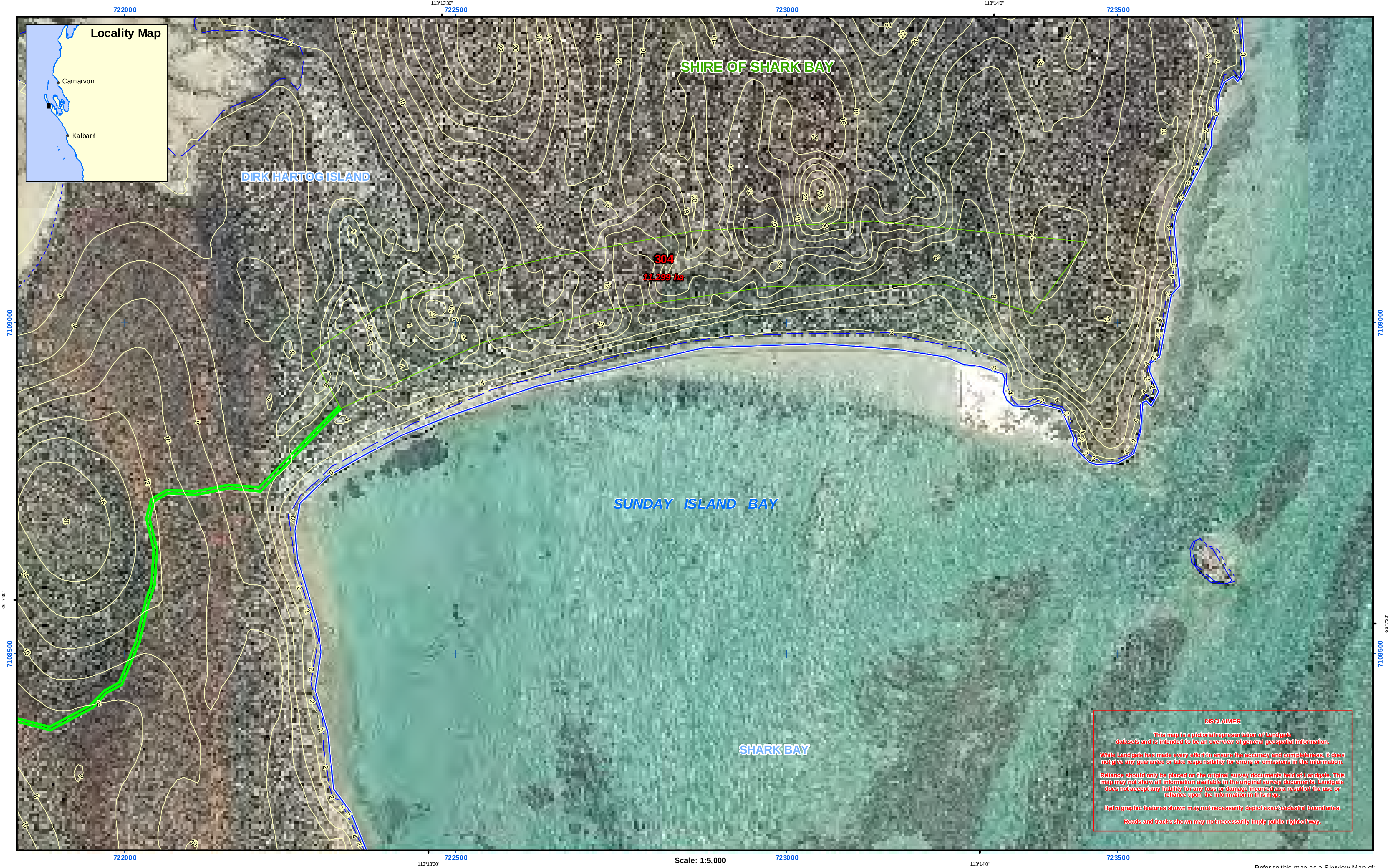

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Grid North

MAP USER INFORMATION

PROJECTION	Universal Transverse Mercator.
DIMENSION DATUMS	Horizontal: Geocentric Datum of Australia 1994. Vertical: Australian Height Datum 1971.
GRID VALUES	Map Grid of Australia (MGA) values are shown in metres.
GRATICULE VALUES	Longitude & latitude values are shown in degrees, minutes and seconds.
DATA SOURCES	Orthophoto sourced from SkyView WA ortho-rectified mosaics. Cadastral and Tenure information sourced from the Spatial Cadastral Database (SCDB) of Western Australia.

ORTHOPHOTO MOSAIC INFORMATION

Mosaic Name:	Edel 1545
Date Flown:	October 2007
Ground Pixel Size (Metres):	0.50
Scanned at (dpi):	1270 dpi
Capture Scale:	1:25 000
Accuracy:	+/- 10m

CADASTRAL HORIZONTAL ACCURACY

+/- 1.0 millimetre at map scale for areas/boundaries that have not been spatially upgraded (this translates to 2 metres at 1:2 000 and 250 metres at 1:250 000).
+/- 0.2 metres in spatially upgraded urban areas.
+/- 2.0 metres in spatially upgraded rural areas.
+/- 10.0 metres in spatially upgraded pastoral/remote areas.

CADASTRAL BOUNDARIES

Surveyed Boundary
Unsurveyed Boundary
Grouped Lot Boundary
Road Frontage
Unsurveyed Road Frontage
Surveyed Water Mark
Unsurveyed Water Mark
Lot Number 52

Landgate
Location Products & Services, Operations, Landgate
Tel: (08) 9273 7181
geodata@landgate.wa.gov.au
www.landgate.wa.gov.au

Refer to this map as a Skyview Map of:

LOT 304
Sunday Island Bay

Map Produced: 6 September 2012

Our Ref: Job 0400/12-13