Capel to Leschenault CHRMAP

Chapter Report: Coastal Hazard Assessment

Peron Naturaliste Partnership

14 April 2022

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14 April 2022

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Dear Joanne

Chapter Report: Coastal Hazard Assessment

We are pleased to present the Capel to Leschenault Coastal Hazard Risk Management and Adaptation Plan Chapter Report: Coastal Hazard Assessment. If you have any queries, please do not hesitate to contact me on (08) 6555 0105.

Yours sincerely

Joanna Garcia-Webb
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WATER TECHNOLOGY PTY LTD

EXECUTIVE SUMMARY

It is internationally recognised that the mean sea level has been rising globally since the nineteenth century and is predicted to rise at an increasing rate in the future (IPCC 2021). Rising sea levels and intensifying storm activity will increase the risk of coastal inundation (temporary coastal flooding), storm erosion and long-term shoreline recession. State governments across Australia have introduced statutory obligations that require local governments to consider and plan for these hazards. In Western Australia (WA), the governing policy is the Western Australian Planning Commission's (WAPC) State Planning Policy No. 2.6: State Coastal Planning Policy (WAPC, 2013, herein referred to as "SPP2.6"). SPP2.6 recommends management authorities develop a Coastal Hazard Risk Management and Adaptation Plan (CHRMAP) for land use or development that is potentially vulnerable to coastal hazards. Specific guidelines have been developed to assist in this process (WAPC, 2019).

SPP2.6 requires adequate risk management planning is undertaken where existing or proposed development is in an area at risk of being affected by coastal hazards over the 100-year planning timeframe. SPP2.6 and the CHRMAP Guidelines provide the risk assessment framework to be applied to identify risks that are intolerable to the community, and other stakeholders such as local governments, indigenous and cultural interests, and private enterprise. Risk Management measures are then developed according to the adaptation hierarchy outlined in SPP2.6.

The Peron Naturaliste Partnership (PNP) comprises membership of nine local government authorities. The PNP's Coastal Adaptation Pathways Project identified the coastal areas of Capel, Leschenault and Greater Bunbury as being particularly exposed to coastal hazards and climate change, which triggered the need for this CHRMAP. The aim of the present study is therefore to investigate the nature and severity of coastal hazards which are likely to affect these regions from Capel to Leschenault over future planning horizons. Refer Figure 1-1 for locality and study area extent. Appendix A contains a suite of locality plans identifying specific beaches, features, locations etc noted within the report, as well as the designated management units (Water Technology, 2021).

The objective of this CHRMAP project is to increase knowledge and understanding of coastal hazard risks, and identify risk management and adaptation measures for implementation. The outcomes will be used to inform local and state government policies, strategies and plans, including (but not limited to); planning strategies, community strategic plans, drainage strategies, asset management plans, emergency management plans, and foreshore management plans. The project will adhere to the WAPC (2019) guidelines with scope and deliverables to be consistent with the objectives identified by these guidelines and SPP2.6. The project will identify the strategic direction for coastal adaptation scenarios from the present-day to 2120 (100 yrs. management time frame), and identify an implementation plan to achieve this direction. Overall, this CHRMAP will develop a flexible adaptation pathway for the region and serve as a key reference for management, planning and policy making for the short-term (0-15 years), medium-term (15-30 years), and long-term (100 years).

This report presents the Coastal Hazard Assessment Chapter Report, which identifies the coastal hazards in the study area that need to be considered in the CHRMAP. Hazard maps are produced defining the erosion and inundation extents for present day, 2035, 2050, 2120. The flow chart displayed in Figure 1-2 indicates where this component sits with reference to the greater study; the 'Coastal Hazard Assessment' phase corresponds to the top part of the bubble shaded in red, presented below.

A summary of the coastal hazards, erosion and inundation is presented in Table 6-1. The full hazard maps are presented online for interactive viewing at the following link:

https://watech.maps.arcgis.com/apps/webappviewer/index.html?id=d43c39fda97d426ea6192d1a7a8543cf

Coastal Hazard Assessment – to understand coastal processes & hazards & identify areas at risk

- TBC: Site Investigation (as required)
  - To gain greater understanding of coastal processes and issues identified during Establishing the Context.
  - Collection of georeferenced photographs and notes for future reference.
- Coastal Hazard Assessment
  - Inundation Hazards
  - Erosion Hazards
- Coastal Hazard Mapping
  - Mapping of all coastal inundation and erosion scenarios at appropriate scale.

Identification of Coastal Assets and Values

- Community Engagement and survey to identify key coastal assets and values
- Coastal asset Information provided by the PNP or from other organisations
- Incorporation of site inspection outcomes (if conducted)

The study area covers a complex shoreline with various types of coastal hazards present in this region. The presence of rivers, an estuary and inlet has increased the complexity of the study, in particular the assessment of inundation hazards where river flood plays a more dominant role than the intrusion of ocean water. **It is acknowledged that the hazard identification component of the present study has been undertaken to provide a broad understanding of exposure than can support government planning at a regional level - and will be superseded once site-specific studies become available, in particular at the estuary/inlet and along the river courses**. Results derived from this study should not be over-interpreted at a micro-scale due to the assumptions applied and the limitations in model resolution. More detailed risk assessments and analysis may be required for the development of detailed engineering measures for specific sites. No geophysical or geotechnical assessments have been undertaken across the study to date. Erosion response across the study area may differ in reality to the predictions of this study due to the lack of data. Further geophysical/geotechnical assessment will be a recommendation of this CHRMAP

ABBREVIATIONS

Abbreviation	Description
AEP	Annual Exceedance Probability
ARI	Average Recurrence Interval
CHRMAP	Coastal Hazard Risk Management and Adaptation Plan
DoP	Department of Planning (now part of DoPLH)
DPLH	Department of Planning, Lands and Heritage
DoT	WA Department of Transport
HSD	Horizontal Shoreline Datum (see SPP2.6)
IPCC	Intergovernmental Panel on Climate Change
HAT	Highest Astronomic Tide
LAT	Lowest Astronomic Tide
LGA	Local Government Area
MHHW	Mean High High Water
MLHW	Mean Low High Water
MSL	Mean Sea Level
MHLW	Mean High Low Water
MLLW	Mean Low Low Water
SLR	Sea Level Rise
SPP2.6	State Planning Policy No 2.6: State Coastal Planning Policy (2013)
WAPC	Western Australian Planning Commission

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1 INTRODUCTION

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Delivery of this project will occur over 9 stages (as summarised in Figure 1-2), each of which represents a key hold point. The staged approached is developed according to the PNP's scope and is in line with the CHRMAP Guidelines (WAPC, 2019).

This report presents the Second Stage: The Coastal Hazard Assessment Chapter Report, which identifies the coastal hazards in the study area. Hazard maps have been produced that define the erosion and inundation extents of varying magnitude (severity) for present day, 2035, 2050, 2120. The flow chart displayed in Figure 1-2 indicates where this component sits with reference to the greater study; the 'Coastal Hazard Assessment' phase corresponds to top part of the bubble shaded in red.

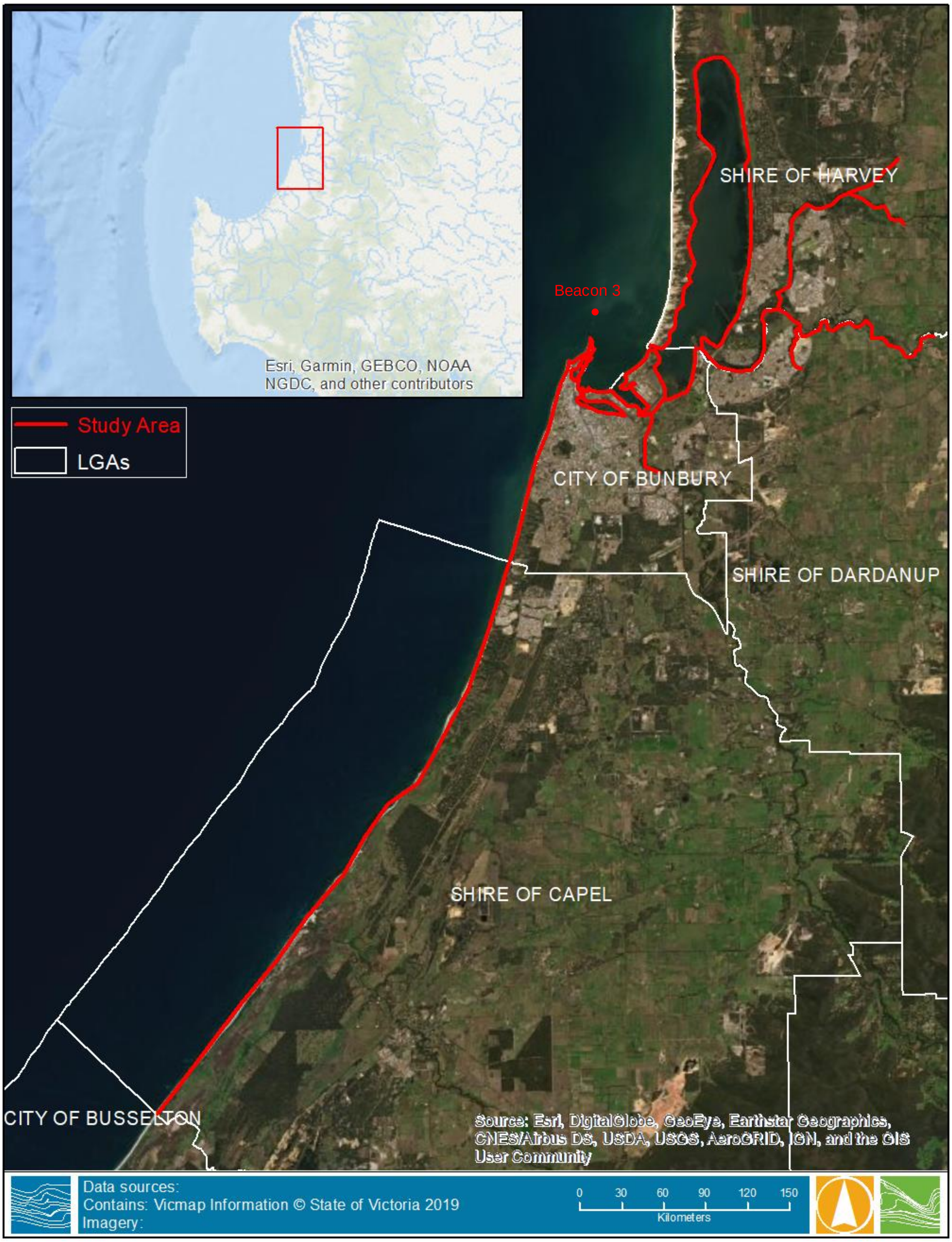


FIGURE 1-1 PROJECT AREA

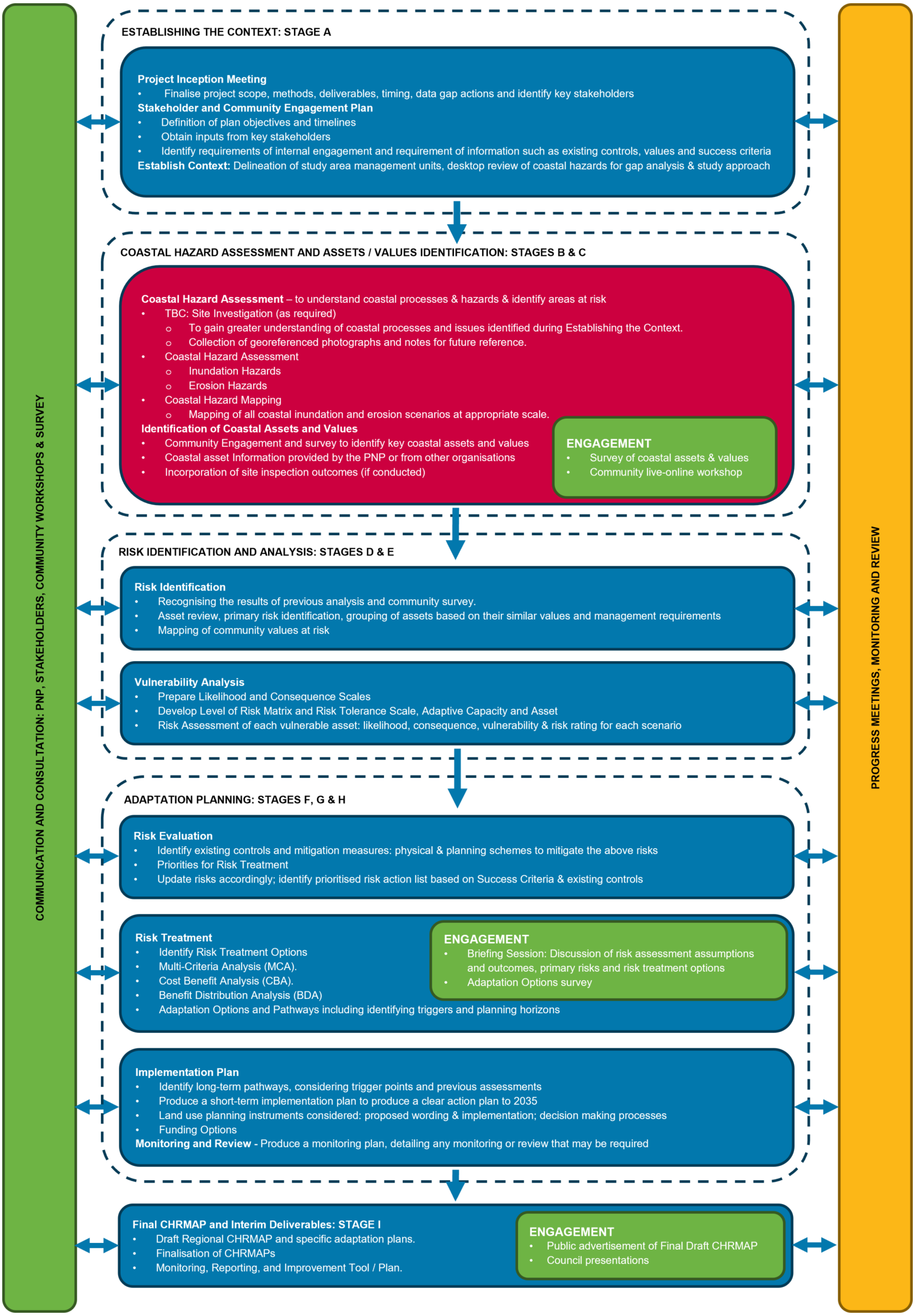


FIGURE 1-2 CHRMAP METHODOLOGY FLOW CHART (ADAPTED FROM WAPC, 2019)

2 DESKTOP REVIEW

2.1 Key Documents

Key documents and datasets have been reviewed to provide context for this coastal hazard assessment on metocean processes, coastal processes and existing coastal hazard information. Any sources of information identified as directly relevant to inform this CHRMAP have been utilised, referenced and reported below as well as subsequent chapter reports. As per Section 1, Appendix A contains a suite of locality plans identifying specific beaches, features, locations etc noted within the report.

2.2 Metocean Condition

2.2.1 Water Levels

Water levels over the project region comprise variations from astronomical tide, wind and wave setup, atmospheric pressure, seasonal and interannual anomalies, riverine discharge, and periodic impacts of tropical cyclones, coastal trapped waves and tsunamis.

The Bunbury tide gauge provides one of the longest water level records in WA, consisting of “paper trace” records back to the 1930s and digital records since 1985.

2.2.1.1 Tide Planes

Tidal planes at Bunbury are presented in Table 2-1 (from Austides 2018 and DoT 2010a). These have been calculated from over 30 years of tidal data recorded at the Bunbury tidal gauge. Tidal motion of the region can be characterised by a dominant diurnal tide, meaning one high tide and one low tide per day. Tidal range is approximately 0.8 m during spring tide and can be much smaller during the neap phase.

TABLE 2-1 TIDAL PLANES

Tidal Plane	HAT	MHHW	MLHW	MSL	MHLW	MLLW	LAT
AusTides 2018 (m AHD)	0.63	0.36	0.25	0.01	-0.23	-0.34	-0.58
DoT 2010a (m AHD)	0.67	0.39	0.28	0.04	-0.20	-0.29	-0.57

2.2.1.2 Non-tidal Water Level Variability

Variations in water level are caused not only by astronomical tides, but also by phenomena including wind and wave setup, atmospheric pressure, and oceanographic variations including seasonal heat budgeting, Leeuwin Current, coastal trapped waves, La Niña effects, pacific decadal oscillation etc.

Wave dissipation and breaking causes water to “pile up” against the coast (wave setup). Atmospheric pressure leads to local changes in sea level, with high pressure lowering the sea level and low pressure increasing the sea level, a process referred to as the inverse barometric effect.

Along the Western Australian coastline, it has long been recognised that oceanographic processes have a substantial influence on seasonal and interannual variability in coastal sea levels, which shows some correlations with the El Nino Southern Oscillation (ENSO) cycle (Pearce & Feng, 2013). Since the 1990s, the Pacific Decadal Oscillation (PDO), with its multidecadal time scale of 20–30 years, has also swung to a negative phase, sustaining positive heat content and more frequent cyclonic winds off the Western Australian coast. These large-scale ocean climate drivers are thought to have led to stronger La Nina over the past two decades. This process is recorded to have caused, for example, approximately 0.3 m water level increase during the 2011 La Nina event which is not related to either tide or local winds. Impacts from these oceanographic processes may be enhanced in the future due to the increased risk of extreme La Nina events under a warmer climate.

2.2.1.3 Storm Surge

Storm Surge

In the Southwest WA region, storm surges arise in relation to strong winter storms moving out of the Southern Ocean, as well as tropical cyclones travelling from the tropics south into the area.

- Winter low pressure storm systems have typical wind speeds of about 20 m/s. Winter storms are the main driver of frequent storm surge and erosion events recorded. Severe winter storms can generate water levels exceeding 1.5 m AHD, as recorded during a winter storm on 16th May 2003. This is about 0.9 m above the HAT level.
- Wind speed from tropical cyclones, even after extra-tropical transformation, may still reach 30 m/s or above. The highest storm tide (1.84 m AHD) level was recorded during TC Alby on 4 April 1978. This was about 1.2 m above HAT level. Tropical cyclones have the potential to generate greater storm levels than winter storms due to stronger wind gusts.

Desktop Review

Geoscience Australia (GA), the then Western Australian Department of Planning (DoP) and the Western Australian Planning Commission (WAPC) collaborated to develop a storm surge modelling methodology for Bunbury (Fountain et al 2010). The study provided the DoP and WAPC an assessment of inundation hazards based on a range of storm surge and climate change scenarios for Bunbury. Model results identified some vulnerable areas over the low-lying land proximal to Koombana Bay and around the Leschenault Inlet/Estuary. A storm surge level of over 2.3 m AHD was predicted for a worst-case synthetic cyclone event (modified from TC Alby track). Results provided in this study will be used to inform the preparation of the current CHRMAP study in terms of the inundation hazard assessment as they are considered fit for purpose.

Damara (2011) estimated the extreme water levels at Bunbury using over 20 years of water level data from the Bunbury tide gauge. Damara (2020) provided an update of this estimate (Figure 2-1). MPRA (2015, Section 2.5) undertook an extreme value analysis using 23 years of DoT data and 48 years of the former Public Works Department data (in total 71 years). Review results are summarised in Table 2-2:

TABLE 2-2 EXTREME WATER LEVELS AT BUNBURY TIDE GAUGE – DESKTOP REVIEW

ARI	1yr	5yr	10yr	50yr	100yr	500yr
Damara 2011 (m AHD)	0.94	1.25	1.32	1.44	1.49	
MPRA 2015 (m AHD)	1	1.2	1.3	1.6	1.7	2.0
Seashore 2018(m AHD)						2.9
Damara 2020 (m AHD)	0.93		1.23		1.55	2.6

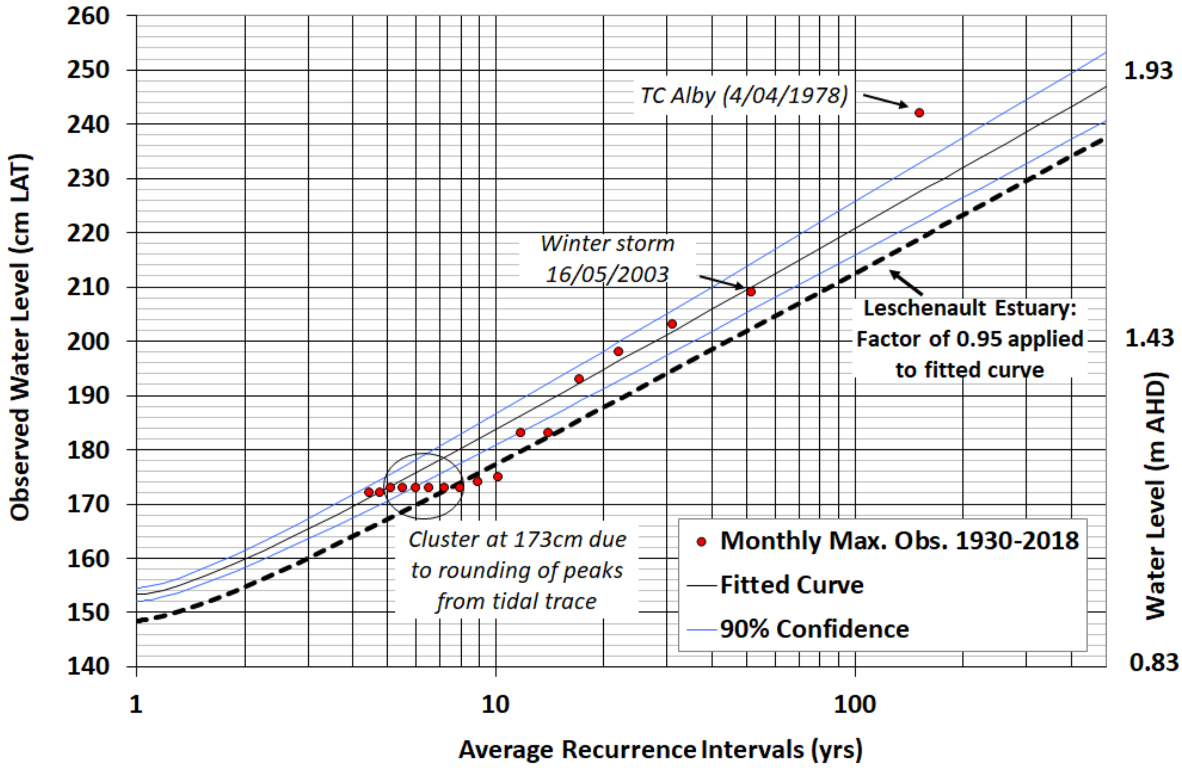


FIGURE 2-1 EXTREME WATER LEVEL ANALYSIS (DAMARA, 2020)

2.2.1.4 Tsunami

Tsunamis are often generated by earthquakes in subduction zones, where the earth's tectonic plates converge. Tsunami waves can propagate for thousands of kilometres across the ocean before dissipation. Burbidge (2008) identified that there have been at least three recorded major tsunami events affecting the Western Australian coast over the last few decades. These include the 1977 Sumbawa, 1994 Java and 2004 Sumatra-Andaman earthquakes. The strongest impacts were found along the northwest coast of Australia, with impacts reducing substantially towards the southwest region (see Figure 2-3). Tsunami hazard usually occurs at a lower frequency than storm surge and river flood events. Nonetheless it remains key information that should not be overlooked for any government planning policies.

Davies & Griffin, (2018) updated the 2008 assessment and produced results in finer detail around Australia. Figure 2-2 presents the results at the 25m contour offshore from the study area: a tsunami wave height of 1.6-1.8m is predicted for the 500 yrs. ARI. This translates to approximately 3.6-4m wave height nearshore if applying Green's Law, the tsunami wave shoaling theory. These values are significantly higher than the values predicted in the 2008 study. From this data the inundation levels are likely to be similar to that of the 500 yrs. ARI storm surge levels. However, the occurrence of earthquakes and tsunami waves are difficult to predict, and therefore there are large uncertainties associated with such estimations.

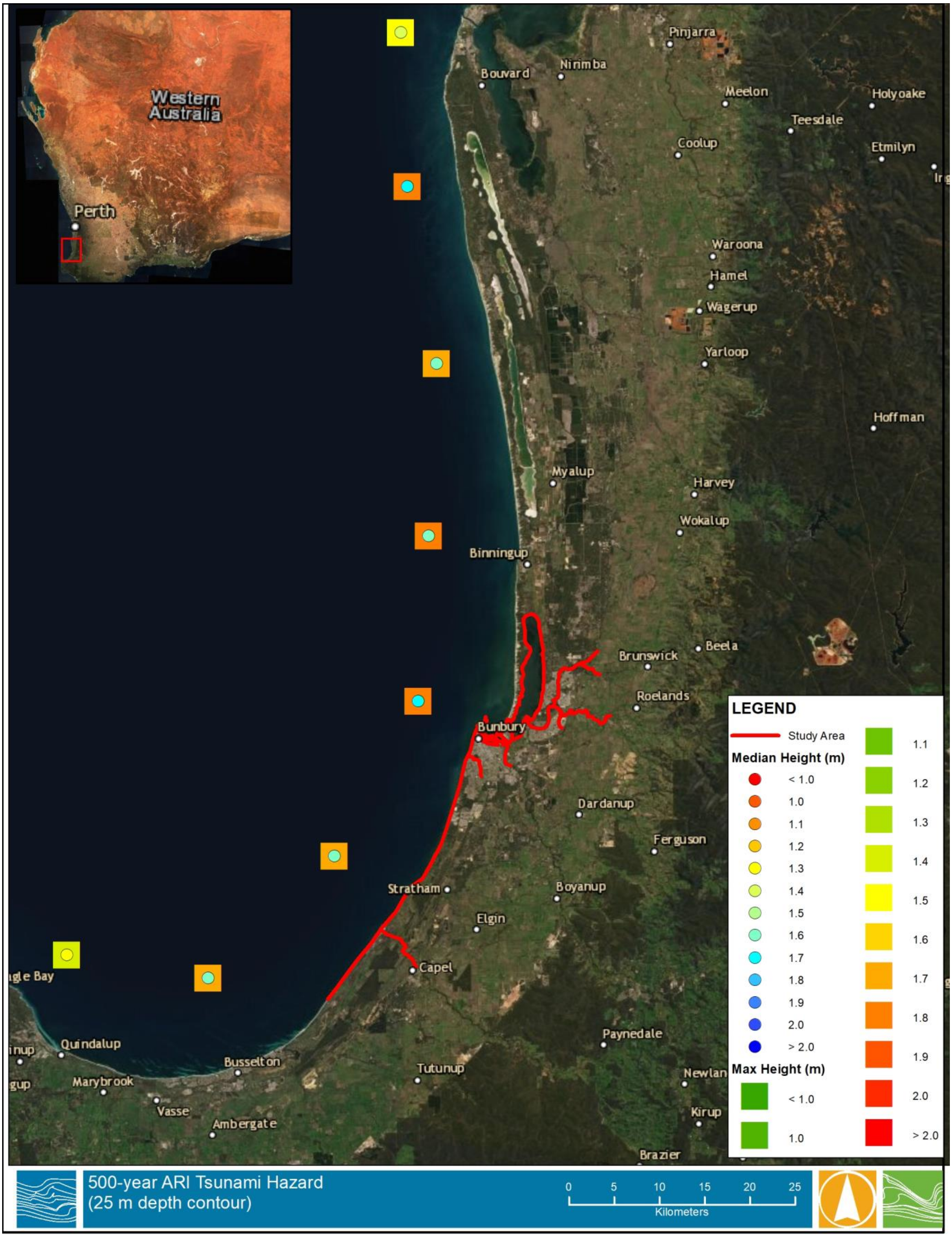


FIGURE 2-2 PREDICTED TSUNAMI MAGNITUDE AT 25M DEPTH CONTOUR: MAXIMUM (SQUARE) AND MEDIAN (CIRCLE) (DATA SOURCE: DAVIES & GRIFFIN, 2018, HTTPS://WWW.GA.GOV.AU/ABOUT/PROJECTS/SAFETY/PTHA)

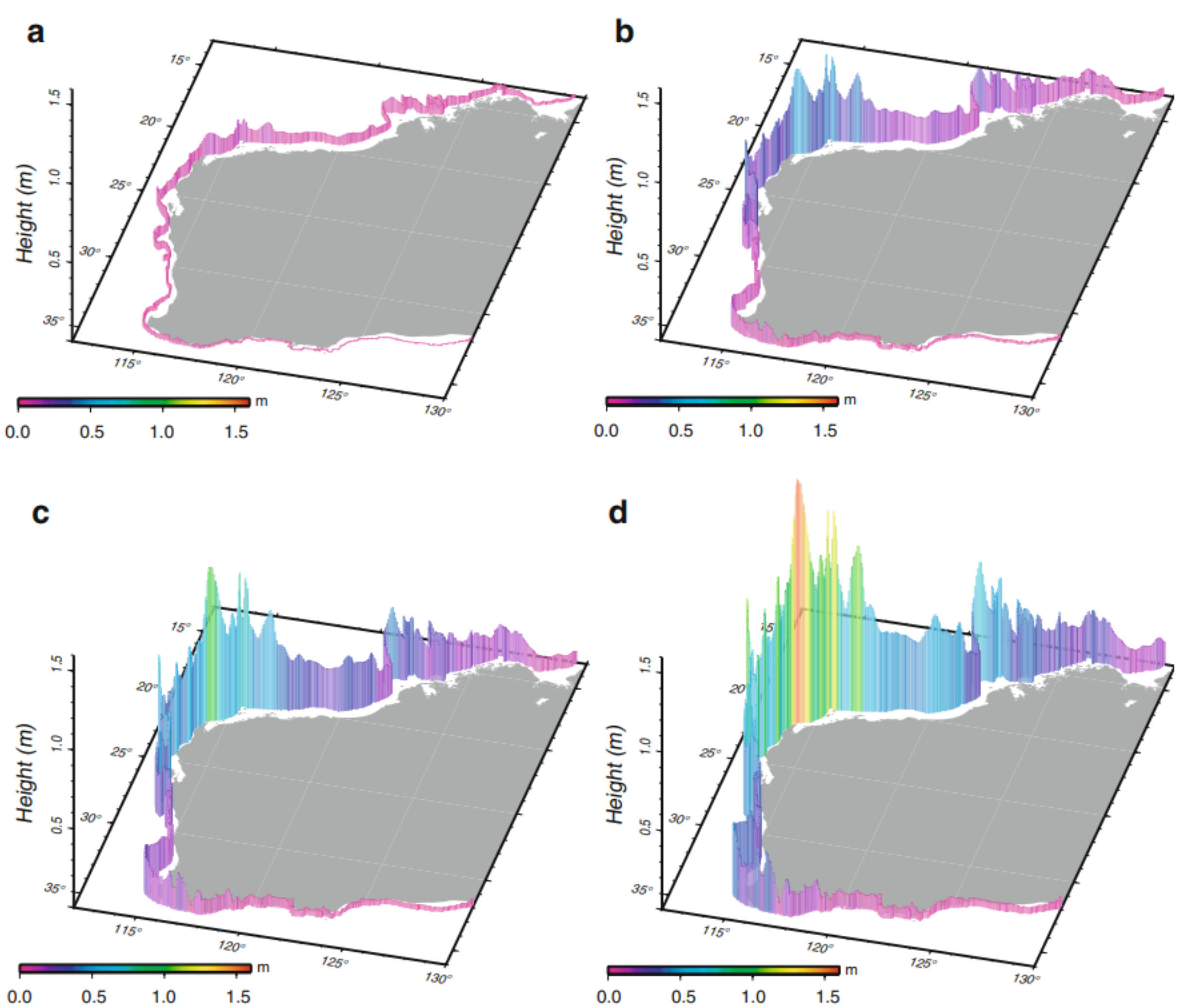


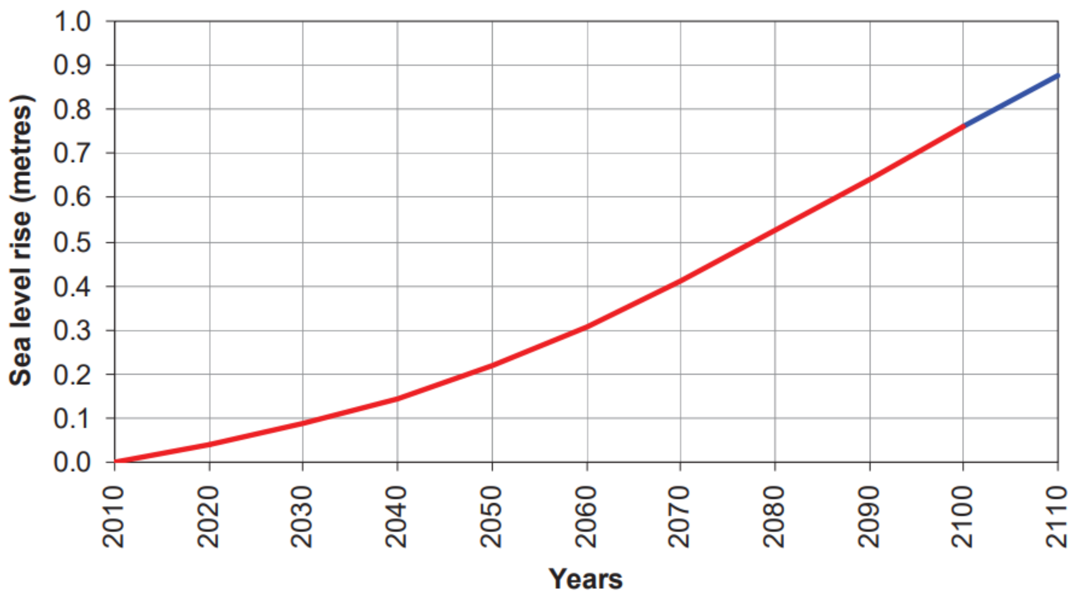
FIGURE 2-3 TSUNAMI HAZARD ASSESSMENT MAP AT 50M DEPTH CONTOUR (A-100YEARS, B-500 YEARS, C-1000YEARS AND D-2000YEARS, TAKEN FROM BURBIDGE (2008))

2.2.1.5 Sea Level Rise

Bicknell (2010) recommended allowances for sea level rise (SLR) application in coastal planning in Western Australia are presented in Table 2-3. The current recommended SLR for 2110 is +0.9 m above 2010 levels - with 0.01 m/year to be added for every year beyond 2110. It is noted that this SLR scenario is consistent with the latest projections provided in the Intergovernmental Panel on Climate Change (IPCC 2021) Sixth Assessment Report (AR6).

TABLE 2-3 SEA LEVEL RISE

Planning Time Frame (yrs.)	2010	2020	2030	2050	2070	2090	2120
Sea Level Rise (m)	0	0.04	0.08	0.22	0.42	0.64	0.98



2.2.2 Wind Climate

2.2.2.1 Wind Climate

In order to assess the local coastal wind climate, wind records from Bunbury Port Beacon 3 (Easting 374019.6, Northing 6315284.3, GD92 MGA 50, see red dot in Figure 1-1) anemometer have been assessed. Wind rose plots (Figure 2-4) show that the study area wind climate has both seasonal and diurnal characteristics:

- Wind conditions at Bunbury are moderate. Wind records at Beacon 3 show a median wind speed of ~5 m/s and a 95th percentile wind speed of ~10m/s (8 m height, 10 minutes' duration).
- The land-sea breeze cycle is a dominant feature of the region, typically with an easterly wind in the morning and a southerly to westerly wind in the afternoon.
- During the spring-summer (Oct-April) period, the typical wind is predominantly south-easterly to south-westerly. For winter months (May-Sep), however, wind conditions become more variable in terms of both speed and direction.
- Damara (2020) extreme wind analysis (based on 16 years of Beacon 3 wind data, wind speed adjusted to 10 m height, see Figure 2-5) shows the strongest storm winds tend to originate from the west, with wind speed varying from about 19.7 m/s for a 1 yrs. ARI event to over 26 m/s for a 100 yrs. ARI event. For easterly directions (0 - 180 °N), extreme wind speeds are less than 20m/s for all investigated ARIs.
- These wind-rose plots are based on single point measurements. Wind conditions may vary along the coast due to the variation of shoreline orientation/formation; however, the general wind climate (moderate wind, seasonal and diurnal cycle) should be consistent within the project domain.

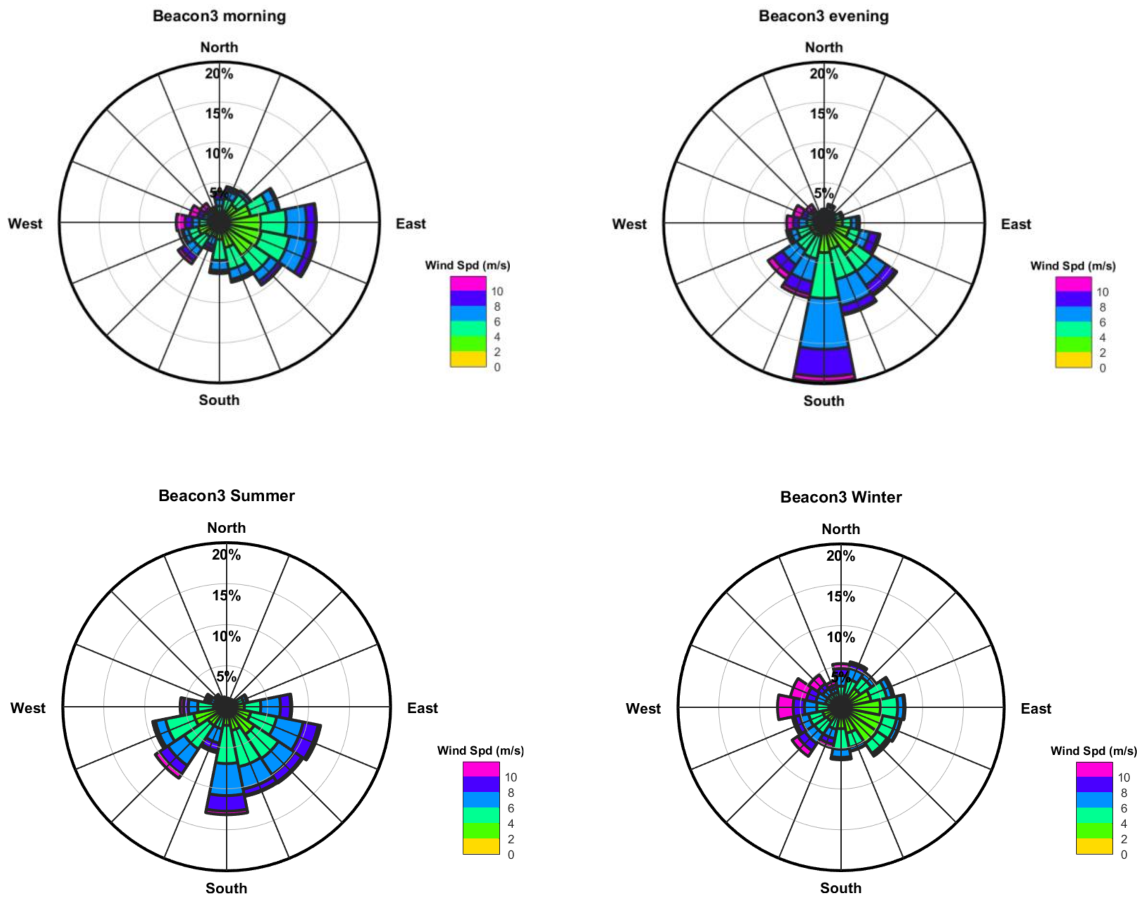


FIGURE 2-4 WIND ROSES AT BEACON 3 (JAN 2012- JAN2021)

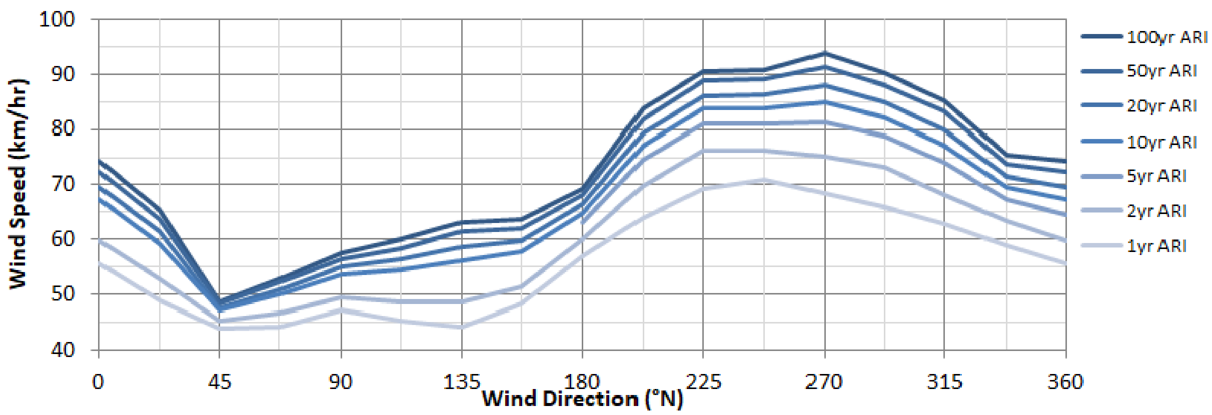


FIGURE 2-5 DIRECTIONAL EXTREME WIND SPEEDS (FROM DAMARA (2020))

2.2.2.2 Tropical/Extra-tropical Cyclones

Tropical Cyclones or extra-tropical transformation of Tropical Cyclones occur primarily between December and April, and occur much less frequently in adjacent months (e.g., TC Mangga in May 2020). Unlike northwest coast of Western Australia where tropical cyclone occurs at a regular basis, the southwest region does not experience cyclones frequently. Tropical cyclones can have a greater impact (in terms of coastal hazards) than winter storms due to the following factors.

- **Extreme Winds** – Maximum wind speeds are a function of the central pressure, the radius to maximum winds, the forward speed of the cyclone and local topographic effects. Cyclonic winds circulate clockwise in the southern hemisphere; however, wind fields are generally asymmetric such that the strongest winds are generally observed on the left-hand side of the direction of cyclone movement. A review of available cyclone track records indicates that a number of cyclones were reported to have gust speeds exceeding 50m/s, although these speeds were not measured over land. Typical cyclonic wind speeds on land have regularly exceeded 30 m/s. This is often beyond the range of the projected extreme wind speeds based on Extreme Value Analysis (EVA) of short-term wind records.

- **Extreme Waves** – Tropical cyclones generate extreme ocean waves as a result of energy transfer from the cyclone winds to the ocean surface. The growth of ocean waves is determined by water depth, wind speed, wind duration and the distance for winds to act over (fetch). Extreme waves can be much higher during tropical cyclones than regular winter storms.
- **Extreme Storm Surge** – A phenomenon of rising water commonly associated with low pressure weather systems (such as tropical cyclones and strong extratropical cyclones). It is driven by the combined action of wind setup, atmospheric pressure reduction and wave setup. Its severity is affected by the shallowness and orientation of the water body relative to the storm path and the magnitude of storm surge may be amplified in a semi-enclosed water body. The peak storm surge often only lasts for a few hours near the region of maximum wind speeds. Occurrence of extreme storm surge at high tide is relatively rare, however such a combination would have potentially catastrophic consequences particularly in semi-enclosed shallow waters, such as Koombana Bay.
- **Intense Rainfall** – The rain bands of a tropical cyclone can expand up to 1,000 km in diameter, with heaviest rainfall usually located at the eye wall. This implies a degree of correlation between extreme storm surge and rainfall during tropical cyclones which may amplify the inundation hazard for the low-lying Leschenault Inlet and Estuary regions.

Review of BoM cyclone database show two key cyclones that have affected the study area.

- **TC Alby** in 1978. TC Alby was one of the most devasting tropical cyclones to affect the southwest coast of Western Australia. It was first noted in the tropical region over 1,000 km to the north of the northwest coast where it started to form. Quickly it intensified and formed a Category 5 cyclone (estimated lowest centre pressure is about 930 hPa in the Indian Ocean and then moved southwards parallel to Western Australian coastline. It underwent an extra-tropical transition near Cape Leeuwin and gradually lost energy in the following days. As per the BoM report, the observed lowest pressure at Cape Leeuwin is about 972 hPa. During the 2nd and 3rd of April winds generated by the storm reached an estimated peak of 200 km/h. At Bunbury, winds were strongest during the period 04 April 10:00 to 04 April 13:30 GMT. Some wind gusts noted at the Bunbury Power Station exceeded 130 km/h (or ~36 m/s).
- **TC Bianca** in 2011. Bianca was a low-pressure system which developed over land near Wyndham on the 21st January. The maximum sustained wind speed recorded during TC Bianca was 96 km/h at Bedout Island at 10.30 am AWST (02:30 UTC) and at 11.20 am AWST (03:20 UTC) 26th January as the system passed to the north of the island. The maximum 3-second wind gust was 118 km/h at 10.30 am AWST (02:30 UTC), 11.20 am AWST (03:20 UTC) and 11.30 am AWST (03:30 UTC) 26 January. The system gradually dissipated over open water to the west of Perth. Although it did not land, strong wind gusts and hail damages were reported by local news.

2.2.3 Wave Climate

2.2.3.1 Wave Climate

Wave climate off the southwestern Australian coastline is dominated by the deep-water swell waves generated by large-scale weather systems over the Indian and southern Oceans. It shows little spatial variation for a large area extending from Perth to over 200 km south of Perth. The seasonal variation is however significant, which is determined by the regional meteorological climate. There are generally four sources of wave energy at Bunbury:

- Offshore swell (from west to southwest) from the Southern Indian Ocean with typical wave periods between 12 to 16 s. Typically, larger waves occur during the winter months (stormy season) than the summer months (calm season).
- Storm waves generated by winter storms associated with mid latitude depressions.
- Wind seas generated by the local sea breeze pattern from the west to southwest that are most dominant in Spring and Summer (October to April).
- Tropical/ extra-tropical cyclones that occasionally pass through Bunbury (e.g., TC Alby in 1978).

Along the Capel coast, nearshore wave conditions are to a large extent dominated by offshore waves.

At Bunbury, waves inside Koombana Bay are attenuated due to the sheltering from the Outer Harbor breakwater. The area is generally well-protected from westerly storms but shows is more exposed to northerly storms.

Wave conditions inside Leschenault Inlet and Leschenault Estuary are independent from offshore waves. For these confined water bodies, waves are primarily wind driven, subject to modulation of water depth, wind forcing and wind fetch. As storm winds are primarily westerly, stronger wind seas are more likely to be encountered on the eastern/south-eastern side of the estuary/inlet.

2.2.3.2 Extreme Wave Condition

Offshore

Lemm (1999) investigated the offshore wave climate on the southwest coast of Western Australia and noted that the offshore wave height can reach about 6.7 m and about 9.8 m for a 1 year and a 100 yrs. ARI event respectively.

ASR (2011) conducted an extreme value analysis of wave heights using 6 years of wave data obtained at Rottnest Island wave buoy. The predicted extreme waves were in general higher than Lemm (1999). The dominant extreme waves were either westerly or south-westerly with significant wave height (Hs) ranging from 9 m for 1 year ARI to ~11 m for 100 years ARI storms.

MPRA 2018 Design event selection provided a list of design storms for erosion hazard assessment which was selected using criteria of total wave power rather than extreme value analysis of highest waves. These events are used in this study for the purpose of erosion extent modelling.

Koombana Bay

Damara (2011) undertook an investigation into erosion and coastal processes affecting the eastern end of Koombana Beach as part of the preliminary design of the Point Busaco revetment. Analysis of Bunbury AWAC data (Southern Ports Authority, SPA) by Damara (2011), described in Seashore (2013), is shown in Table 2 4. The analysis is based on 14 years of data at Beacon 3 and 3.5 years of data at Beacon 10. It indicates over 55% reduction in wave heights between the two points as a result of the wave refraction and diffraction.

TABLE 2-4 EXTREME WAVE HEIGHTS AT SPA AWACS (SEASHORE, 2013)

	1 yr	2 yr	5 yr	10 yr	20 yr	50 yr	100 yr
Beacon 3	2.7	3.0	3.1	3.2	3.3	3.3	3.4
Beacon 10	0.9	1.1	1.2	1.3	1.4	1.5	1.6

Casuarina Harbour

DoT deployed two AWACs near the entrance and inside the Casuarina harbour (2015-2016). Data shows that the maximum of measured wave heights reduces from about 0.6 m near the entrance to about 0.2 m inside the harbour. Wave energy is thereby low for this semi-enclosed waterbody.

Leschenault Estuary

Damara (2020) has investigated the extreme wave conditions inside the estuary. A hindcast of wave conditions from 2011-2018 suggests a maximum significant wave height (Hs) of 0.6 m and that exceptionally strong winds are required to generate wave height above 0.7 m (>100 years ARI event). This implies a reasonably low wave energy environment for the estuary.

Leschenault Inlet

Wave information inside Leschenault Inlet is not available. The inlet is small and confined, and therefore the local wave climate is expected to be low energy and dominated by local sea waves.

2.3 Coastal Processes

2.3.1 Geomorphological Setting

Geomorphological processes drive the long-term landform evolution, and regional scale shoreline movement. The location of beach waterlines and vegetation lines changes over a range of time scales:

- At the geological scale (10,000-100,000+years), coastal change is dominated by long-term (eustatic) sea level change and large-scale geological processes primarily dealing with the location and movement of rock.
- At geomorphic scales (100-10,000 years), coastal evolution is determined by the sediment transport driven by regional and local metocean climate and sediment provenance and availability.
- Over planning scales (10-100years), sediment sources and sinks and pathways due to local landform changes and metocean climate and weather events.
- Over coastal management scales (days to 10 years), significant changes occur due to storms – generally cross-shore erosion, as well as seasonal shoreline variations that are linked to the seasonality of the local wave climate.

The geomorphological setting at the project site was described in detail in Searle and Semeniuk (1985) and Semeniuk et al. (2000). Stratigraphic profiles (Figure 2-6) show that the foreshore region consists of Safety Bay sand at the foredune, underlain by Leschenault Formation (typically below the elevation of MSL) / Becher Sand and a limestone/clay/sandy clay foundation underneath. This stratigraphic profile is generally representative for coasts between Busselton and Bunbury.

In the past 6,000 years, there have been significant shoreline variations (Semeniuk et al. 2000). At geological scales, this shoreline has a variable nature due to limited rock features and presence of mobile sand ridges.

The foreshore is generally characterised by simple offshore bathymetry, sand dunes parallel to the coast and depressions/wetlands/lakes between dune ridges. Studies have noted the presence of underlying limestone rock in some areas, but it is seldom observed above mean sea level. Outcropping basalt rock is present between Rocky Point and Casuarina Point above mean sea level at Bunbury. Beach sands are predominantly made up of quartz from re-working of Holocene deposits. Some calcareous sand is present from adjacent estuaries and seagrass beds and riverine inputs are minimal.

2.3.2 Sediment Cells

Sediment cells are spatially discrete areas of the coast within which marine and terrestrial landforms are likely to be connected through processes of sediment exchange, often described using sediment budgets. Sediment cells are used to assist coastal planning, management, engineering, science, and governance along the coast.

The project domain comprises multiple sediment cells including R06A-3(c, d), R06A-4 (a, b) and R06B-5a (Stul et al, 2015). A summary of sediment cells is provided in Table 2-5 below and in Figure 2-7 to Figure 2-9.

TABLE 2-5 SEDIMENT CELL SUMMARY (STUL ET AL, 2015)

Sediment Cell	Study Area	Geomorphological Feature
R06A-3d	Forrest Beach to the mouth of Capel River, up to -15 depth offshore	Broad shallow waters and sandy beaches; Parabolic dunes or frontal dunes; Land depression behind the dune.
R06A-4a, b	The mouth of Capel River to Bunbury Harbour, up to -15 m depth offshore	Narrow parabolic dunes or frontal dunes; Land depression behind the dune.
R06B-5a	Koombana Bay, up to -15 m depth offshore	Estuarine landforms, flood-prone land with installed mitigation works; Rock structure restricting sediment transport; Adjacent cells have a different shoreline aspect; Presence of engineered structures.

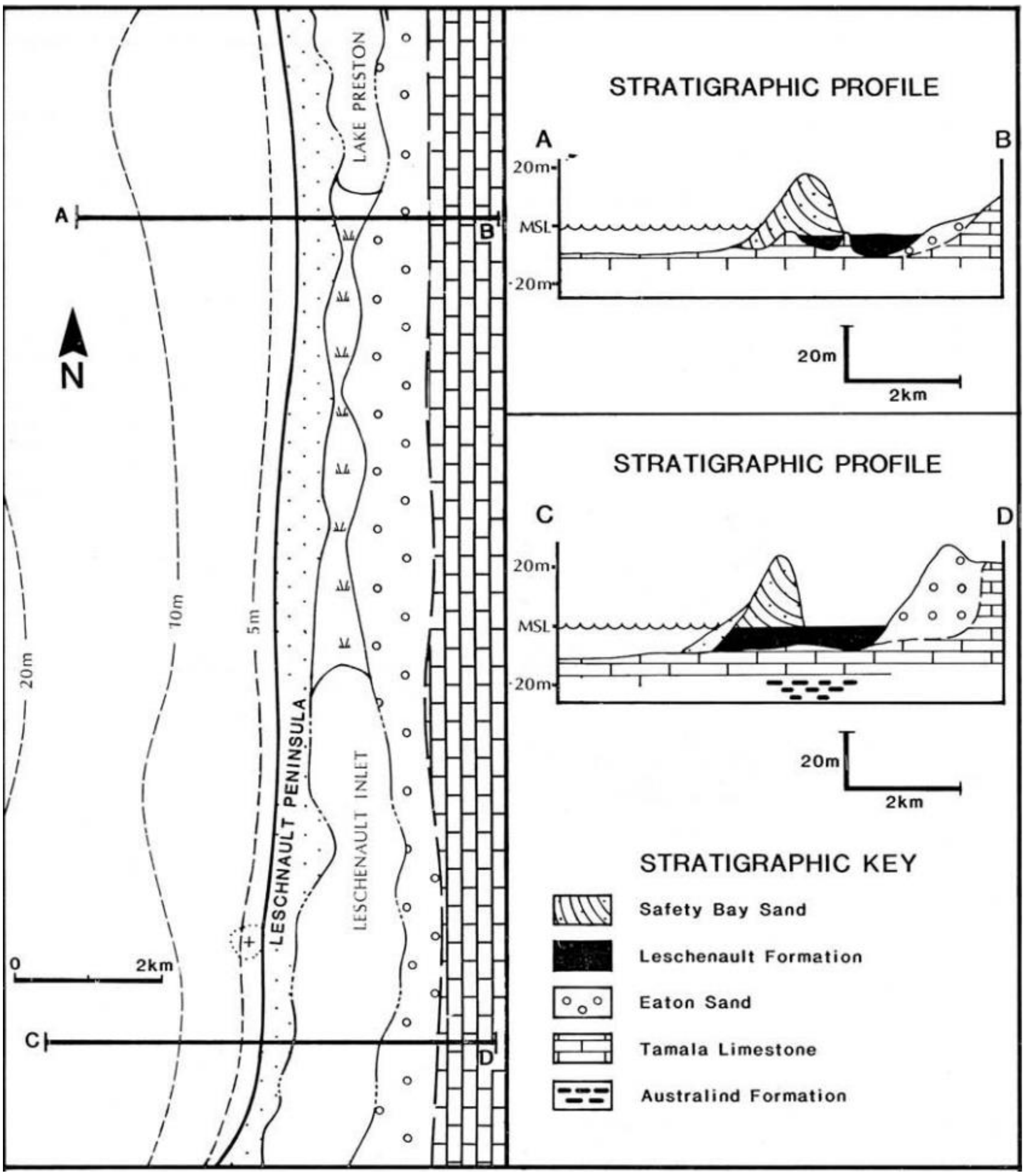


FIGURE 2-6 REGIONAL MORPHOLOGY AND STRATIGRAPHIC PROFILES (SEARLE AND SEMENIUK (1985))

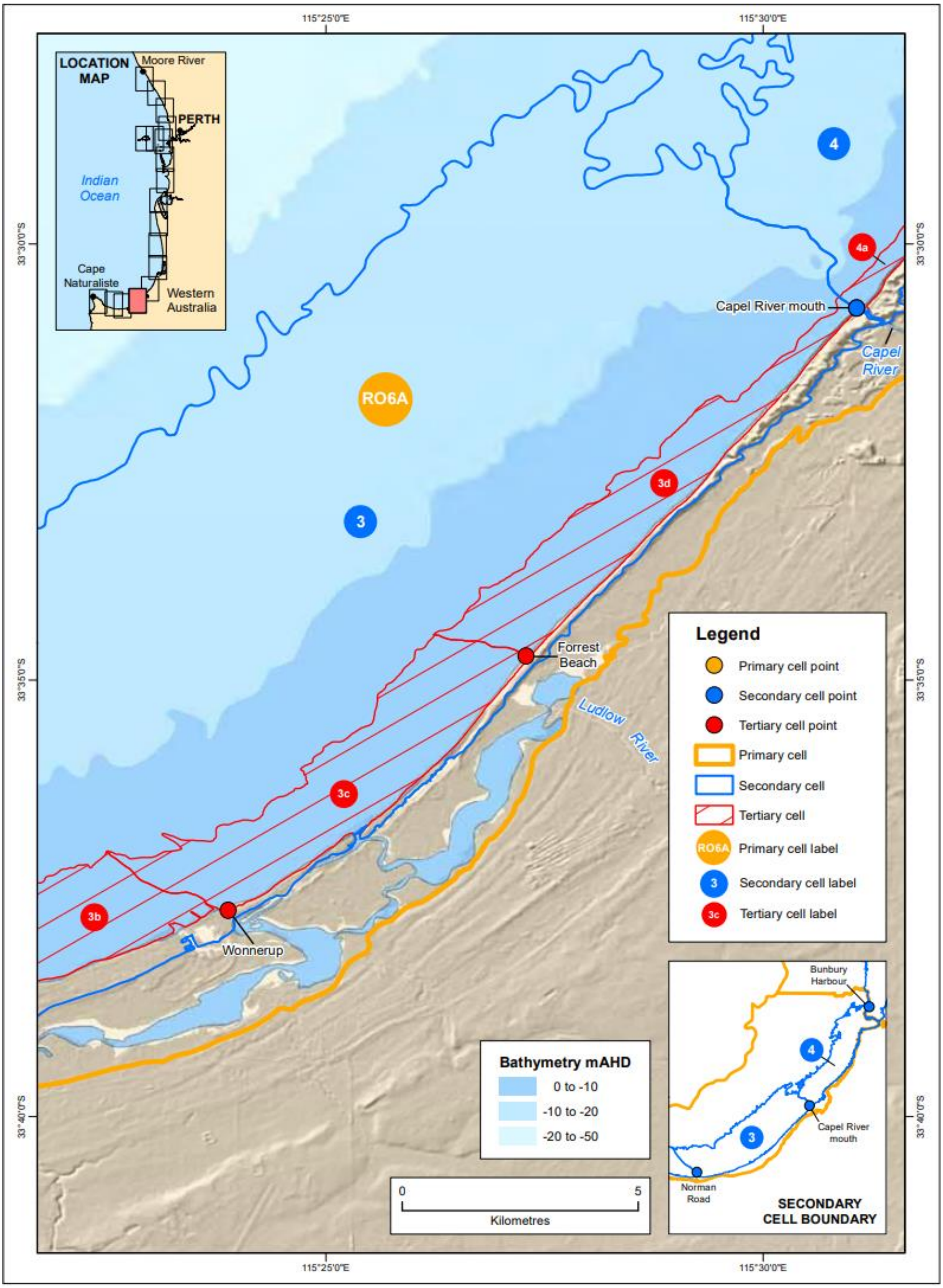


FIGURE 2-7 SEDIMENT CELL (WONNERUP TO PEPPERMINT GROVE BEACH). IMAGE SOURCE: STUL ET AL (2015)

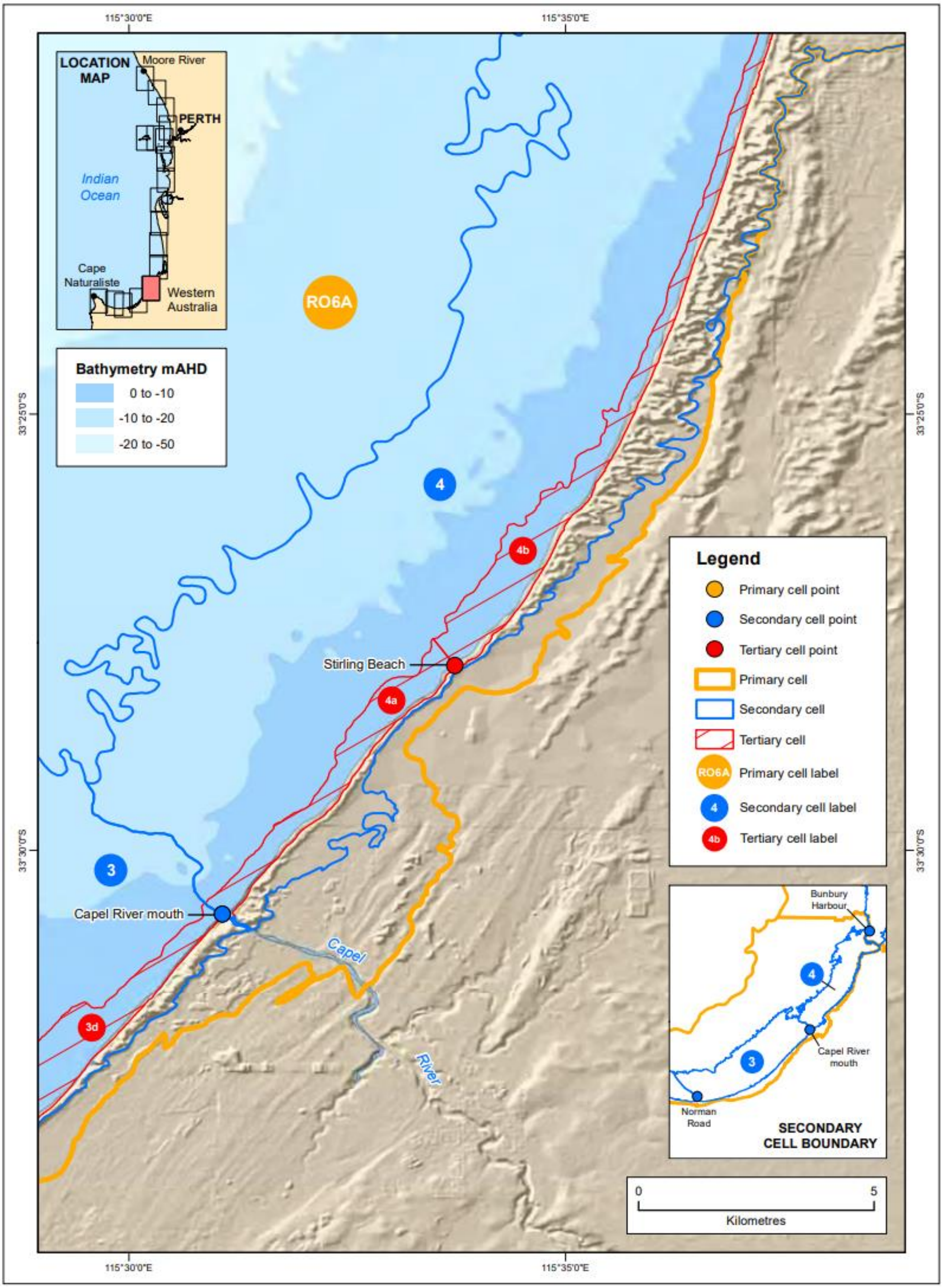


FIGURE 2-8 SEDIMENT CELL (CAPEL)). IMAGE SOURCE: STUL ET AL (2015)

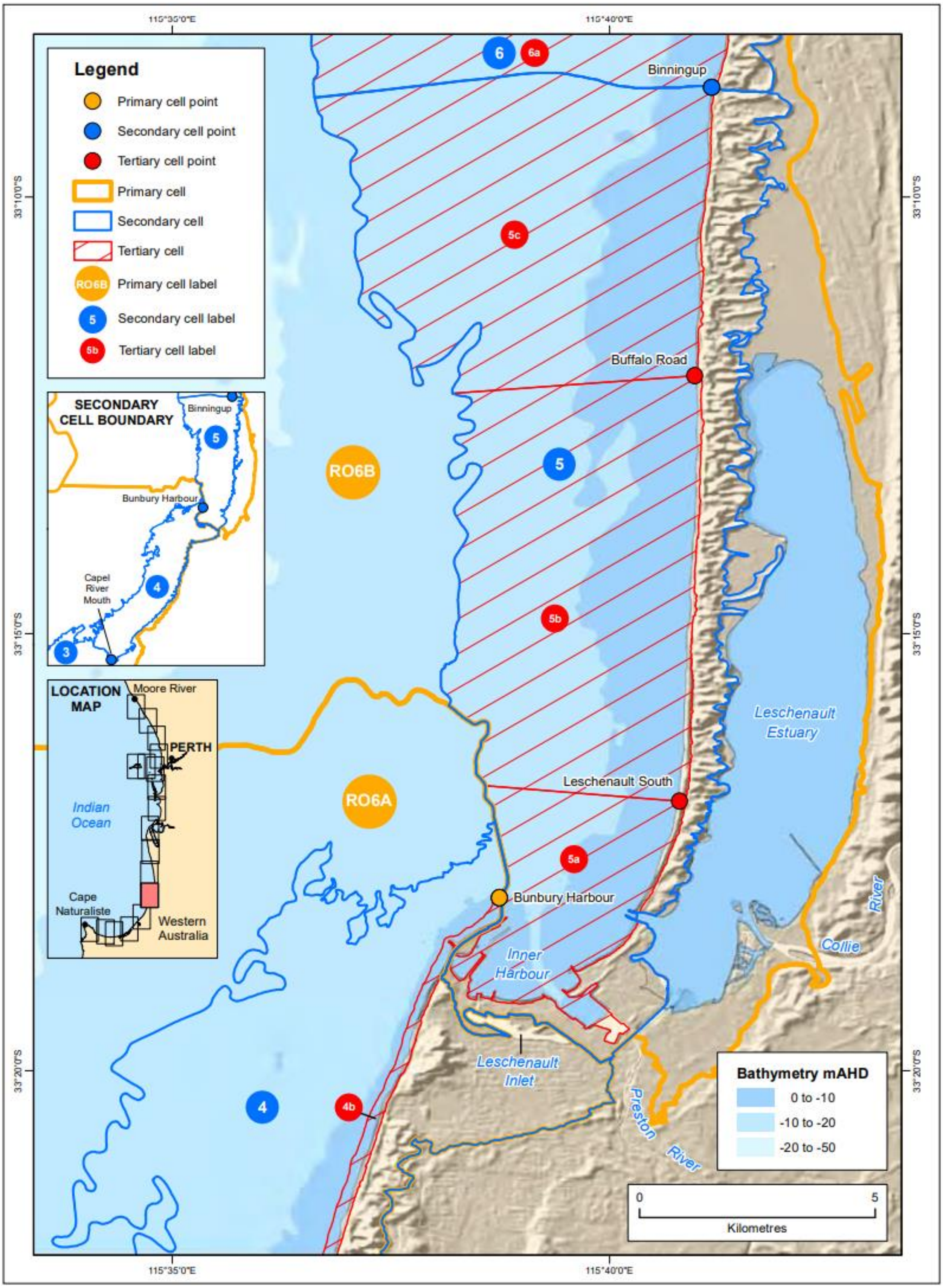


FIGURE 2-9 SEDIMENT CELL (BUNBURY TO LECHENAULT ESTUARY). IMAGE SOURCE: STUL ET AL (2015)

2.3.3 Sediment Transport and Local Morphology

The alongshore sediment transport within the project domain predominantly flows in a northwards direction, driven by the dominant westerly/south-westerly swells throughout the year. Temporary southwards longshore transport may be experienced during a storm generating northerly winds and waves – and these may occur in both winter and summer (less likely) months.

The dynamics of beach formation and local scale morphological changes have been assessed through the review of historic reports and aerial imagery sourced from Google Earth and Metro Map (high resolution) for key locations in the study area from south to north.

2.3.3.1 Peppermint Grove Beach

Morphological changes along Peppermint Grove Beach (Table 2-6) have been reviewed with results summarised as:

- Capel River mouth experiences occasional breaches. The location of the river mouth is generally stable, but this is understood to be influenced by occasional active management by the Water Corporation
- Beach width variation has been observed. Some significant storm erosion was experienced close to the river mouth as shown in 2005 image.
- In general, there was no clear observation of significant net long-term erosion or accretion. Vegetation line is stable and consistent over the past 16 years.

TABLE 2-6 SATELLITE IMAGES – PEPPERMINT GROVE BEACH

 2005	 2011

2014

2021

2.3.3.2 Dalyellup Beach

Review of satellite images (Table 2-7) shows variation in beach width likely associated with seasonal fluctuations. The current beach is wider than year 2017 and 2013 while slightly narrower than 2005. Land development has progressed in the last 16 years, while vegetation over the foredune was not affected.

TABLE 2-7 SATELLITE IMAGES – DALYELLUP BEACH

2005

2013

 2017	 2021

2.3.3.3 Bunbury

Ocean Drive, Casuarina Breakwater and the Outer Harbour

Sediment transport along Ocean Drive is similar in nature to Capel Coast due to its exposure to a similar wave climate.

Basalt rock outcrops at Point Casuarina have stabilised the shoreline and contributed to a wide beach along Bunbury Back Beach on the southern side of Wyalup Rocky Point. Sand has accreted against the spur groyne, north of Rocky Point, reflecting the northwards littoral drift. Some sediment has bypassed the groyne and deposited against the Casuarina Breakwater near McKenna Point. This has created a pocket of sand against the breakwater. Sediment within this pocket is relatively stable during calm periods, but can be mobilised by a southerly storm which may transport the sand further north and around the head of the breakwater. It is one of the main sources of sediment feeding into the outer harbour and Koombana Bay. The shipping channel and its associated maintenance dredging is likely to act as a barrier to net sediment movement from south to north in the outer harbour.

Satellite images show loss of beach width in 2010 by storm erosion (see Table 2-8). The beach face gradually recovers in the following years. The widest beach was evident in 2020 (slightly wider than year 2017 and 2005) while significantly wider than year 2010. There was no clear trend of shoreline movement in the past 16 years.

Several seawalls provide some additional protection to key assets along this section of coast, primarily at Bunbury Back Beach. This includes buried and exposed seawalls that are understood to be protecting the café, surf life-saving club and associated car parks. Design drawings have been provided by City of Bunbury which are factored into the development of erosion hazard lines.

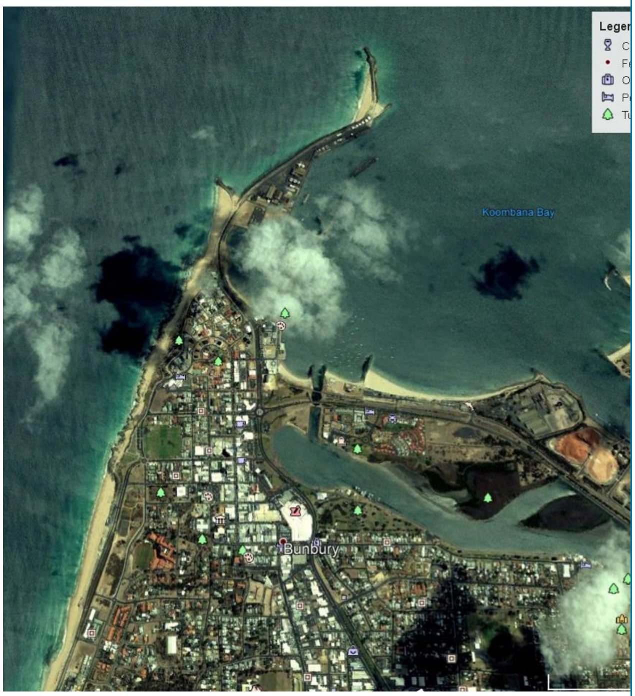
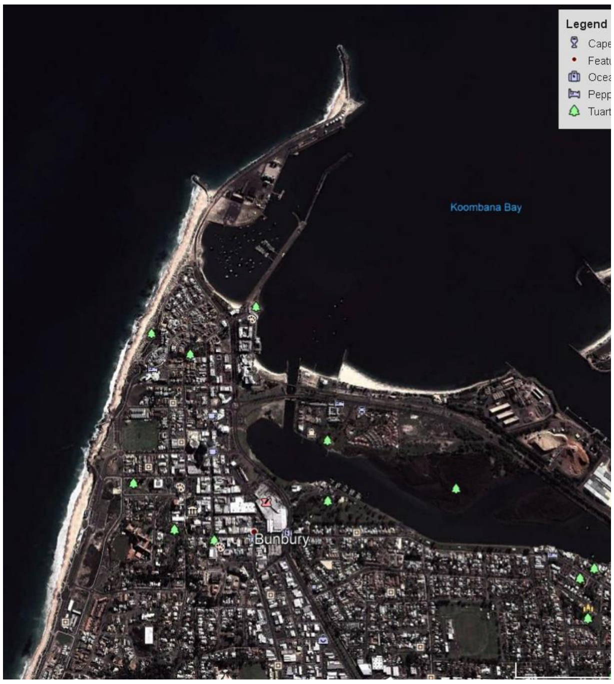
Jetty Baths Beach & Ski Beach

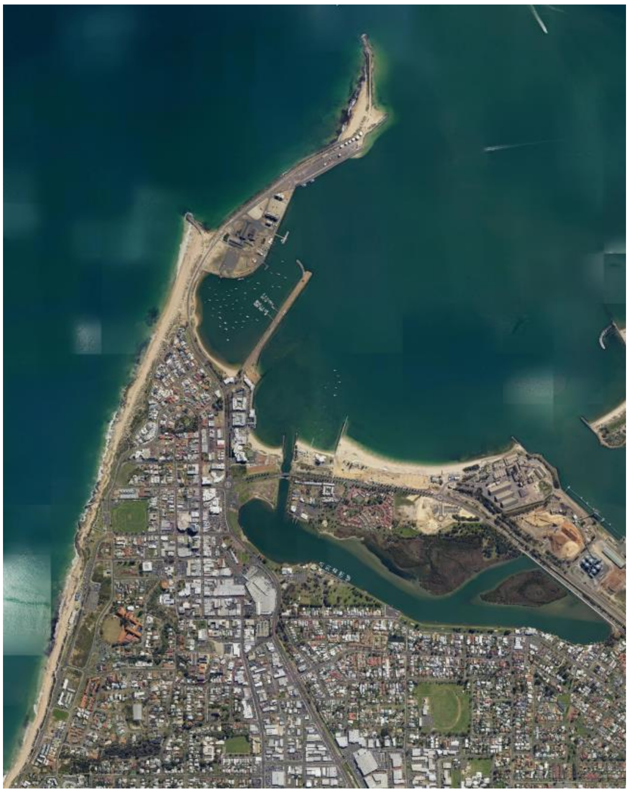
Jetty Baths Beach and Ski Beach have been stable according to the satellite imagery (Table 2-8). This is likely determined by:

- Lower wave energy environment when compared to Koombana Beach, Back Beach and other more exposed sites.

- These two beaches have been isolated by physical controls (Jetty Road, between Marlston Waterfront and the Plug groyne) and formed local scale sediment cells.
- Relatively coarse sediment grain size at Jetty Baths Beach and Ski Beach. GHD (2019) took four sediment samples from Ski Beach to assist a coastal stability and setback review for the Koombana North development. Sediment grain size were consistent at all sites with D_{50} values between 0.35 and 0.4 mm. This is coarser than sediment sampled at Koombana Beach (GHD 2019).

TABLE 2-8 SATELLITE IMAGES - BUNBURY

 2005	 2010

 2017	 2020

Koombana Beach

Sediment transport along Koombana Beach has been investigated by Seashore (2013) and then again reviewed by GHD (2019). Both studies suggest that the net sand transport along Koombana Beach was westwards. Review of these two studies suggests:

- Significant accretion was observed along the western portion of the beach. This has been concluded based on monitoring programs undertaken during 1991-2009 and 2009-2012. There was weak erosion at the western side during 2009 and 2012 which is not considered significant.
- The eastern portion experienced continuous erosion as also noted by the monitoring program.
- The estimated littoral drift rate is in the range of 1000-2000 m^3/yr, with rates varying by chainage along the beach and also by year.
- Storm erosion was investigated by GHD (2019) which has identified some erosion potential (6 to 20 m of horizontal erosion for a 100 yrs. ARI storm relative to the current shoreline).

Koombana Beach has been heavily engineered, consisting of groynes on both ends of the beach, the Point Busaco Revetment protecting the eastern side of the beach, a buried rock revetment protecting the Dolphin Discovery Centre in the centre of the beach, as well as various concrete and limestone edge treatments along the western portion of the beach as part of the 2017 foreshore redevelopment. All these coastal structures had and will influence the morphology of Koombana Beach into the future.

Koombana Beach forms a local scale sediment cell for which beach sands are trapped between groynes for most periods of the year. Sediment may be lost through cross shore sediment transport during storms and bypass of sands across the groynes.

Leschenault Inlet

Within Leschenault Inlet, the shoreline is either protected by rock revetment (on southern, eastern and northern sides) or mangroves habitats (on the north-eastern side of the inlet). Segments of sandy coast are present in the vicinity of Bunbury Boat Ramp (near the plug training wall). Review of satellite images show minimal changes in landforms in the inlet.

For such a low wave energy environment, sediment mobility is low even during the stormy season. The City of Bunbury undertakes minor maintenance of the Sykes Foreshore beaches through sand replenishment and is currently considering future management options. Other than this, no severe erosion has been reported according to document review.

2.3.3.4 Leschenault Estuary

A number of historic studies (Semeniuk et al. 2000, Damara, 2020) have been undertaken to evaluate the changes of the foreshore in Leschenault Estuary. Findings are summarised below.

- Human activities and engineering works have substantially affected the estuary environment (mostly done before 1970s). These activities have formed the base of the current landform, particularly on the southern side near the inner harbour.
- Construction of the Cut entrance in the 1950s, with substantial influx of marine sediment to form a flood sill (Colman 1983), an ebb sill and more recent breach of training wall (MP Rogers & Associates 2015).
- Division of the estuary basin into Leschenault Inlet and Leschenault Estuary (1970s).
- Activities associated with mineral sands processing and disposal of pigment plant by-products to the Leschenault Peninsula area via pipeline over the estuary.
- Capital and maintenance dredging of Collie River through to the Cut.
- Construction and development of canal estate subdivisions toward the southern end of Leschenault Estuary.
- Morphological changes after 2000s: Damara (2020) has undertaken a detailed review of Leschenault Estuary morphology using both survey information and aerial images (refer Figure 2-10), showing that:
  - Very limited changes on land.
  - Accretion at the northern extent of the estuary.
  - Some significant changes adjacent to the channels, the Cut, Collie River and Preston River. Weak accretion was found near Preston River Delta and the mouth of Collie River due to riverine sediment inputs. Light erosion was found immediately to the south of Collie River mouth. Bed level changes near The Cut are rather complex, comprising a mixture of erosion and accretion of the channel and flood/ebb sills.
  - Small bed level changes along the riparian boundary in order of 0.2 m-0.4 m for the southern portion of the estuary over the period of 2005-2018. Note that this difference is in the same order of magnitude as the uncertainty level of LiDAR Survey (band error in the range ±0.2 m).
  - Some changes may have been influenced by activities such as maintenance dredging and spoiling of sediment.

Overall landforms of the Leschenault Estuary have not changed much since the early 2000s. Some areas were identified to have weak accretion (northern side), while others were found to experience weak erosion. The changes are not significant enough to draw a conclusive erosion/accretion pattern of the region. Overall sediment transport rate is low inside the estuary, except near the mouth of Collie / Preston River (riverine inputs) and at The Cut entrance.

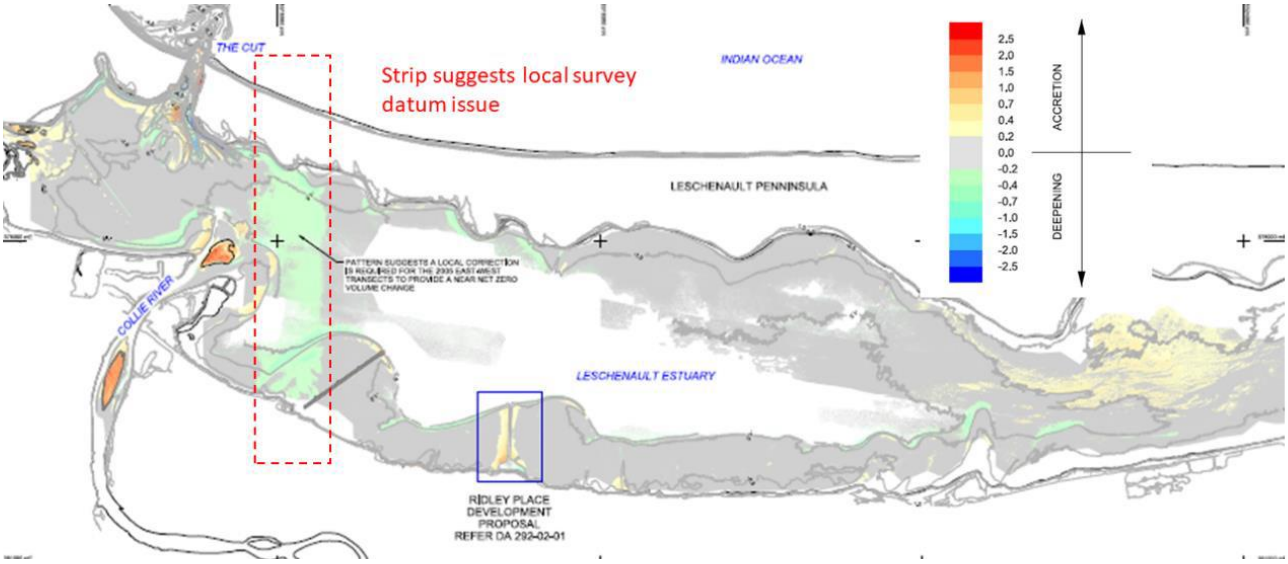


FIGURE 2-10 LESCHENAULT ESTUARY BATHYMETRY DIFFERENCE (2005-2018, PLOT SOURCED FROM DAMARA, 2020)

2.3.3.5 Riverbank Erosion

Preston River

Satellite images show a generally consistent river course (Table 2-9). Kalgulup Regional Park has been established by DBCA and includes the banks of the Collie and Brunswick Rivers, the Leschenault Peninsula, Maidens Reserve and associated nearby reserves, and also along the course of the Preston River bounded by soil embankments/roads located at up to 200 m distances from the riparian boundary.

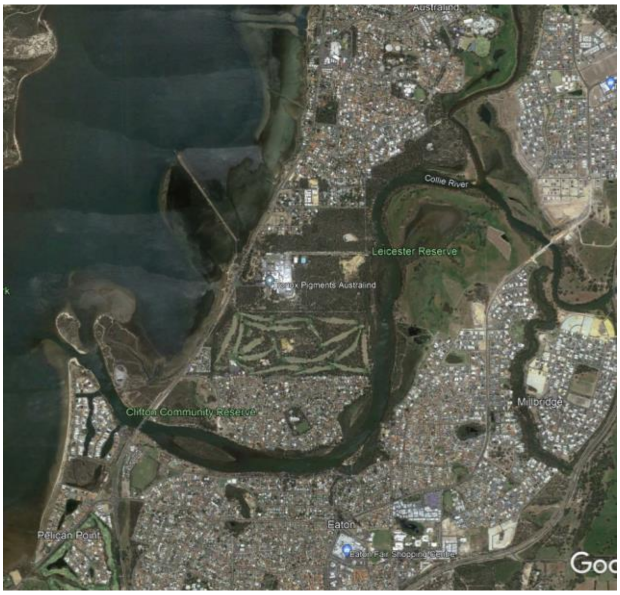
Preston river has been historically re-aligned will flood levees constructed up to the South-Western Highway. Riverbank/Riparian zone condition summaries were not presented in literature provided.

Collie River and Catchment Area

Seashore (2020) has investigated the riverbank condition along the lower section of Collie River (affected by both riverine and oceanic forcing). As per their site inspection, most of the foreshore is in moderately degraded condition. While there is a broad range of foreshore management works, many areas have not been engineered.

Further upstream, riverbank morphology is dominated by riverine processes. Healthy vegetation growth is found along the middle and upper riverbank including both primary and secondary branches, forming a barrier to prevent riverbank erosion. Riverbank condition is however unknown due to lack of reported information. Satellite images show that the location of riparian zone did not change significantly in past 20 years, indicating generally low energy along the course of Preston, Wellesley and Brunswick Rivers.

TABLE 2-9 SATELLITE IMAGERY – PRESTON/COLLIE RIVER

2005	2018
	
	

2.4 Existing Coastal Monitoring and Management

2.4.1 Coastal Monitoring

Coastal monitoring activities in the study area include the following:

- Beach width measurements
- Dune measurements

- Oblique aerial photos
- Field photographs

Beach width and dune measurements

The PNP currently undertake annual monitoring of primary dune positions in a number of locations, and monthly beach width monitoring across the study area. Dune monitoring is undertaken within the local government area (LGA) of Bunbury (commenced in October 2017) and some data was gathered in the Harvey and Capel LGAs. Previous studies note the dynamic nature of the local sand dunes and the role of unvegetated dune blowouts in shaping the local foreshore landforms.

PNP coordinate the undertaking of beach width monitoring at several locations within the LGAs (https://www.peronnaturaliste.org.au/projects/monitoring-project/): Harvey (11 sites), Bunbury (8 sites) and Capel (6 sites) at approximately monthly intervals and have done since March 2017 (Figure 2-11). The beach widths are measured by LGA officers using handheld GPS or tape measure from the dune toe. This location is determined by observing the waves for several minutes and locating the approximate mid-point between the highest level on the beach that the water reaches and the lowest level that the water recedes. This method does not correct for water levels (i.e., during the periods of higher water levels the beach appears narrower although sand may not have eroded) but is undertaken at low tide (if practicable) for consistency and is useful to monitor long term behaviour of the beach and to compare between sites. As per Figure 2-11, beach widths have varied by between 10-120m at the sites between March 2017 and March 2021, but typically are constrained to changes within a 10-30m envelope seasonally and intra-annually.

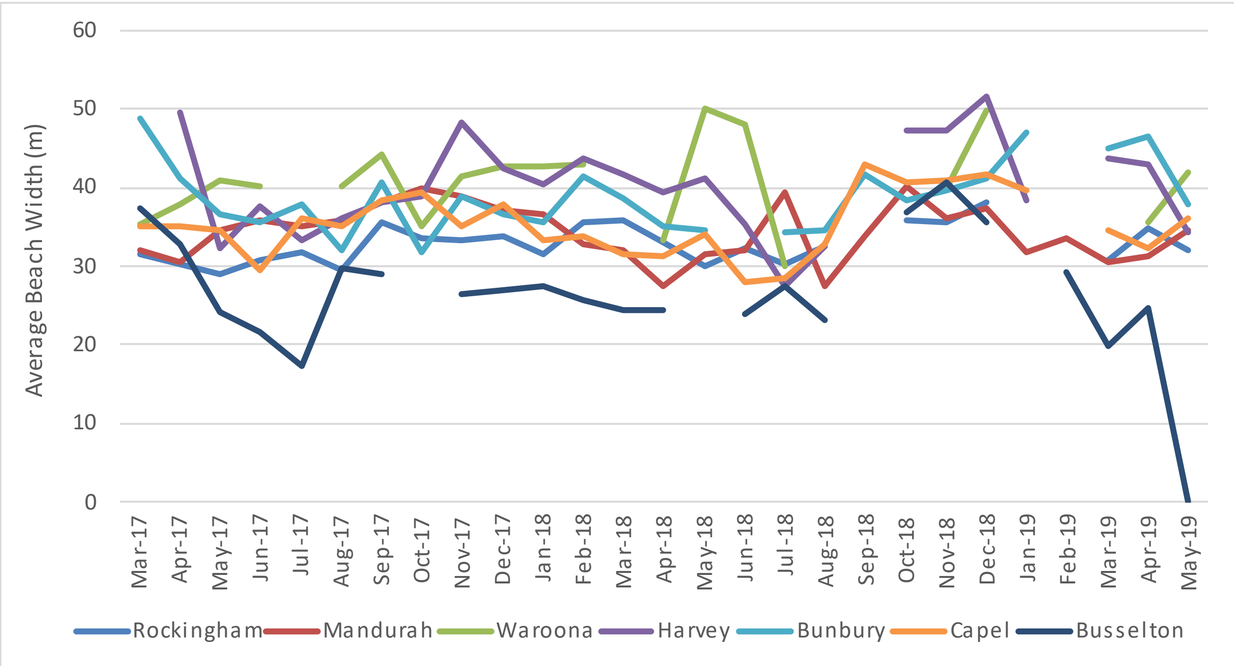


FIGURE 2-11 AVERAGE (BY LGA) OF BEACH WIDTH MEASUREMENTS COORDINATED BY PNP FOR MARCH 2017 TO MAY 2019 (SOURCE: PNP)

Oblique aerial photos

The University of Western Australia (UWA) in collaboration with the PNP collect oblique aerial photos approximately twice per year and have done since December 2014 (UWA, 2021; Figure 2-12). The bi-annual photos provide a qualitative means of assessing seasonal and longer-term coastal change. With more advanced processing the photos may also be able to be used to derive quantitative information. Prior to 2017 the photos were taken using a point-and-shoot camera by PNP staff from a helicopter. Beginning in 2017 the photos were taken by UWA as geo-tagged photos collected from a helicopter flying at approximately 300 m elevation and 300 m offshore.

FIGURE 2-12 EXAMPLE OBLIQUE AERIAL PHOTO COLLECTED BY UWA FOR PNP AT PORT OF BUNBURY INNER HARBOUR - JUNE 2020.

Beach field photos

PNP coordinate the collection of approximately monthly field photographs whilst undertaking beach width measurements (described above) and at the same locations. In general, four (4) photos are collected at each site – one in each direction at the mid-point (between waterline and dune toe) and at the dune toe (Figure 2-13).

FIGURE 2-13 EXAMPLE BEACH FIELD PHOTOS FROM SEDIMENT CELL R06A4A IN SHIRE OF CAPEL 20/5/2021, COLLECTED AT SAME TIME AS BEACH WIDTH MEASUREMENTS.

CoastSnapWA is a coastal monitoring program which uses photos taken by community members on smart phones from fixed marker points which determine their field of . These photos are then uploaded, shared via social media and / or emailed to a database where, in addition to providing qualitative information of the along-coast morphology and beach state, beach width measurements and shoreline position are extracted. (UWA, 2021; Figure 2-14). There are three (3) CoastSnapWA sites in the study area at Dalyellup, Koombana Bay and the Collie River foreshore.

FIGURE 2-14 EXAMPLE COASTSNAPWA PHONE CRADLE (LEFT) AND EXAMPLE PHOTO FROM THEIR DALYELLUP SITE

2.4.2 Coastal Management Activities

The land managers currently care, control and maintain the foreshore and the assets within it by undertaking the following:

- Management of the foreshore amenities, car parks, boat ramps and associated infrastructure including dual use paths. This includes maintenance, rubbish removal, cleaning.
- Coastal monitoring activities in collaboration with PNP and subcontractors – outlined earlier in this document.
- Patrols by LGA Rangers of foreshore area and beaches.
- Coastal revegetation programs depending on sourcing grant funding and support from community groups and members such as local schools.

- Operation and maintenance of the Bunbury Storm Surge Barrier.
- Beach replenishment of heavily eroded sections of beach via occasional sand renourishment (e.g. via City of Bunbury).
- Management and maintenance of coastal structures (breakwaters, groynes, seawalls).

2.5 Existing Coastal Hazard Documentation

2.5.1 Coastal Erosion

2.5.1.1 Coastal Erosion Hotspots

There are two known erosion hotspots of state significance along the study area's coastline according to the WA Department of Transport (DoT) state-wide assessment (Seashore Engineering 2019):

- Koombana Beach
- The Cut

Koombana Beach was substantially re-formed in the 1970s as part of the inner harbour and estuary works. The beach was created from dredged sand and has a history of erosion at its eastern end and accretion at its western end (i.e., clockwise rotation) (Seashore Engineering 2019). There is a partially buried rock revetment at the eastern end of the beach to protect SPA infrastructure. There is a buried seawall in front of the Dolphin Discovery Centre. The beach itself is at risk from ongoing erosion and severe events as are the sections of foreshore not protected by revetments. The medium to longer-term risk is that no dry beach will be available for recreation for large parts of the years and erosion of foreshore infrastructure.

The Cut is a drainage channel excavated in the 1950s by the then Public Works Department to provide drainage from the estuary and associated rivers to the ocean (Seashore Engineering 2019). Rock revetment training walls were constructed in subsequent decades to stabilise the channel. In 2012 the northern training wall failed allowing sand from the northern beach to migrate into the channel. DoT undertook emergency repair works in 2014 but this is an orphaned asset from the Public Works Department and the management responsibility for the structure and channel have never been resolved. The beach to the north has a net erosion trend so in future years sections of the northern training wall will become impacted by wave action from the northern side – not what the wall was designed for. The channel is used for boating despite this never being the intent of the structure because of the presence of navigation hazards (mobile sandbars).

There are also three watchlist locations in the study area, W24 at Ocean Drive in Bunbury from Hastie Street to Scott Street; W25 at Peppermint Grove Beach and W26 at South Forrest Beach, both in the Shire of Capel (Seashore Engineering 2019). There is only a narrow beach and dune buffer seaward of infrastructure in these locations.

2.5.1.2 Other Coastal Erosion Hazard Information

Damara (2012) prepared regional erosion hazard lines to 2110 under contract to the Peron Naturaliste Partnership to consider the potential economic impact of coastal hazard risk. The lines were not prepared in accordance with SPP2.6, instead utilising a geological regional recession study which focused on sediment transport between the coast and continental shelf. As such they are not directly comparable hazard lines determined by other methods. They do however provide useful background information and represent what erosion could be possible over the next 100 yrs.s and the variability associated with these types of projections.

More recently GHD (2019) determined erosion hazard lines for the sandy sections of Koombana Bay, as well as Casuarina Beach, in accordance with SPP2.6. Hazard lines were determined for present day (2018), 2030, 2070 and 2120. This information will be used to compare and cross-check erosion hazards for the broader study area.

Damara (2020) assessed the erosion hazard risk for part of the Leschenault Estuary's eastern shoreline using a local case conceptual model based upon observations at the Ridley Place study area and expectations of future behaviour for similar low-energy estuary beaches.

2.5.2 Coastal Inundation

In 2012 Damara prepared mapping depicting the potential extents of coastal inundation for the Peron Naturaliste Partnership to consider the potential economic impact of coastal hazard risk. The inundation determinations were broadly prepared in accordance with SPP2.6 and have been included as extreme water level information in Section 2.2.1 of this report.

Inundation extent was considered for Koombana Bay by GHD (2019) and mapped for sections of Koombana Bay and Casuarina Beach. Damara (2020) reviewed extreme water levels to inform hazard characterisation of the Leschenault Estuary shoreline. The relevant extreme water level information from both studies has been included in Section 2.2.1 of this report and considered when determining the inundation hazard for the broader study area.

There were two potential inundation hotspots identified along the study area's coastline according to the DoT's state-wide assessment (Seashore Engineering 2019):

- Australind town
- Bunbury CBD

The assessment was not systematic or exhaustive as the study's focus was on erosion.

3 COASTAL HAZARD ASSESSMENT METHODOLOGY

3.1 Study Framework

The coastal hazard identification approach has been developed based on the following policies and guidelines:

a. State Planning Policy 2.6 State Coastal Planning Policy (SPP2.6)

b. Coastal Hazard Risk Management and Adaptation Planning Guidelines (CHRMAP Guidelines)

c. State Planning Policy 2.9 Water Resources (SPP2.9)

3.2 Study Limitations

The study area covers a complex shoreline with various types of coastal hazards present in this region. The presence of rivers, an estuary and inlet has increased the complexity of the study, in particular the assessment of inundation hazards where river flood plays a more dominant role than the intrusion of ocean water.

It is acknowledged that the hazard identification component of the present study has been undertaken to provide a broad understanding of exposure than can support government planning at a regional level - and will be superseded once site-specific studies become available, in particular at the estuary/inlet and along the river courses. Results derived from this study should not be over-interpreted at a micro-scale due to the assumptions applied and the limitations in model resolution. More detailed risk assessments and analysis may be required for the development of detailed engineering measures for specific sites e.g., erosion control along a riverbank that requires geotechnical investigation. Also, the Department of Water and Environmental Regulation (DWER) may have their own additional planning policies implemented over river courses, for which a CHRMAP study does not usually cover. Outcomes of this coastal hazard assessment should not affect the implementation of any existing polices. Water Technology will be cognisant of the limitations of this assessment in the development of adaptation options, and highlight the trigger points for which options should be implemented in the CHRMAP implementation plan, rather than relying on the timeframes indicated by the coastal hazard assessment results.

No geophysical or geotechnical assessments have been undertaken across the study to date. Erosion response across the study area may differ in reality to the predictions of this study due to the lack of data. Further geophysical/geotechnical assessment will be a recommendation of this CHRMAP.

3.3 Horizontal Shoreline Datum

The horizontal shoreline datum (HSD) is defined as the active limit of the shoreline under storm activity. It is the line from which the erosion hazard allowance will be applied from. In this assessment HSD has been determined by:

- Present day vegetation lines which often characterise the upper limit of seasonal storm impacts. The vegetation line can be difficult to establish within a reach where there are seasonal beach variations.
- Elevation of the 100-year ARI Peak Steady Water Level (about 1.7m AHD for 100-year ARI storm). For open coast, a 2 m AHD elevation is generally appropriate to outline the potential unimpacted area for typical winter storms if vegetation lines are deemed too conservative for hazard mapping.
- For estuary environments with the presence of large tidal flats and vegetation growth, a conservative approach is used to define the HSD as the limit of storm inundation or riparian boundary as the HSD boundary.

The HSD line is included in the erosion hazard maps.

3.4 Erosion Hazard Study Approach

SPP2.6 (WAPC, 2013) has provided a clear guideline for evaluation of erosion hazards within the reach of tidal impacts. It stipulates the following components be considered when evaluating the coastal erosion risk:

- Storm erosion in response to storm waves and loss of beach material.
- Historic shoreline movement that highlights the chronic/long term evolution of the coast. This could be contributed by littoral drift processes, larger scale morphological movements, long-term water level/wave dynamic variations (~18.6 yrs. tidal cycle, interannual climate oscillations e.g., La Niña effects, Pacific Ocean decadal Oscillation etc.) and climate change impacts (SLR, more intense storms and rainfalls etc.).
- Direct response to future sea level rise.

SPP2.6 indicates the methods for determining the allowance for erosion for a sandy coast are derived principally for open coastlines. For erosion on tidal reaches of inland waters, allowance should be assessed in a site-specific context, with the methodology to be developed appropriately for each site.

Model tools are demonstrated in Appendix C and Appendix D.

3.4.1 Open Coast

For open coast sections of the study area, the assessment of erosion risk was undertaken as per SPP2.6, which has documented a standard approach to undertake the coastal hazard assessment. This includes a clear definition of the Horizontal Shoreline Datum (HSD), erosion allowances as well as storm scenarios to be modelled.

- As per SPP2.6, HSD is defined as the active limit of the shoreline under storm activity. More practically, this will be defined by topographic contours (upper limit level of wave action) and compared to the vegetation line (area not constantly affected by storms) in aerial photographs to ground-truth this value.
  - This is roughly 2m AHD, with some manual adjustments to the vegetation whenever considered appropriate across the study area.
- Allowance for the current risk of storm erosion (S1) estimated by use of the SBEACH storm erosion program, with consideration of longshore processes contributing to storm erosion risk.
- Allowance for historic shoreline movement trends (S2) estimated by analysis of historic vegetation lines.
- Allowance for erosion caused by sea level rise (S3) through application of the Bruun Rule, as per SPP2.6
- Uncertainty allowance as per SPP2.6
- Additional consideration for landform stability in accordance with larger scale sediment mobilisation
- Consideration to erosion controls in place whenever appropriate

There may be some local effects of occasionally exposed rock outcrops at some beaches in the study area including Peppermint Grove Beach, Dalyellup Beach, and Bunbury Back Beach. These local effects are considered at a broad scale through review of landform stability in accordance with larger scale sediment mobilisation. A conservative approach is used in the absence of detailed geotechnical investigations, and we believe this is appropriate for the purpose of planning projects. A recommendation of geotechnical investigations will be provided as an outcome of this CHRMAP.

3.4.2 Leschenault Inlet

The shoreline within Leschenault Inlet has a secondary risk of erosion due to the presence of foreshore controls and small wind fetch for development of erosive storm waves (less than 0.3 m for typical winter storm).

At present day, wave induced erosion is relatively minor, given the small waves inside the inlet even during severe storms. Under future SLR, the area will likely still be sheltered unless the entire foreshore of Koombana Bay is eroded. It is therefore not envisaged that there will be significant erosion risk inside the inlet, if the existing seawall was designed to standards with ongoing maintenance/management. It is possible that the existing seawall may require maintenance and upgrades to reduce overflow of flood water under the impact of climate change. Future erosion risk will likely be determined by overtopping of seawater over the crest and across the road which is investigated separately by the inundation hazard assessment. The mangrove habitat to the north of the inlet may encounter additional permanent inundation and shoreline retreat; and such impact is investigated in the context of coastal inundation as well. Due to the presence of the existing walls, and the proximity of development around the inlet, it is assumed these physical controls will remain in place for the planning timeframe. The existing seawalls (limestone /concrete) are designed for erosion protection under present day conditions, and will likely be suitable into the near future with minimal maintenance requirements, given the small storm waves in such a confined water body (about 200m in width and 2 km in length). Future seawall upgrades may be required to mitigate inundation risk under increasing sea level. These upgrades (no existing drawings) are not considered in inundation/coastal process modelling but will be re-evaluated in the development of adaptation options, together with the potential upgrade of the storm barrier.

The extent of erosion hazard is determined by the contour of permanently tidal inundated area relative to the current shoreline position (HAT plus future SLR, e.g. 1.5 m AHD in 2120).

3.4.3 Leschenault Estuary

The shoreline within Leschenault Estuary has a moderate risk of erosion due to the larger fetch (distance available for wind to blow over water and generate waves) and lack of physical controls. From literature review, wave heights inside the estuary can be up to 0.7 m high, subject to wind conditions and storm surge level. The extent of erosion hazard is assessed through a combined estimate of erosion potential (in line with S1 erosion allowance of the open coast) and increased frequently inundated zones from future SLR.

S1 is assessed in line with the SPP2.6 methodology. The approach is slightly modified to represent local conditions for S2 and S3:

- The assessment of S2 allowance is based on review of satellite images (high resolution images from Metro Map) rather than DoT vegetation lines (not available for the estuary). The review has shown much of the estuary foreshore is dynamic and subject to negligible changes, in particular on the northern side. For these areas, S2 allowance may not be considered.
- River mouths are treated separately. Dynamic areas at the delta are excluded from the existing shoreline.
- The Bruun Rule that applies to open sandy coast cannot capture landform/geomorphological effects in an estuary environment. The shoreline response to SLR is evaluated using a site-specific approach:
  - Excluding delta/tidal flat areas under active development from the present HSD.
  - A fixed erosion allowance for S3 as per SPP2.9 (WAPC, 2006) for S3 (i.e., a foreshore reserve of 50 m in 100 years for estuary water).

Refer Table 3-1 for summary of this process.

3.4.4 Riverbanks

Riverbank erosion is an important geomorphological phenomenon in the fluvial and estuary environment. It is often affected by river hydraulics, natural meandering of river courses, sediments, geotechnical conditions of the bank as well as presence of vegetation etc. Riverbank erosion generally starts as a slow process, however once accumulated it may cause detrimental impacts to the surrounding environment. Unfortunately, there is no established method to evaluate the risk of riverbank erosion in the CHRMAP context. In most cases, the assessment would depend on historic riverbank movements and geotechnical investigation(s).

Given these is no straightforward and universal approach for such assessment in relation to coastally affected waterways, and detailed site inspections are almost always required to address site-specific issues, it is reasonable to adopt existing policy allowances in the absence of complex assessments for this Coastal Hazard

Assessment (CHA). Detailed engineering studies are still required to identify site specific riverbank erosion issues and can be undertaken as outcomes of the CHRMAP.

Given all the above considerations, the erosion hazard assessment along the riverbanks is undertaken based on SPP2.9 (WAPC, 2006):

- For main waterways e.g., Collie River, Preston River, a 'foreshore reserve' width of 30 m by 2120 is applied.
- For secondary channels influenced by SLR (refer Section 3.5.2.3) e.g., upper Collie River and Preston River, a setback allowance of 15 m by 2120 is applied.
- Flexibility for site specific reasons e.g., topography, bank condition and protection.

The method demonstrated above is implemented to evaluate erosion risk along segments of river courses subject to the combined impact of riverine and coastal processes (or tidal reaches of inland waterways).

For river courses dominated by inland processes, riverbank erosion is dominated by river flows, sediment composition, riverbank slope and condition of vegetation etc. Literature review indicates that for rivers located in a micro tidal environment such as the study area, the main cause of erosion is from river flood discharge and sediment composition (clay/sand). Tide and ocean waves usually play a secondary role on riverbank erosion, in particular for the mid- and upper- stream channels of the Collie River, where both small tidal range and the sheltering provided by the Leschenault Estuary contributes to a weak dynamic environment for coastal processes. There are some levels of exposure to boat wakes, however such impacts area determined by human activities not climate change.

DWER has an existing Operational Policy 4.3 which requires a more comprehensive site-specific assessment based on biological and physical features. These inland waterways are identified through review of flood levels simulated by the DWER flood model. For inland waterways showing minimal impact from tide /sea level rise, the analysis for this CHRMAP is kept as broad-scale as possible to avoid unnecessary duplication of work in developing adaptation options for regions not covered by the CHRMAP scope. Essentially, if the 100 years SLR has only negligible impact to flood levels/currents in the river channel, the adaptation options should not be developed under the framework of CHRMAP, rather the analysis should be undertaken based on projection of future rainfall / evaporation rates under the framework of DWER Operational Policy. For inland river courses, simple guideline allowances provide no additional values to the management of erosion along riverbanks.

3.4.5 Land Depression along the Capel Coast

The land depression along the Capel coast is not directly affected by coastal processes at present due to the protection of foredune and embankment walls. With sea level rise, the area may be affected under storm surge conditions, assuming the culverts are opened. The shallow water depth and potential vegetation growth will likely mitigate any coastal erosion processes. It is not envisaged that these land depressions will be affected by coastal erosion, unless the entire foredune is eroded. The dune reserve is assessed as greater than $100m^3$,. As per SPP2.6, this indicates the dune is unlikely to be removed during storm activity. This should continue to be monitored in the future.

3.4.6 Physical Controls

As per SPP2.6, variations for areas of industrial/public/commercial/defence development include.

- For temporary facilities with design life of less than 30 years, erosion allowances are considered assuming that no structures are in place.
- For permanent structures e.g., port structures and those structures inside Koombana Bay, it is assumed that these structures will be in place and remain functional during the 100-yea. planning period.

As discussed in Section 3.4.2, the defences around Leschenault Inlet are assumed to remain in place. It is however notable that future upgrades may be required to mitigate inundation risk (discussed in more detail within the inundation hazard assessment).

The buried seawall and discontinued revetment along Bunbury Back Beach were designed to stabilise the foreshore area. Review of design drawings show different specifications along different segment of the shoreline. Some areas have only one thin layer of revetment for which the protection is not considered as effective for erosion control, and are not considered to provide protection in the erosion hazard assessment. For some segments of buried/exposed seawalls (near the two carparks between Stockley Rd and William St and between Beach Rd and Hayward St) where two-layer 1-5 tonne armour rocks were used for erosion control, the design is considered as effective during their design life. As such, these sections, it is assumed that the seawall will prevent shoreline erosion.

Whilst beaches within Koombana Bay are assessed as open coast, it is assumed the physical controls in this area (the outer harbour breakwaters) will remain in place throughout the planning timeframe.

A spatial summary of the physical controls impacting the erosion assessment is provided in Figure 3-1.

3.4.7 Summary

A summary of the erosion assessment approach is provided in Table 3-1. This is presented pictorially in Figure 3-2.

TABLE 3-1 SUMMARY OF EROSION HAZARD ASSESSMENT METHOD

Shoreline Type	Erosion Assessment
Open Coast	Standard method as per SPP2.6. This considers erosion allowances relative to the present Horizontal Shoreline Datum. ▪ HSD is defined by topographic contours, ground truthed by vegetation line. ▪ Allowance for the current risk of storm erosion (S1) estimated by SBEACH model. ▪ Allowance for historic shoreline movement trends (S2) estimated by analysis of historic vegetation lines. ▪ Allowance for erosion caused by sea level rise (S3) through application of Bruun Rule ▪ Uncertainty allowance as per SPP2.6 ▪ Hazard lines are defined by HSD+S1+S2+S3+uncertainty Consideration of erosion controls: ▪ Physical controls such as Groynes, Port facilities, Outer breakwater and jetty road breakwater are considered as permanent structures assuming ongoing maintenance and management. These are key facilities that determines the overall landscape of Bunbury coast. ▪ Erosion controls that are designed with large armour rocks and proper toe protection are considered as effective for their design life e.g., buried seawalls along Ocean Drive, Ski Beach and Koombana Beach. ▪ Temporary protection such as thin layers of pavement are not considered as erosion controls. Consideration of landform stability in accordance with sediment cells and geomorphological features wherever appropriate. Rocky shoreline definition requires continuous rocky surface extending above the reach of storm waves plus SLR. If the rocky surface is lower than the active limit of waves, the shoreline should be defined as a mixed or sandy type. Our analysis shows no continuous rock cliff above the reach of storm impact. Unless otherwise notified by geotechnical assessments, the shoreline within the study domain is considered as 'sandy' type for the purpose of coastal planning and management.

Shoreline Type	Erosion Assessment
Estuary	For shallow foreshore with/without riparian boundary, hazard lines defined by HSD+S1+S2+S3+uncertainty with fine scale adjustment to define the HSD: ▪ HSD defined by the location of riparian boundary / inundation line (HAT level, 0.6m AHD, as boundary of tidal inundation) / physical controls. ▪ Allowance for the current risk of storm erosion (S1). SBEACH model used to evaluate the extent of erosion generated by the strongest possible waves in the Estuary. ▪ Allowance for historic shoreline movement trends (S2) estimated by review of historic vegetation lines/satellite images/historic reports. ▪ A fixed allowance of 50 m is assumed as a response to SLR (or S3) by 2120, as per SPP2.9 recommendations. The estimated erosion hazard lines are compared against the permanent inundation extent (HAT water level +SLR) in 2121. Both are reported to facilitate erosion hazard assessment. Tidal flats and dynamic river deltas are excluded from current shoreline.
Leschenault Inlet	Leschenault Inlet has a very limited impact from storm waves. Erosion of shoreline is largely contributed by increasing sea level and overflow of flood water. Shoreline movement is determined in context with tidal inundation from SLR and operation of the storm barrier. Total erosion allowance is estimated at 0.6m + SLR (eg 1.5 m AHD in 2120)
Riverbank	For riverbanks, methods derived for open coast by SPP2.6 are not applicable. SPP2.9 is used to guide the development of erosion hazard lines. ▪ a 'foreshore reserve' width of 30 m by 2120 for main waterways (Preston, Collie River, Capel River) ▪ a 'foreshore reserve' width of 15 m by 2120 for secondary channels (Branches of Collie River, Miller River, Henty River Brunswick River, Wellesley River etc.) We have noted several breaches through the coastal barrier near the Capel River mouth. This erosion is investigated at a broader scale by historic shoreline movement and also in the context of open coast erosion. Detailed analysis of breach activation is beyond the scope of current study. River courses dominated by in land processes are not investigated by this study. DWER has an existing Operational Policy 4.3 which requires a more comprehensive site-specific assessment based on biological and physical features.
Land depression behind the sand dune (Shire of Capel)	No erosion risk considered.

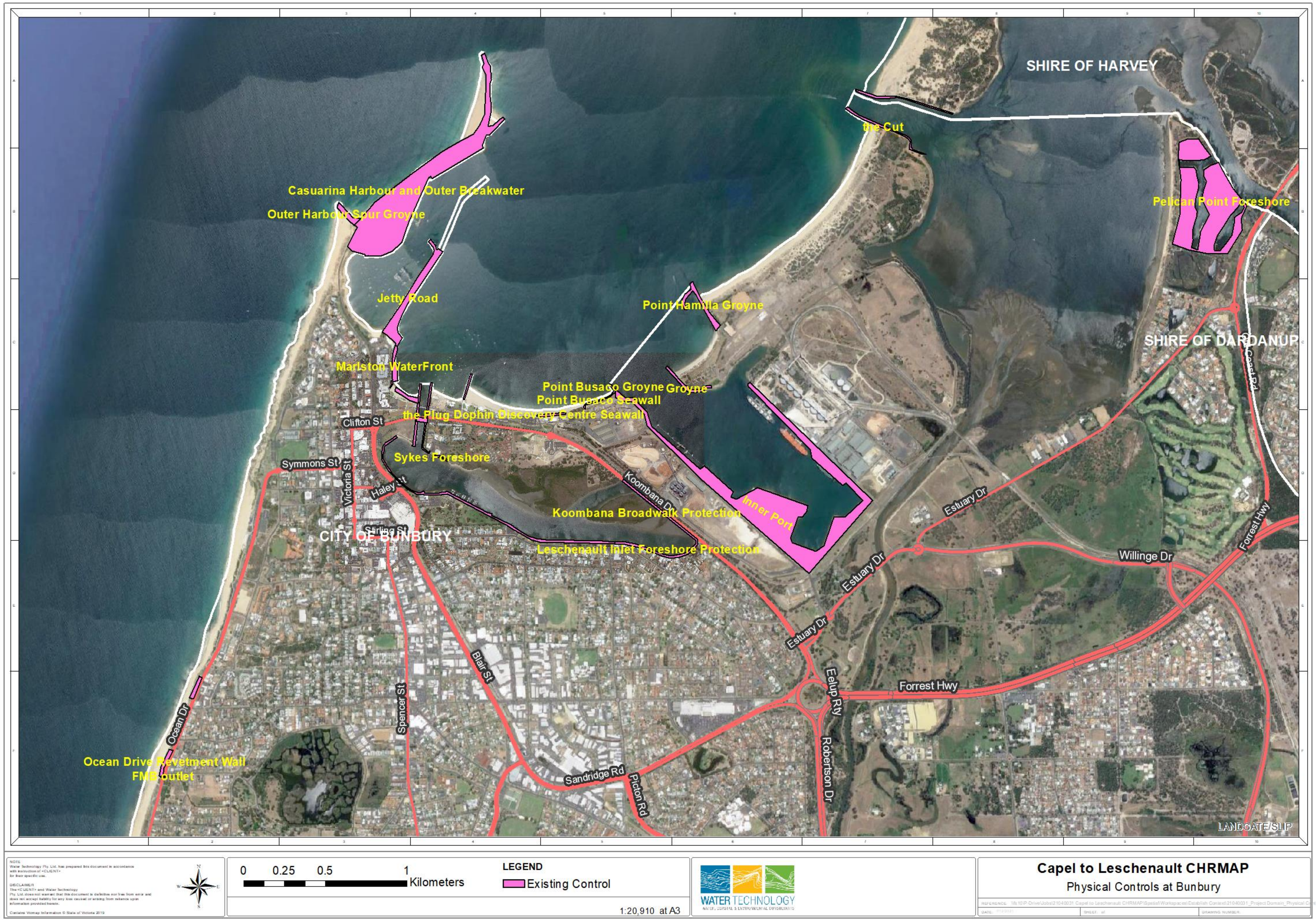


FIGURE 3-1 PHYSICAL CONTROLS

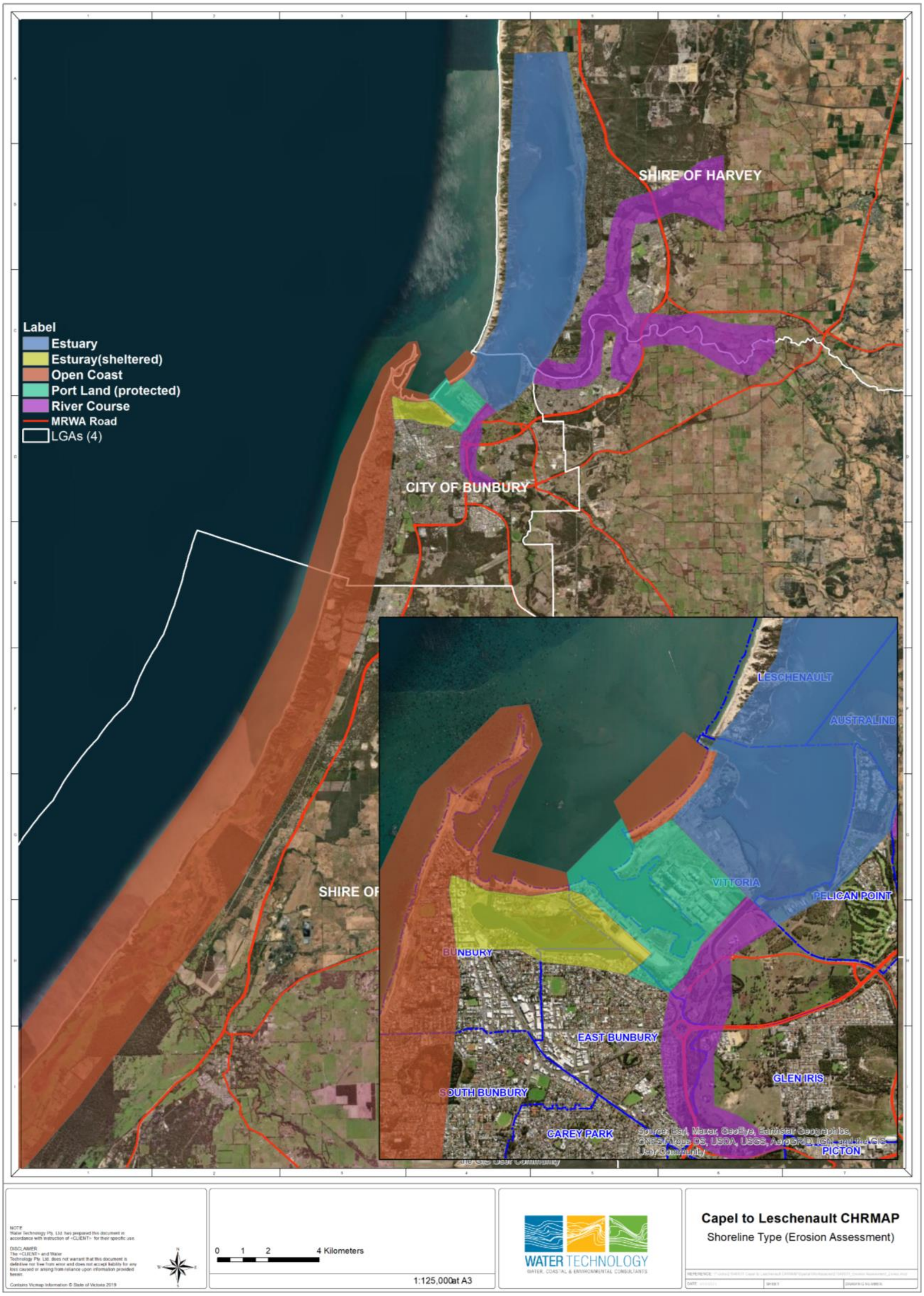


FIGURE 3-2 SHORELINE TYPES FOR EROSION HAZARD ASSESSMENT

3.5 Inundation Hazard Study Approach

Inundation is one of the primary coastal hazards of the region. Historic studies have identified multiple mechanisms that have contributed to the high-water levels along the coast and in the estuary.

SPP2.6 requires the allowance for inundation to be the maximum extent of inundation calculated as the sum of S4 Inundation plus the predicted extent of sea level rise. Being a coastal Policy, it does not apply to areas where inland processes dominate the inundation/flooding process.

3.5.1 Modelling Tools

The DHI MIKE storm surge model has been used to simulate the inundation extent in the study area coastal zone from Capel to Leschenault Estuary. The approach was proposed to account for the complexity of inundation processes in Leschenault Estuary, along river channels, and in the land depression of Capel which cannot be accurately assessed by a simple bathtub model approach, particularly with the inclusion of catchment flood impacts. The model however did not attempt to replace the existing riverine catchment flood model along the Collie River supplied by DWER which has been carefully calibrated through inclusion of MIKE11 network for rivers, drainages, bridges and culverts, all of which are crucial inputs to simulate accurate river hydraulics.

Although the storm surge model includes all major river courses, model results along the Collie River are limited to only cover areas affected by SLR. However, all major river courses are included in the model domain to provide river discharge inputs and flood storage, so that the inundation extents within the full tidal reach of the estuary (including future SLR) can be appropriately assessed.

A set of ARI storm events have been simulated for the assessment of coastal inundation hazards (Table 3-2). Refer to Appendix C for a detailed description of the modelling tools utilised in this assessment.

Inundation risk along the Collie River (for river courses beyond the impact of tide/SLR) is mapped directly from DWER flood model results.

3.5.2 Model Implementation

3.5.2.1 Open Coast

Inundation along the open coast is evaluated by Water Technology's Danish Hydraulic Institute's MIKE storm tide model which has been calibrated to hindcast the storm tide conditions during TC Alby. The model simulates the combined effects of peak steady water level as well as wave setup through a coupled Hydrodynamic and Spectral Wave model.

For the 500-year ARI event, the inundation level is modelled through simulation of a representative cyclone which is developed based on the existing TC Alby track, with modifications to locate the cyclone eye near the Bunbury region (peak surge lasts for up to 4 hours). The timing of the peak storm surge is shifted to match the timing of the MHHW level. Overall, a reasonably conservative storm tide is provided based on comprehensive modelling investigations.

For lower return period storms, the inundation levels from existing studies are adopted to drive the inundation model (see Section 2.2.1). A synthetic storm tide sequence is produced as a model boundary condition based on typical MHHW levels as well as a simple cosine function (about 4 days duration) to represent the process of storm surge.

TABLE 3-2 INUNDATION HAZARD MODELLING SCENARIOS (MINIMIUM 2 DAYS OF STORM DURATION)

ARI (years)	Model Domain (excluding Collie River)				Collie River
	Current Sea Level (2020)	**2035 (0.12 m SLR)**	**2050 (0.22 m SLR)**	**2120 (0.98 m SLR)**	**Current Sea Level (2020)**
1	1-year ARI water level + tide variation 1 year ARI river discharge	1-year ARI water level + tide variation 1 year ARI river discharge SLR	1-year ARI water level + tide variation 1-year ARI river discharge SLR	1-year ARI water level + tide variation 1-year ARI river discharge SLR	Rerun of DWER flood model using 1-year ARI flood
10	10-year ARI water level + tide variation 10-year ARI river discharge	10-year ARI water level + tide variation 10-year ARI river discharge SLR	10-year ARI water level + tide variation 10-year ARI river discharge SLR	10-year ARI water level + tide variation 10-year ARI river discharge SLR	DWER flood model results 10-year ARI flood
100	100-year ARI water level + tide variation 100-year ARI river discharge	100-year ARI water level + tide variation 100-year ARI river discharge SLR	100-year ARI water level + tide variation 100-year ARI river discharge SLR	100-year ARI water level + tide variation 100-year ARI river discharge SLR	DWER flood model results 100-year ARI flood
500	Tide variation, 500-year ARI cyclone 500-year ARI river discharge	Tide variation, 500-year ARI cyclone 500-year ARI river discharge SLR	Tide variation, 500-year ARI cyclone 500-year ARI river discharge SLR	Tide variation, 500-year ARI cyclone 500-year ARI river discharge SLR	DWER flood model results 500-year flood

3.5.2.2 Estuary and Inlet

The storm tide levels inside the estuary and the inlet are determined from the MIKE storm tide model (as per Open Coast section above). This process-based inundation model considers the following factors that may affect the inundation levels in the confined waters of Leschenault Estuary and Inlet:

- Storm duration and constrained water exchange through the estuary/inlet openings have significant impact to the storm tide levels inside the estuary. The small opening at the Cut behaves like a filter to dampen the signal of short peaks while withholding peaks with longer duration. Review of post-flood survey data has shown about 0.5 to 1 m of water level difference between Koombana Bay and Leschenault Estuary during TC Alby. This is based on simulation of a 3 to 4 hours peak surge during TC Alby, as once tide retreats, the peak surge level will drop accordingly.
- The Storm Surge Barrier is one of the key physical controls to mitigate the inundation hazard for the Bunbury townsite. As per discussions with DoT and the Steering Committee, this has been modelled as closed using the design parameters taken from the drawings supplied by DoT. Damage/ loss associated with malfunctioning of the storm barrier could be catastrophic from an inundation perspective. It is assumed that the storm barrier will be maintained to ensure it remains operational for the planning timeframe.
- River flows have significant impacts to water levels in the estuary and along the river which have been incorporated as model inputs.

3.5.2.3 River

River flood hazards occur at a higher frequency than storm surge hazards in Leschenault Estuary and along the river flood plain. This sets the current CHRMAP apart from many other CHRMAP projects where inundation hazard of tidal waters is primarily contributed by the coastal storm tide. Assessment of river flood and spreading of flood water requires comprehensive modelling of river flow (see Figure 3-4 for locations of river courses). Catchment flood inputs are used to simulate inundation extents along the river flood plain.

SPP2.6 does not provide a clear guideline to evaluate the risk of river flood, particularly in areas where river flood impact becomes more dominant.

Five Mile Brook

Five Mile Brook is connected to the ocean through two outlet pipes (with flip open valve). It shows no impacts from regular tide at current sea level and very limited impact even during extreme storms. This water body is included in the inundation modelling, given the potential impact of drainage discharge and its impact to the extent of coastal inundation. However, Five Mile Brook will not be considered in the erosion hazard assessment.

Five Mile Brook Southern Diversion

Review of DEM data shows the diversion drain heading south has a high ground level (bed level ranging from ~1 m AHD near the beach exit to over 4 m AHD upstream) and is bounded by either high dunes or vegetated embankments (crest level over 4 m AHD). It is unlikely that this diversion drain will be affected by coastal processes at present and in near future. In the 100-year period, the impact of SLR to water level may appear along the lower 1.5 km section of the drain. Inundation risk from the ocean is still low, as long as the embankment walls between the foredune and the Bussell HWY are maintained to standard. This diversion is not considered in our inundation model due to its negligible impact to inundation of coastal assets. Maintenance requirement of this drain will be included as a recommendation in future stages of the CHRMAP.

Collie River

A key objective of this study is to evaluate the inundation risk along the Collie River in response to future SLR and develop options/plans to adapt to the predicted inundation hazard. As per SPP2.6, the coastal zone is defined as the areas of water and land that may be influenced by coastal processes. Regions beyond the impact of tide and SLR are excluded from the scope of the CHRMAP study as no adaptation plan is required if not affected by SLR from climate change. Other climate change factors e.g., increasing/decreasing rainfall, should be investigated in detail by appropriate river flood risk assessment under DWER and other policies.

DWER provided Water Technology with a comprehensive flood model for Collie River and Leschenault Estuary (including model setup files and results). For this CHA, Water Technology has undertaken a review of modelled water level differences (per DWER 2014 report and model outputs) before and after 0.9 m SLR for a 100 yrs. ARI flood, in order to identify the areas under the influence of SLR. The modelled water level differences are presented in Figure 3-3 which show that:

- The water level within Leschenault Estuary will increase by the same amount as the projected SLR.
- The impact of SLR reduces with distance from the river month upstream. The modelled impact from SLR (100 yrs. Flood, 0.9 m SLR) reduces from 0.9 m in the estuary to less than 0.1 m in the river about 2 km upstream from the Old Coast Rd Bridge. This 0.1 m difference is within the range of numerical error for typical hydrodynamic simulations in coastal and estuary environment.

SLR has more profound impact to inundation level along the open coast and in Leschenault Estuary, significantly attenuated impact (10 to 40% of SLR) for the lower section of Collie River and almost negligible (<10% of SLR) impact to the middle and upper sections of Collie River. It is reasonable to exclude the river courses over 2 km upstream of the Old Coast Rd Bridge from this CHA, as inundation hazards along the upper river courses should be investigated by more comprehensive river flood analysis (e.g., DWER flood study).

Inundation extents beyond the impact of SLR are mapped as per DWER flood study results.

Preston River

Preston River envelopes the eastern boundary of Bunbury City and is directly connected to the Leschenault Estuary. Inundation hazard along Preston River is investigated through numerical simulation of storm surge and river flood. Riverbanks are implemented as line structures to prevent any calculation error from insufficient model resolution over the embankment walls. Flood water can still overtop over the embankments if water level is greater than the crest level of the embankments.

The current model did not consider any planned/proposal diversion of Preston River resulting from expansion of Bunbury Port.

Capel River

Capel River is one of the major waterways connecting to the ocean within the study area. The river is narrow near the townsite and gradually widens downstream of Bussell HWY crossing. It runs through a flat land depression and is bounded by embankments with culvert openings for the purpose of flood water drains. Capel River is included in the inundation model with embankments built in as line structures allowing overtopping of flood water over the crest. The culverts connecting the drainage paths to the Capel River are also included to evaluate coastal inundation impact at the land depression. Conservative culvert settings have been used to produce more conservative model results.

3.5.2.4 Physical Controls

Key flood/inundation controls are implemented in the model as follows:

FMB outlet

Review of current FMB outlet showing the following specifications:

- Two outlet pipes (1.8 m diameter) with pressure generated opening flaps. One is in operational condition while the other one is currently not being used (locked shut). The performance of the locked outlet (if in use) may be affected by the one in operation.
- The pipe valves are opened from the land side by water pressure if water level in FMB is higher than ocean water.

- Two pumps, each has capability to pump 540L/s so overall about 1.1 m^3/s pumping capacity. The pumps are for the purpose of using jets to flush the sand build up on the ocean side so the outlet can be opened by water pressure.
- Two pumps cannot work together with the outlet pipes.
- Pumps usually run for 20mins with 10 mins break.
- At the outlet, the peak flow could be up to 8.5 m^3/L as per Water Technology (2012). This requires a flow speed of about 3.3 m/s for one outlet pipe to be in operation, and about 1.7 m/s flow speed for two outlet pipes to be in operation.
- The performance of the outlet will be affected by the increased sea level. It is unknown whether this has been considered by the current design.

To be conservative, the outlet has been implemented in the model as:

- Two outlet openings each having 2 m diameter. This will allow inflow of ocean water within the model through the outlet pipes if ocean water level is higher than the creek. This configuration is more conservative than the current design which allows only one way flow.
- Assuming the road/outlet will be protected, given they are key coastal infrastructure. This is flagged as prerequisites for risk treatment options for the inundation hazard at Bunbury.
- The FMB flood discharge is modelled with the same timing as storm surge which is a conservative assumption.

Leschenault Inlet Storm Surge Barrier

This has been included in the model as a DIKE with a crest level of 2.1 m AHD as per supplied design drawings (refer Appendix B). The operation process of this storm barrier is not modelled, it is simply simulated as closed. This should have no impact on the results of the inundation hazard assessment, as this storm barrier will always be closed during the simulated storm events. For storm events with water levels below 2.1 m AHD, the model does not allow ocean inundation into Leschenault Inlet. For water levels above 2.1m AHD, water flows over the DIKE and can enter the inlet, similarly to the real life process.

Roads, Flood levees and Riverbanks

Dike structures have been used at multiple locations along the roads, riverbanks and along key flood barriers. This is particularly important to reduce the “leak” of flood water through grid points not fully resolved by the model.

Culverts

Culverts are included at multiple locations e.g., the two culverts downstream of Capel River, bridge openings/culverts near Preston River. Hydraulic performance of these culverts was checked, confirming acceptable performance. In the final simulations, these culverts were widened to produce more conservative results, regarding to the uncertainties of future operation, maintenance and upgrade.

Exclusions

Despite the efforts to include more hydraulic structures for more accurate inundation hazard mapping, it was not intended to include all inland flood controls/drainage networks for such a large study area CHRMAP study. Key flood controls are included as these have profound impact to the prediction and management of coastal inundation risk. Some controls are tuned to be relatively conservative to serve the purpose of regional planning and management.

For all investigated scenarios, rain on grid rainfall inputs and infiltration is not considered, nor are the various urban drainage networks, structures and paths.

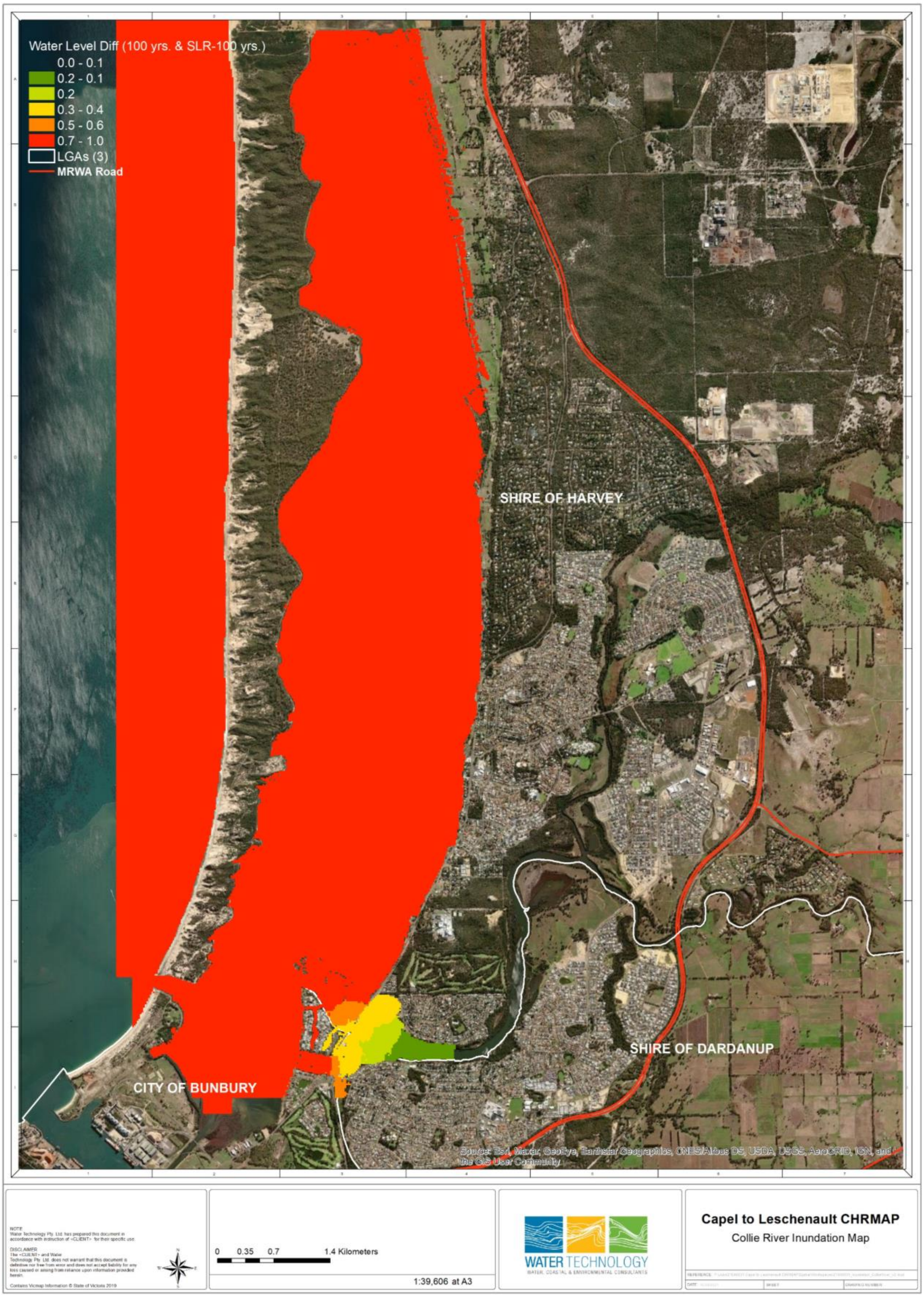


FIGURE 3-3 MODELLED WATER LEVEL DIFFERENCE (100 YRS. FLOOD WITH SLR – 100 YRS. FLOOD)

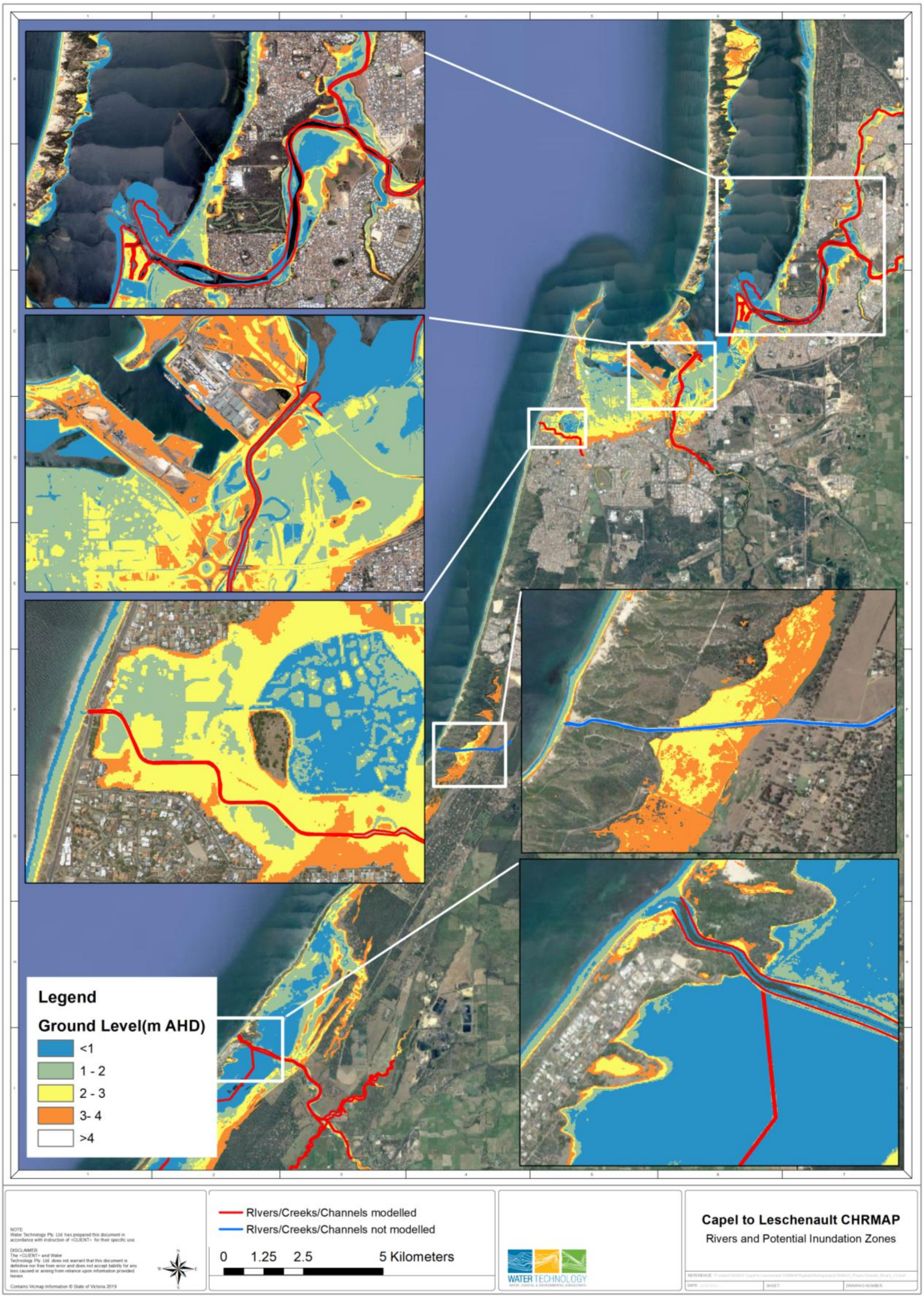


FIGURE 3-4 RIVER COURSES WITHIN THE STUDY DOMAIN

4 EROSION HAZARD ASSESSMENT

As per Section 3 study methodology, the erosion hazard study is carried out by the following steps:

- Simulate storm erosion for the 100 yrs. ARI storm (S1).
- Evaluate historic shoreline movement trends based on DoT vegetation lines (S2).
- Evaluate sea level rise impacts for present day, 2035, 2050 and 2120 (S3).
- Apply corrections for controlled shoreline segments.
- Evaluate total erosion values for each coastal management zones and for four different planning periods i.e., present day, 2035 (short term), 2050 (medium term) and 2120 (long term).
- Establish an erosion matrix considering both exposure levels and planning periods.
- Mapping of erosion hazard lines.

4.1 S1 Allowance

The potential for storm-induced erosion is assessed using the SBEACH numerical model by applying the MPRA (2018) storm. It is assumed that the subsurface of the shoreline within the study site is of a uniform uncemented sandy constituency. Complex geological features are beyond the capability of the SBEACH model framework and relevant impacts are factored in for the risk assessment component of the CHRMAP.

Refer to Appendix A and Appendix D for a detailed description of the wave modelling and simulation of storm erosion. The estimated S1 allowance is included in the total erosion hazard allowance table (Table 4-2, Section 4.4).

4.2 S2 Allowance

The historic shoreline trend is estimated through review of available historical shoreline changes (DoT vegetation lines from 1942 onwards). The approach is to analyse historical aerial imagery/shorelines and to use the horizontal change in the vegetation line as an indicator for historical shoreline changes. This approach is applicable on natural coastlines where vegetation is free to recede in response to erosion.

Refer to Appendix D for more detailed description of historic shoreline analysis using DSAS 5.0. The findings can be summarised as follows (see Figure 4-1 to Figure 4-3):

- The shoreline at Peppermint Grove Beach and to the south shows a slight trend of long-term accretion (0 - 0.4 m per year) over recent decades. The 2016 shoreline is about 0-8 m behind (landward) the 2008 shoreline, while still a few metres ahead (seaward) of earlier shorelines. As the observed variations in shoreline position is of the order of 10 m over a long-time frame, it is difficult to differentiate seasonal variations from the digitalised shorelines. The trend of accretion is not apparent and is uncertain for the future regarding the impact from SLR. It is envisaged that a 0 m shoreline movement would be appropriate to approximate the S2 allowance in this region.
- A weak erosion trend is observed at the mouth of Capel River (immediately to the north of Peppermint Grove residential area). Due to the dynamic nature of the river mouth, this section of shoreline is considered more vulnerable to storm erosion, and has less inherent ability to recover during periods of calmer summer waves. A modest nominal allowance (0.4 m per year erosion) is considered appropriate for the S2 allowance over this vulnerable section of coast.
- The shoreline between Capel River mouth and Dalyellup experience a similar historic movement, albeit with weak erosion at some sections of the coast (<0.2 m per year). We could however observe a trend of progressive erosion in the past 14 years at a rate of 0.4-0.8 m per year to the south of Dalyellup. The value is not included in Figure 4-1 as there are only two shorelines as inputs which lack statistical significance. For most areas of the coast, the current shoreline is still a few metres seaward of the 1991 and earlier shorelines. The reversed trend of shoreline movement following the 1990s likely reflects the

impact of climate change, which has become more apparent since the 1990s. As the net movement of shoreline is within 10 m for the most recent 20 years, it is difficult to differentiate the impact from seasonal beach variations (in order of 10-20 m as per PNP beach monitoring program).

- The shoreline north of Dalyellup to Bunbury Outer Harbour has been relatively stable with no clear trend of erosion/ accretion. This section of coast shows the natural shoreline variation of the order of ±10 m. It is reasonable to assume a stable shoreline over this section of coast, given the similar magnitude of variation showing by seasonal beach erosion. Slightly more accretion at the northern end is associated with the implementation of the spur groyne (in 1950s/1960s) as well as sand accumulation against the rock outcrops at Wyalup Rocky Point. Since the 2000s, the shorelines gradually converge showing up to 10 m variations across years.
- The shoreline inside the Casuarina Boat Harbour (or Bunbury Outer Harbour), along Ski Beach shows moderate accretion since 1941, mainly contributed by engineering works completed. In recent years, there has been almost no change in shoreline position. Koombana Bay Sailing Club shows a weak erosion of less than 0.2 m per year. Koombana Beach experiences overall weak erosion (<0.2 m per year) on the western side and a moderate erosion of up to 0.4 m per year on the eastern side. The shoreline within 200 m distance from Point Busaco Groyne is within the jurisdiction of Bunbury Port for which the shoreline has been stabilised by seawall structures (no trend of erosion observed).
- The beach connecting the port to Turkey Point (near The Cut) shows a clear trend of accretion at about 1-1.5 m per year since the construction of rock groynes at Point Hamilla and the cut opening. This has been interrupting the littoral drift process leading to accretion at the beach and reduced sand supply to the northern side of the Cut.

The analysis suggests most shorelines are either weakly accreting (for shoreline on southern side of Peppermint Grove Beach) or experience a weak erosion except Turkey Point where the shoreline accretes at an approximate rate of +1 m per year. Along the open coast, there is a general trend of recession since 2008. The 2016 line is almost always landwards of the 2008 shoreline. It is however unclear whether this is due to different methods used to derive the shoreline positions. Review of more recent satellite imageries shows the 2016 shoreline is very much in line with current shoreline indicating a pause/decline of such trend.

Looking at a broader time frame, all shorelines are considered to be reasonably stable. Water Technology considers a 0 m per year rate for shoreline on the southern side of Capel River and 0.2 m per year of erosion for shoreline to the north along the open coast is appropriate. Accretion within Casuarina Harbor is unlikely to continue for current landform settings (enclosed harbour). Koombana Beach has different shoreline movement rates on eastern (0.4 m per year) and western end (0.2 m per year). Due to the potential risk of beach breaching at Turkey Point under future SLR, the strong historic accretion (>1m per year) is unlikely to continue thereby not considered for erosion hazard mapping.

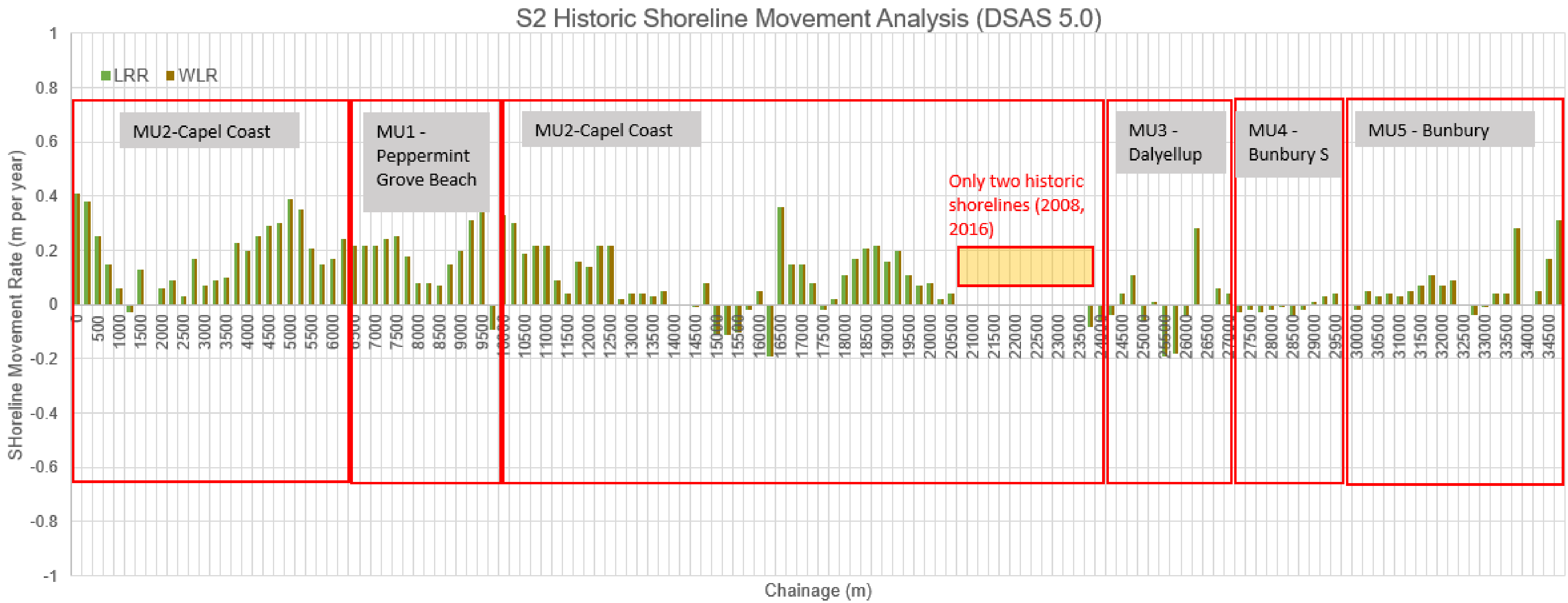


FIGURE 4-1 HISTORIC SHORELINE MOVEMENT (M PER YEAR) FROM CAPEL TO BUNBURY, (+) = ACCRETION AND (-) = EROSION, LRR DENOTES LINEAR REGRESSION RATE, WLR DENOTES WEIGHTED LINEAR REGRESSION RATE

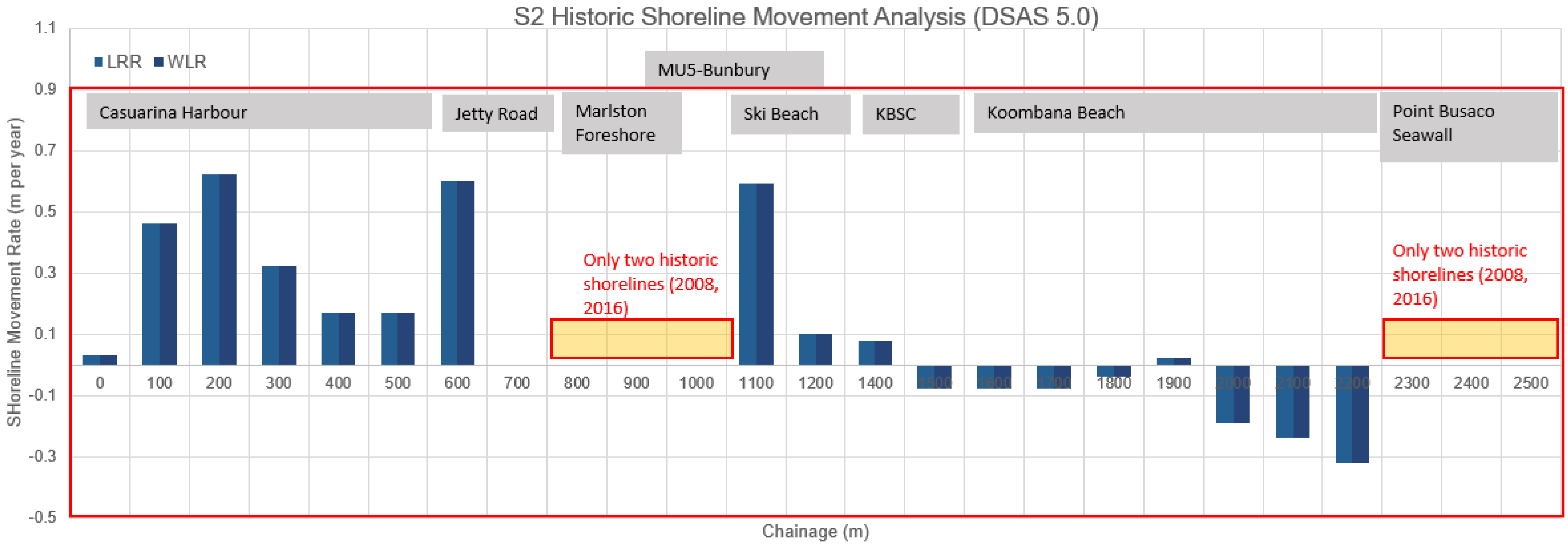


FIGURE 4-2 HISTORIC SHORELINE MOVEMENT (M PER YEAR) AT BUNBURY

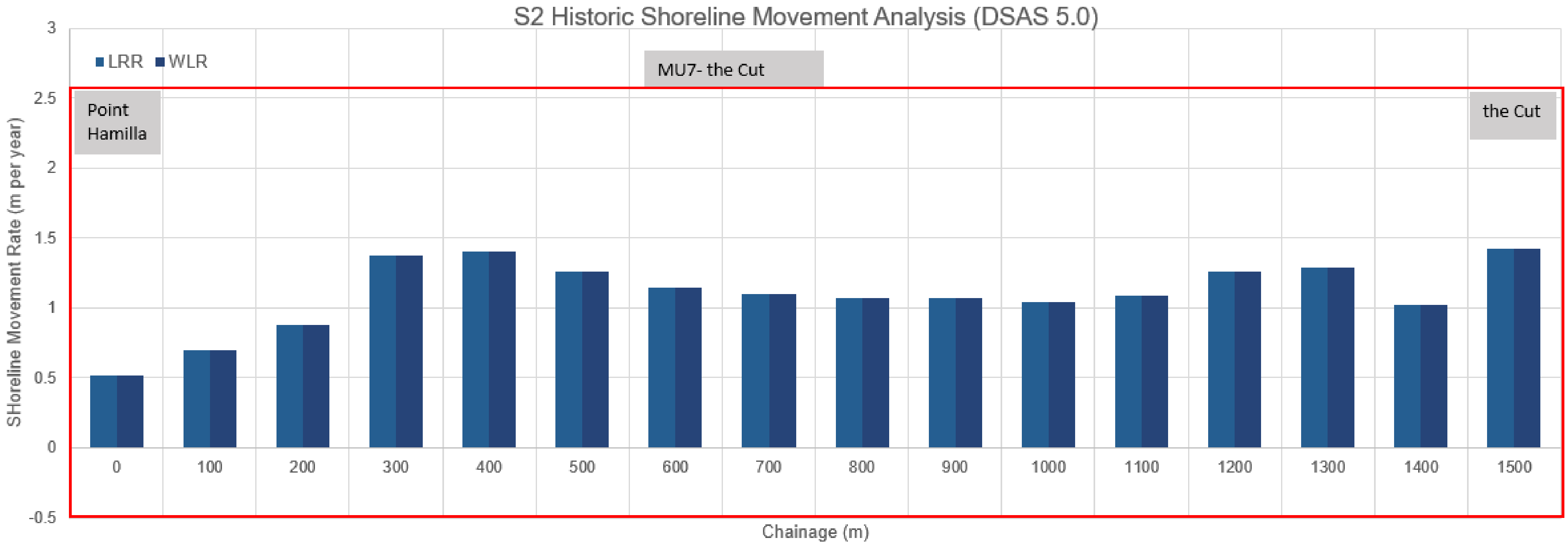


FIGURE 4-3 HISTORIC SHORELINE MOVEMENT (M PER YEAR) AT TURKEY POINT

4.3 S3 Allowance

Along the beach slope, rising sea level will cause additional inundation and retreat of the shoreline which is often characterised by the Bruun rule (Bruun, 1962). According to SPP2.6 and project applications, the shoreline recession due to future sea level rise can be estimated as being equivalent to 100 times the adopted sea level rise value (in metres) over the defined planning periods for sandy/mixed coasts. The multiplier of 100 is based on the Bruun rule (Bruun, 1962) over a mildly sloping shoreline.

SLR impact will be applied in context with local landform conditions which would be treated differently for open coasts and estuary environments (Table 4-1). Note S3 allowance will not be considered for locations where permanent physical controls (i.e., seawalls) are in place.

TABLE 4-1 SUMMARY OF S3 ALLOWANCES

Planning Time Frame (year)	Present day	2035	2050	2120
Sea Level Rise (m)	0	0.12	0.22	0.98
Open Coast S3 (m)	0	12	22	98
Estuary S3 (m)	0	7.5	15	50

4.4 Total Erosion Hazard Allowance

The total erosion hazard allowance is presented in Table 4-2. Erosion hazard maps can be viewed in high detail at the following link:

https://watech.maps.arcgis.com/apps/webappviewer/index.html?id=d43c39fda97d426ea6192d1a7a8543cf.

TABLE 4-2 EROSION HAZARD ALLOWANCE SUMMARY

Profiles	S1 (m from HSD)	S2 (m/year)	S3 (m/year)	Uncertainty (m/year)	Erosion Allowance (m from HSD)			
					2020	2035	2050	2120
1 (MU1)	14.0	0	1	0.2	14	29	42	132
2 (MU1)	12.0	0	1	0.2	12	27	40	130
3 (MU1)	23.0	0	1	0.2	23	38	51	141
4 (MU2)	14.0	0	1	0.2	14	29	42	132
5 (MU1)	17.0	0	1	0.2	17	32	45	135
6 (MU1)	10.0	0	1	0.2	10	25	38	128
7 (MU1)	23.0	0	1	0.2	23	38	51	141
8 (MU1)	28.0	0.4	1	0.2	28	49	68	186
9 (MU3)	26.0	0.2	1	0.2	26	44	60	164
10 (MU3)	29.0	0.2	1	0.2	29	47	63	167
11 (MU3)	24.0	0.1	1	0.2	24	40.5	55	152
12 (MU4)	21.0	0	1	0.2	21	36	49	139
13 (MU5)	19.0	0	1	0.2	19	34	47	137
14 (MU5)	19.0	0	1	0.2	19	34	47	137
15 (MU5)	17.0	0	1	0.2	17	32	45	135
16 (MU5)	27.0	0	1	0.2	27	42	55	145
17 (MU5)	30.0	0	1	0.2	30	45	58	148
18 (MU5)	8.0	0	1	0.2	8	23	36	126
19 (MU5)	14.0	0	1	0.2	14	29	42	132
20 (MU5)	39.0	0	1	0.2	39	54	67	157
21 (MU5)	4.0	0	1	0.2	4	19	32	122
22 (MU5)	10.0	0.1	1	0.2	10	26.5	41	138
23 (MU5)	9.0	0.1	1	0.2	9	25.5	40	137
24 (MU5)	12.0	0.3	1	0.2	12	31.5	49	160
25 (MU6)	14.0	0	1	0.2	14	29	42	132
26 (MU6)	21.0	0	1	0.2	21	36	49	139
27 (MU6)	21.0	0	1	0.2	21	36	49	139
28 (MU7)	15.0	0	1	0.2	15	30	43	133
29 (MU8)	3.0	0	0.5	0	3	10.5	18	53
30 (MU9)	5.0	0	0.5	0	5	12.5	20	55
31 (MU9)	3.0	0	0.5	0	3	10.5	18	53
32 (MU9)	3.0	0	0.5	0	3	10.5	18	53
33 (MU9)	3.0	0	0.5	0	3	10.5	18	53
34 (MU9)	5.0	0	0.5	0	5	12.5	20	55
35 (MU9)	5.0	0	0.5	0	5	12.5	20	55
Preston River	0.0	0	0.3	0	0	4.5	9	30
Collie River	0.0	0	0.3	0	0	4.5	9	30

5 INUNDATION HAZARD ASSESSMENT

5.1 Inundation Levels

The modelled peak steady water levels are presented in Table 5-1 and detailed in Appendix C-2-4. The Cut opening has some notable impacts for the surge peaks inside the estuary water. The water level differences are smaller for 1-year, 10-year and 100-year storms as duration of these storms were expanded to cover multiple tidal cycles. This is to represent the longer duration of winter storms compared to extratropical cyclones.

5.2 Inundation Extent

An overview of inundation extents within the study domain are presented in Figure 5-1 to Figure 5-5. The full map set is provided in Table 6-1 and at the following link:

https://watech.maps.arcgis.com/apps/webappviewer/index.html?id=d43c39fda97d426ea6192d1a7a8543cf

Inundation extents along the middle and upper Collie River (including branches) are mapped based on DWER river flood model (present day, not affected by SLR). Flood plain (low lying land along the river courses) is under consistent risk of river flooding. There is however a clear boundary where river flood does not reach further due to a rapid increase in ground elevation at the outer edge of this flood plain. Areas under flood risk are most likely limited within the envelope of the established foreshore reserve. Existing development activities were planned to be beyond the reach of the 500 yrs. ARI flood. SLR has very limited impact to the inundation extent mapped by Figure 5-1.

Inundation extents along the open coast, land depression at Capel, Bunbury coast and Leschenault Estuary/Inlet are simulated by the calibrated storm surge model for all required storms including 1 yrs., 10 yrs., 100 yrs. and 500 yrs. storms and planning timeframes including present day, 2035, 2050 and 2120. The model has considered impacts from river floods e.g., flood discharges at Five Mile Brook, Capel River, Preston River and Collie River, as well as some major controls such as riverbanks, flood levees, roads, main bridge openings, Leschenault Inlet storm barrier (present day barrier level included in model), FMB drainage inlets and culverts. The model does not however simulate the on-grid rainfall/infiltration, nor flood flows through urban flood infrastructure (such as pipes and urban stormwater networks). Model results show that:

- At present day, the existing storm barrier is functional during a 1-year, 10-year and 100-year event. The Bunbury CBD area is predicted to be inundated in the present day 500-year cyclone. Differences in levels outside and inside the Leschenault Inlet are a result of the storm barrier – represented as a weir / dike within the model.
- The current design of the FMB outlet is sufficient to discharge 1-year and 10-year river floods (assuming 2 outlet pipes in operation). For more extreme events, coastal water may intrude into FMB and contribute to inland flooding. Modelling assumed a two-way flow through the outlet pipes (conservative settings to allow for potential malfunctioning of the pipes).
  - The modelled inundation (>100ARI) near Big Swamp Reserve is caused by river flood overflow from Five Mile Brook. Results were compared to Water Technology's 2012 detailed FMB flood model and noted consistent model results. The present study has a lower model resolution and more conservative inundation extent as infiltration/urban drainage networks were not modelled.
- In the present day, the land depression behind Peppermint Grove Beach is affected by both riverine and coastal flood, with different extents of impact for different ARI storms. Most coastal assets and occupied land at Peppermint Grove does not appear to be affected even by the greatest storm (500-year ARI) modelled as they are located well above the level of coastal inundation. A large area of land near the mouth of Preston and Collie River and land depression at Peppermint Grove Beach has a ground elevation of 2 m AHD or lower which is only slightly higher than the HAT level in 2120. These areas will be exposed to risk of consistent tidal flooding.
- In 2035 (short term) and 2050 (medium term), the inundation extents are quite similar to the present day. This is due to the small SLR allowance (0.1-0.2 m) considered for the short to medium term planning.

- In 2120, the 100-year ARI storm level (~2.7 m AHD) is predicted to be greater than the crest level of the existing Storm Surge Barrier (~2.16 m AHD). Most low-lying land (ground level 3 m AHD or lower) near Leschenault Inlet, Bunbury Port and Bunbury CBD is predicted to be affected by coastal inundation during the 100-year and 500-year ARI storms. The extent of impact is much smaller for a 100-year ARI storm. Due the protection of the Storm Surge Barrier, most urban land is not predicted to be affected by more regular storms (e.g., 1-10-year ARIs).
- For 2120, a greater extent of inundation is also found at the land depression behind Peppermint Grove Beach, the Big Swamp Reserve and Leschenault Estuary.

TABLE 5-1 MODELLED PEAK STEADY WATER LEVEL (M AHD)

Locations	Peak Steady Water Level (m AHD), various ARIs (years)															
	Present				2035				2050				2120			
	1	10	100	500	1	10	100	500	1	10	100	500	1	10	100	500
Leschenault Estuary	1.1	1.5	1.9	2.1	1.2	1.6	2.1	2.3	1.3	1.7	2.2	2.9	2.1	2.4	2.9	3.1
Koombana Bay	1.1	1.4	1.9	2.8	1.2	1.5	2.0	2.9	1.3	1.6	2.1	2.9	2.1	2.4	2.9	3.7
Leschenault Inlet				1.2				1.3				1.9		0.6	1.9	2.6
Open Coast (Bunbury)	1.1	1.4	1.9	3.0	1.2	1.6	2.0	3.1	1.3	1.7	2.1	2.8	2.1	2.4	2.8	3.9
Open Coast (Capel)	1.1	1.4	1.8	2.7	1.2	1.5	1.9	2.8	1.3	1.6	2.0	2.8	2.1	2.4	2.8	3.6
Land Depression	1.0	1.2	1.5	2.3	1.1	1.2	1.5	2.4	1.1	1.2	1.6	2.4	1.2	1.5	2.4	3.4

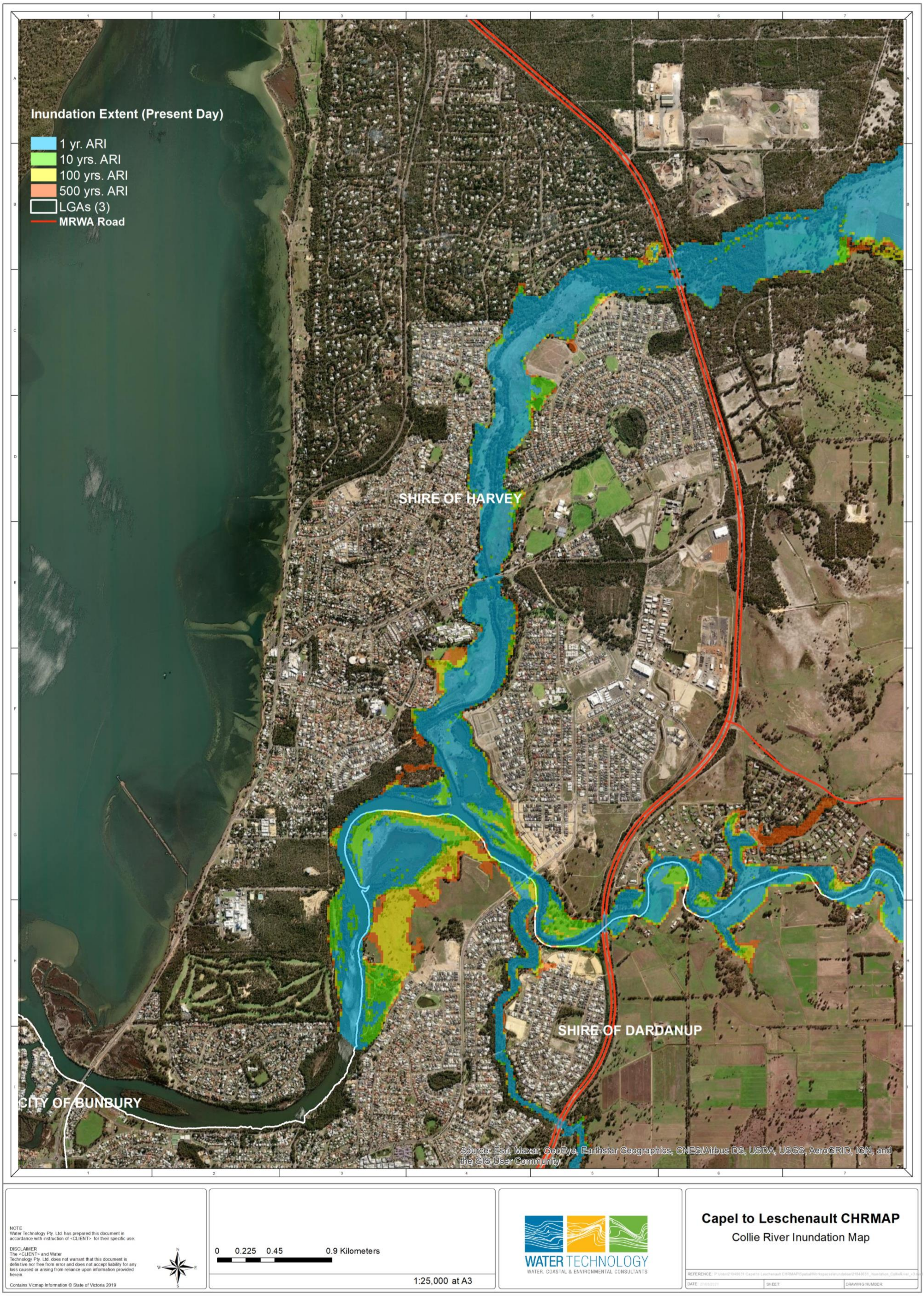


FIGURE 5-1 PRESENT DAY INUNDATION EXTENT AT COLLIE RIVER (1YR., 10 YRS., 100 YRS. AND 500 YRS. ARI PRESENTED IN BLUE, GREEN, YELLOW AND RED RESPECTIVELY)

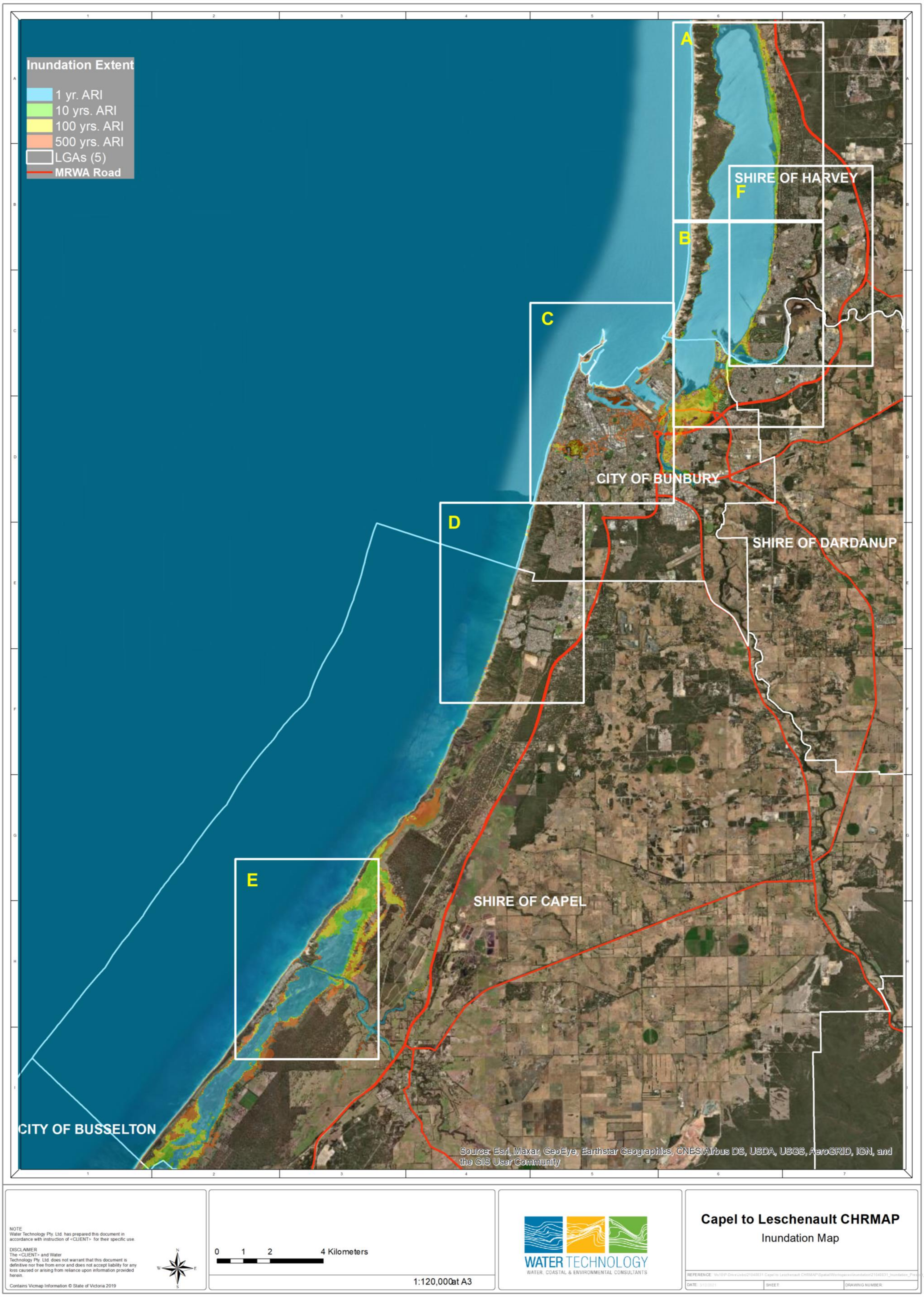


FIGURE 5-2 PRESENT DAY INUNDATION EXTENT (1YR., 10 YRS., 100 YRS. AND 500 YRS. ARI PRESENTED IN BLUE, GREEN, YELLOW AND RED RESPECTIVELY)

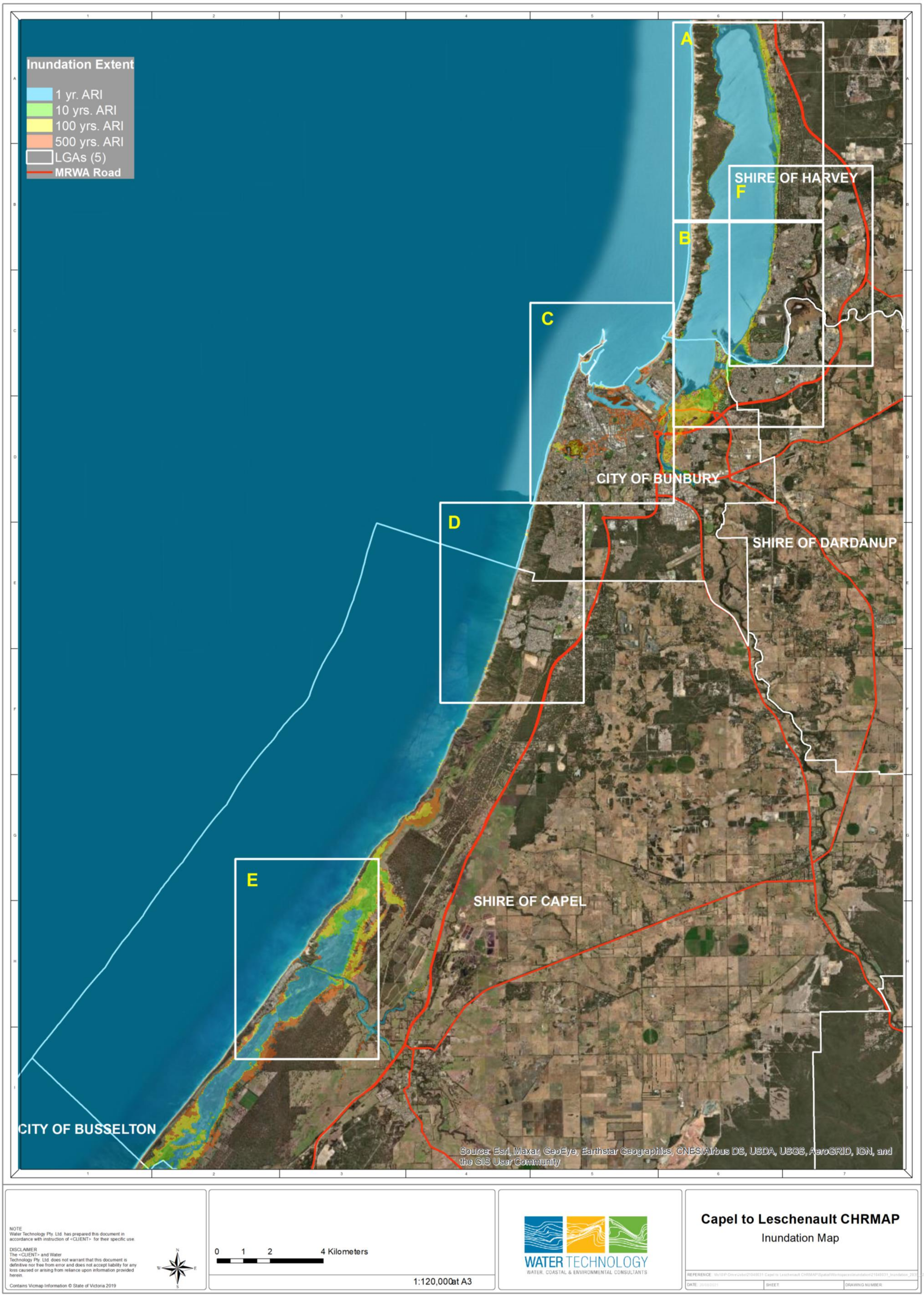


FIGURE 5-3 2035 INUNDATION EXTENT (1YR., 10 YRS., 100 YRS. AND 500 YRS. ARI PRESENTED IN BLUE, GREEN, YELLOW AND RED RESPECTIVELY)

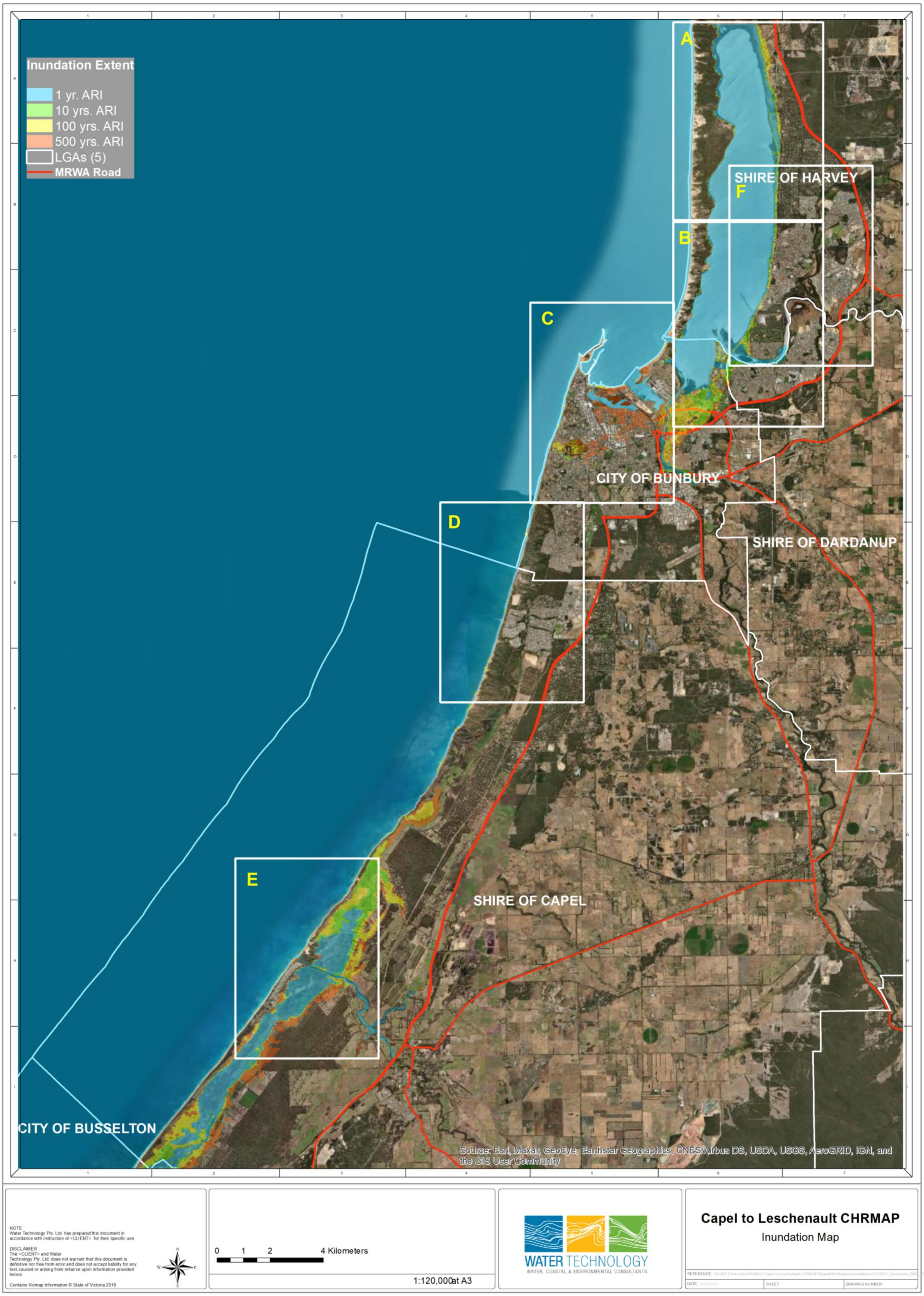


FIGURE 5-4 2050 INUNDATION EXTENT (1YR., 10 YRS., 100 YRS. AND 500 YRS. ARI PRESENTED IN BLUE, GREEN, YELLOW AND RED RESPECTIVELY)

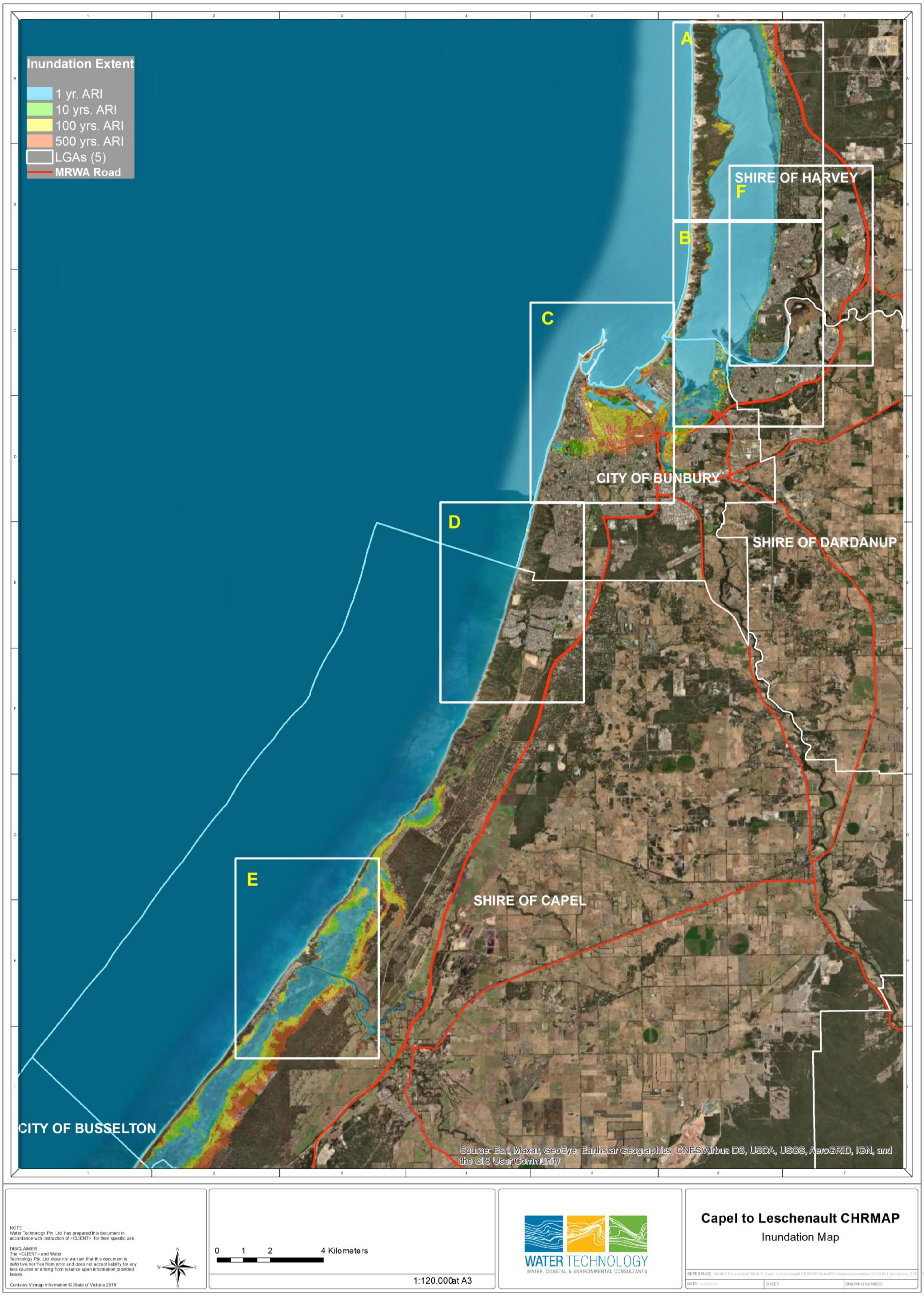


FIGURE 5-5 2120 INUNDATION EXTENT (1YR., 10 YRS., 100 YRS. AND 500 YRS. ARI PRESENTED IN BLUE, GREEN, YELLOW AND RED RESPECTIVELY)

6 SUMMARY OF HAZARD ASSESSMENT OUTCOMES

The outcomes of the coastal hazard assessment for each management unit (Figure 6-1) are summarised and discussed in Table 6-1 below.

Hazard extents can be viewed in high resolution via the link:

https://watech.maps.arcgis.com/apps/webappviewer/index.html?id=d43c39fda97d426ea6192d1a7a8543cf

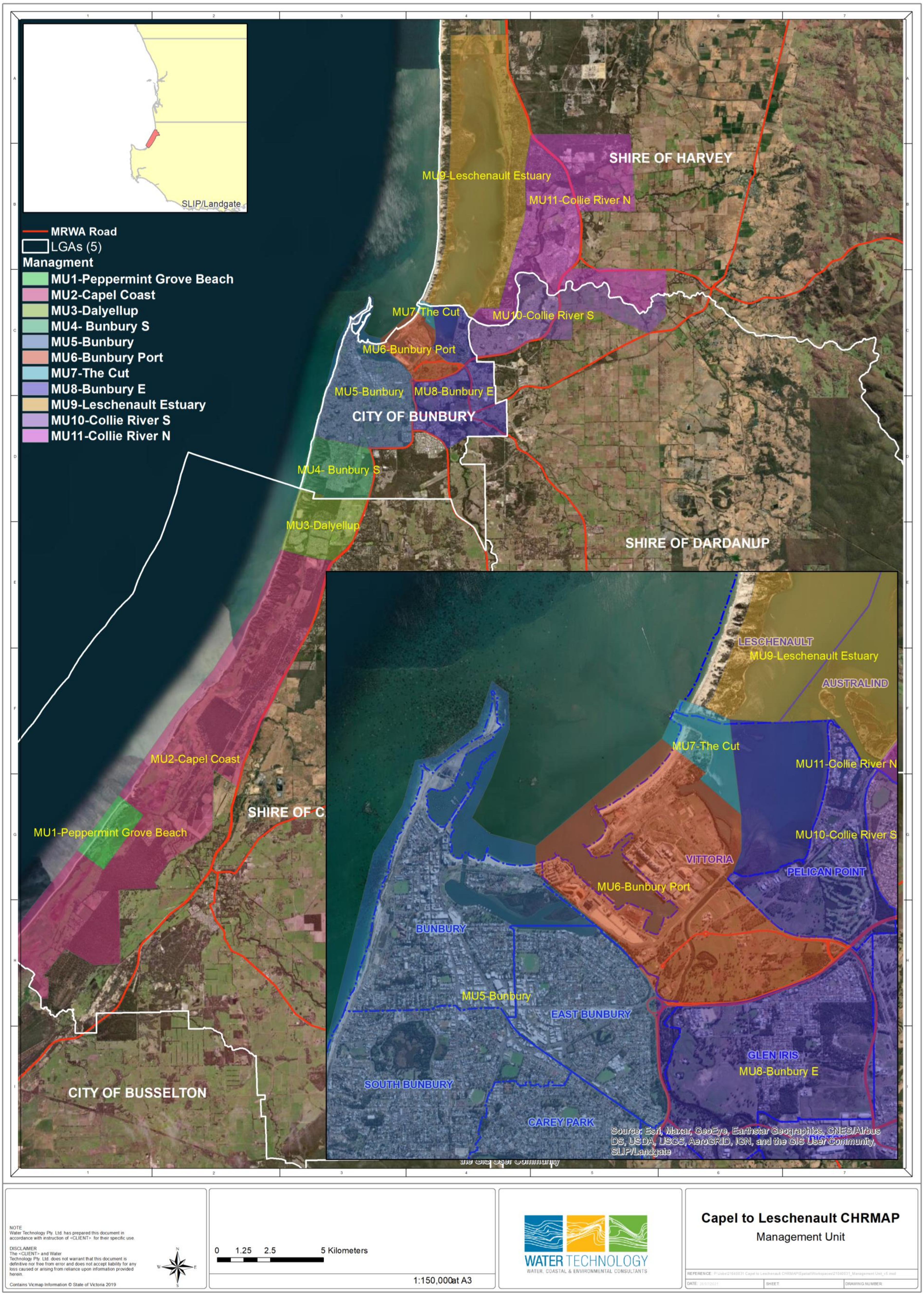
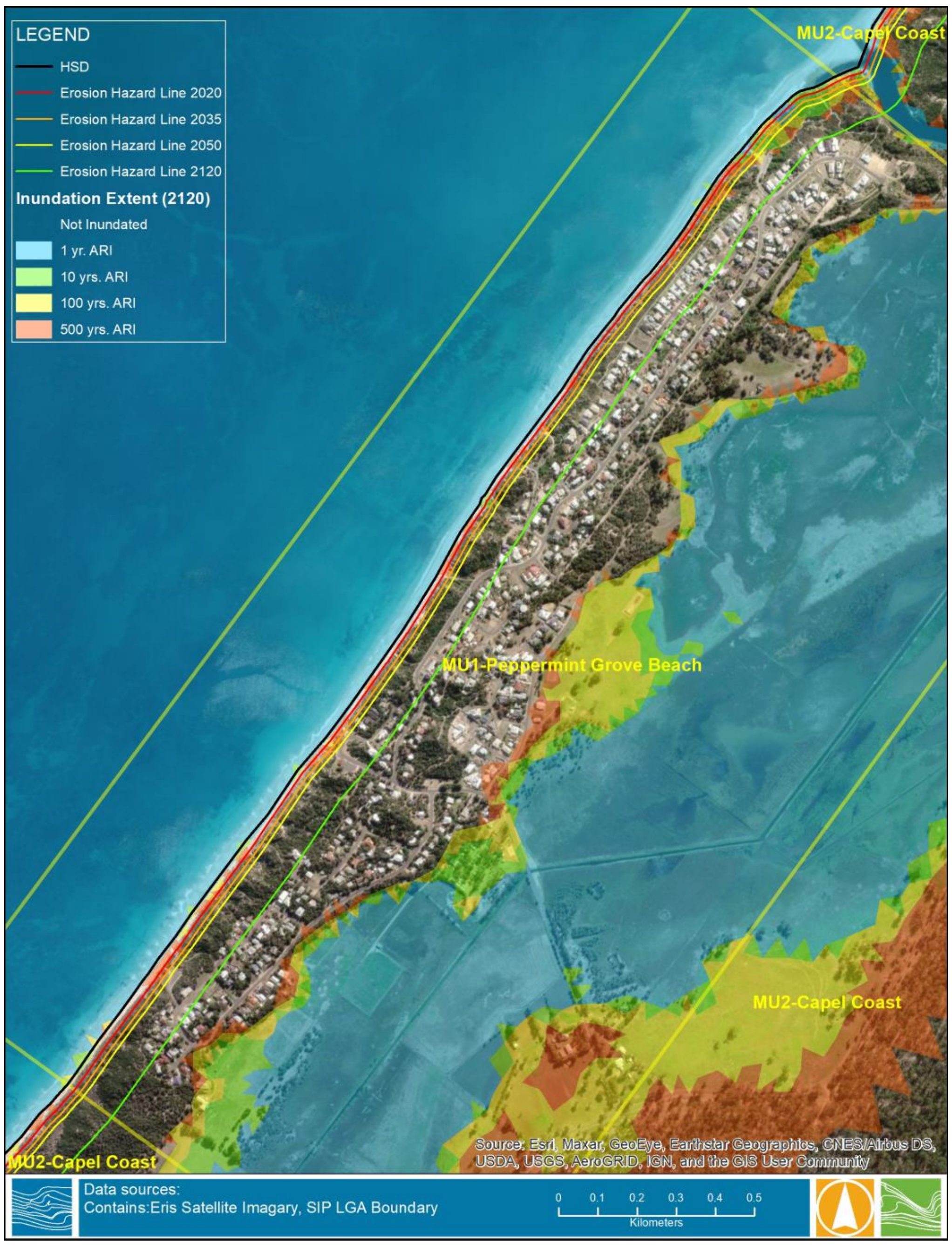
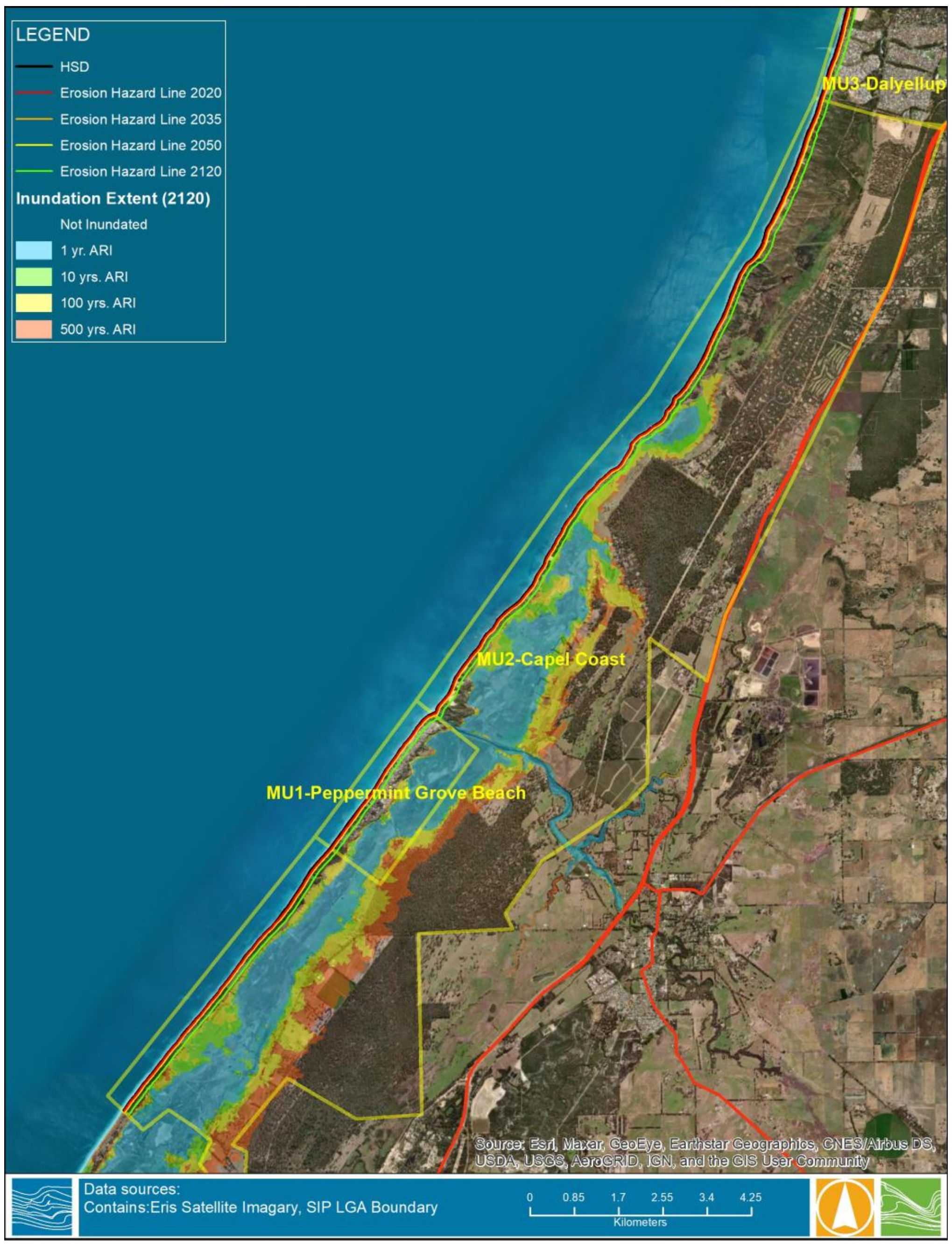


FIGURE 6-1 STUDY AREA AND MANAGEMENT UNITS

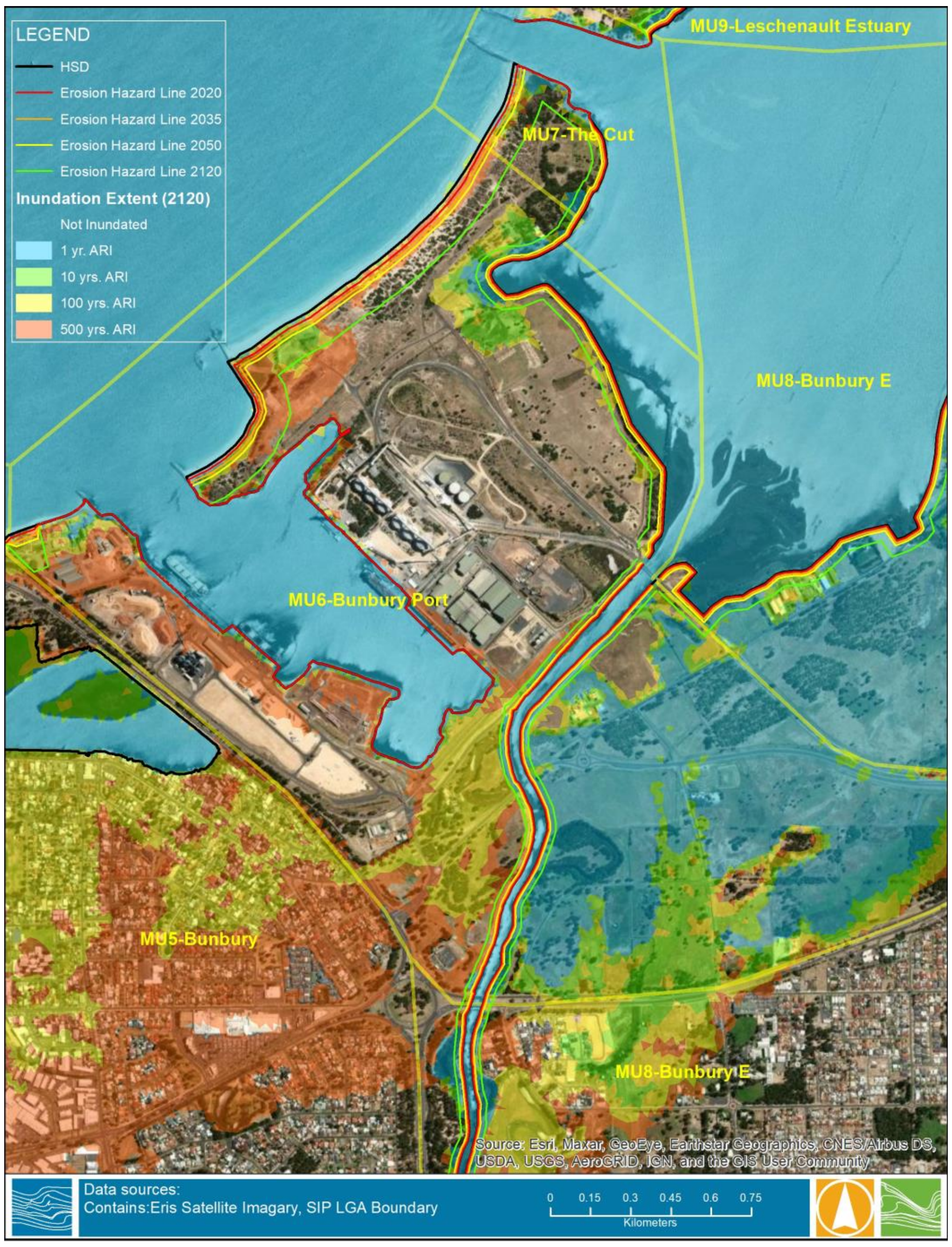
TABLE 6-1 SUMMARY OF COASTAL HAZARDS FOR EACH MANAGEMENT UNIT

Management Unit	Erosion & Inundation Hazard	Summary
MU1 – Peppermint Grove		▪ In 2120, the land depression behind the residential area will be under constant risk of inundation. Most of the residential properties are not predicted to be affected. The existing sand dune acts as a natural barrier for coastal inundation. The inundation model assumes ocean water enters the land depression through Higgins Cut, Capel River and culvert openings, and that the sand dune is not eroded. ▪ Peppermint Grove is particularly vulnerable to erosion hazard as there is only a 50-100 m wide reserved sand dune. Properties are predicted to be within the erosion hazard zone by 2120.
MU2 – Capel Coast		▪ The inundation extent extends across the land depression adjacent to Capel River. In the north of the management unit, inundation is minimal. ▪ Erosion allowances are similar along this stretch of shoreline (sandy type) ▪ Erosion risk of assets (foreshore reserves, resorts, toilets, car parks, farmlands and estates etc.) are determined by their distances from HSD.

Management Unit	Erosion & Inundation Hazard	Summary
MU3 – Dalyellup		▪ Inundation is not a high risk in this management unit ▪ Residential properties in Dalyellup are predicted to be in the erosion hazard zone by 2120. ▪ The SLSC car park is predicted to be in the erosion hazard zone by 2035. ▪ The treatment ponds of the Bunbury Wastewater Treatment Plant are predicted to be in the erosion hazard zone by 2120. ▪ The Tronox landfill site is predicted to be slightly in the erosion hazard zone by 2120.
MU4 – Bunbury S		▪ Inundation is not a high risk in this management unit. ▪ Erosion is predicted to impact natural assets only within this management unit.

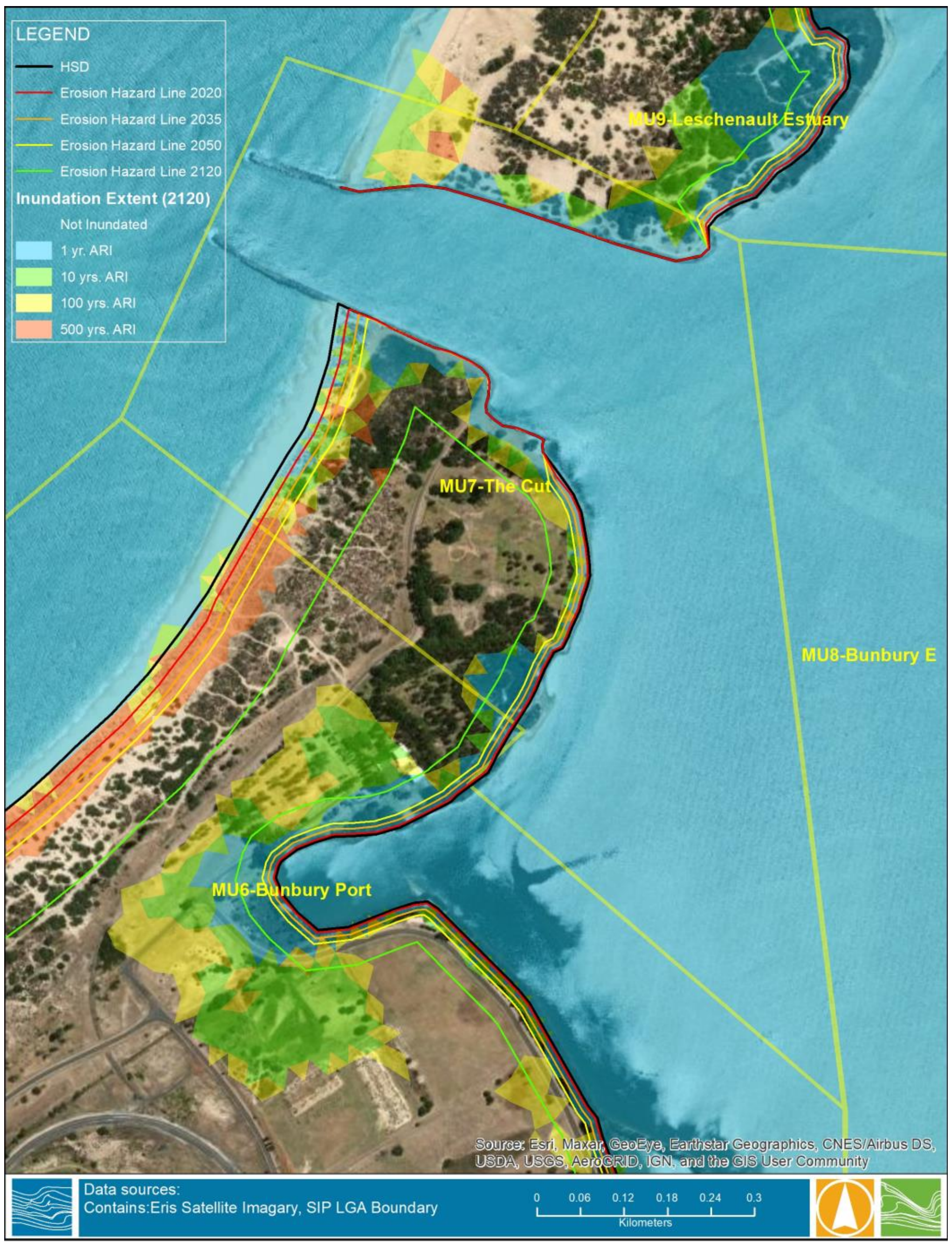
<table>
<tr><th>Management Unit</th><th>Erosion & Inundation Hazard</th><th>Summary</th></tr>
<tr><td>MU5 – Bunbury including open coast, Koombana Bay and Leschenault Inlet</td><td>
</td><td>

- Inundation is a significant risk across much of this management unit. The inundation risk is predicted to increase from present day to 2120. By 2120, the 100-year ARI is predicted to inundate a significant residential and commercial area.
- The Storm barrier plays a key role in inundation control. The risk of coastal inundation would be much greater if the storm barrier was not in operation.
- Much of the CBD is predicted to be under water during a 100-year and 500-year ARI storm in 2120. The crest of current storm barrier is about 2.1 m AHD, which is not predicted to be high enough to withstand these storms in 2120.
- Erosion is a significant risk for buildings and natural assets along the western coast of the CoB.
- Koombana Bay and Leschenault Inlet are heavily engineered. Erosion may still occur along shorelines not protected by structures.
- Access to the outer harbour (Casuarina Drive) is at risk from 2035.

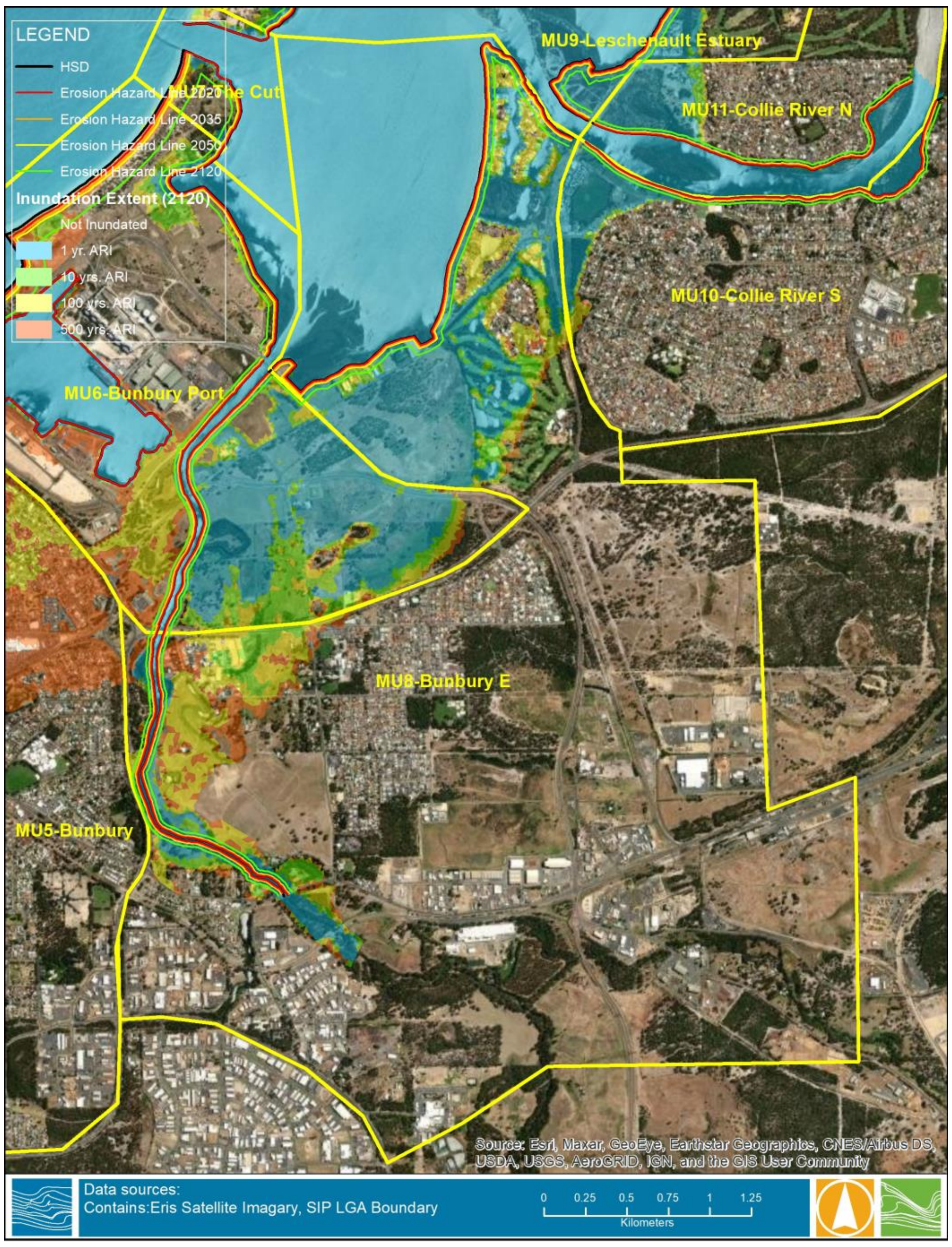
</td></tr>
<tr><td>MU6 – Bunbury Port</td><td>
</td><td>

- Inundation risk at the shipping yard and other lower ground areas.
- Main port facilities are not affected as they are located at higher ground and are protected by controlled shorelines.
- By 2120, the land near the entrance to the inner Port will be within the erosion hazard zone. Reinforcement may be required for shoreline segments not protected.
- It is noted that a high-level study using policy setbacks provides no additional value to the planning and management of lands along the Preston River (at the back end of the port).
  - Water Corporation levees have not been considered in the development of these lines

</td></tr>
</table>

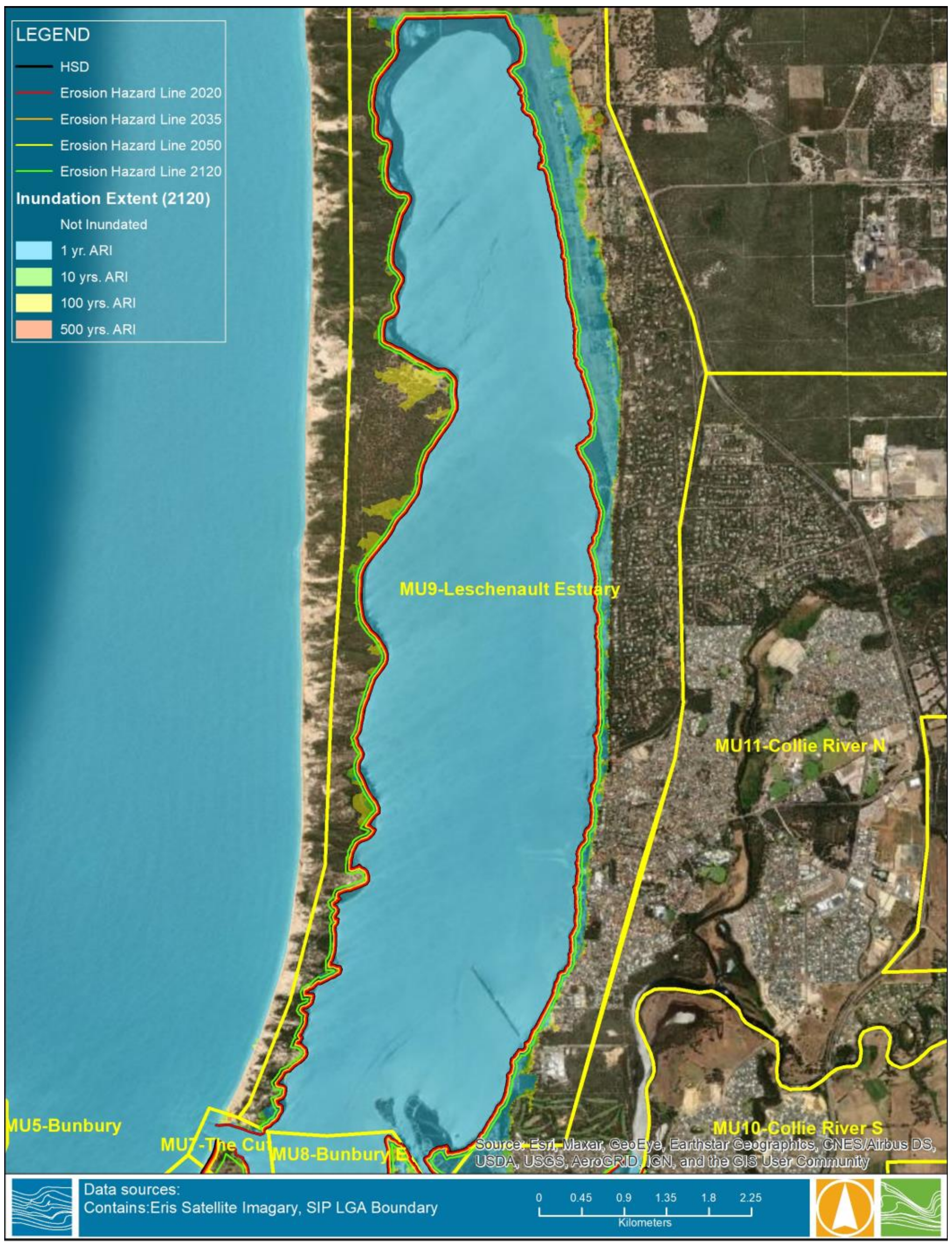
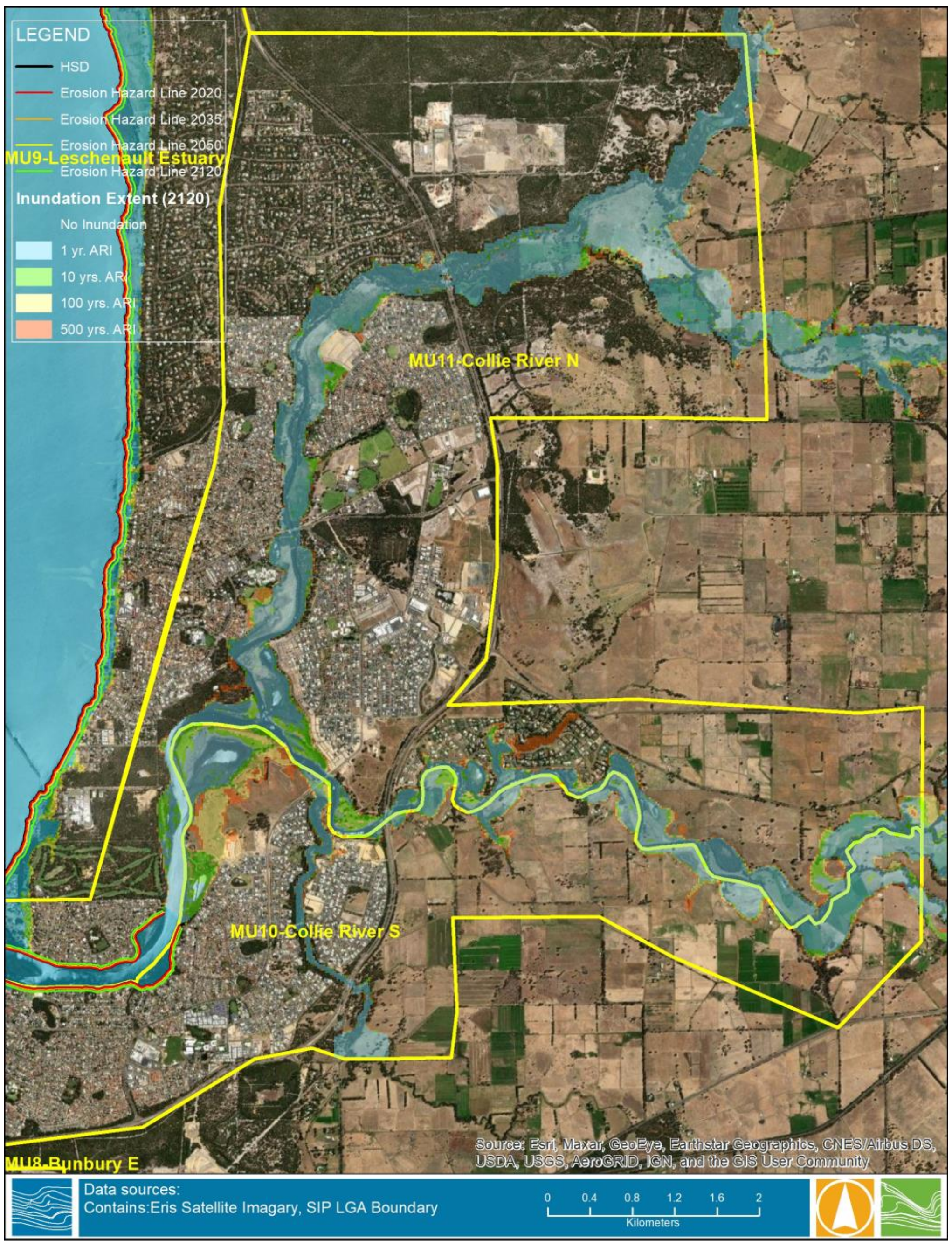
<table>
<tr><th>Management Unit</th><th>Erosion & Inundation Hazard</th><th>Summary</th></tr>
<tr><td>MU7 – the Cut</td><td>
</td><td>

- The Cut entrance is at risk of erosion by 2120. Seawater may erode the sand dune behind the seawall if it is not designed and constructed to standards. Attention must be paid to the impact of overtopping and breaching of the sand dune behind the seawall.
- Inundation is not a key risk in this management unit.

</td></tr>
<tr><td>MU8 – Bunbury E including Vittoria Bay, Pelican Point and Districts along Preston River</td><td>
</td><td>

- The areas surrounding Preston River and the Estuary are at risk of inundation from the present day.
- Foreshore Park and the commercial properties on Estuary Drive are predicted to be in the coastal erosion hazard zone by 2120.
- It is assumed the canal infrastructure will be maintained; however, the canal properties are at risk from erosion along the river and estuary fronts by 2120. This prediction however only serves the purpose of government planning and should not be used for risk assessment of individual properties.

</td></tr>
</table>

<table>
<tr><th>Management Unit</th><th>Erosion & Inundation Hazard</th><th>Summary</th></tr>
<tr><td>MU9 – Leschenault Estuary</td><td>
</td><td>▪ Inundation along the eastern shoreline of the estuary is a risk from the present day. This affects foreshore reserve and residential / commercial assets.
▪ Significant portions of land may be affected by tidal inundation by 2120. The majority of this is foreshore reserve, with the exception of the Australind Tourist Park.
▪ The predicted extent of inundation is greater than the extent of erosion, especially along the eastern shoreline of the estuary.</td></tr>
<tr><td>MU10 and MU11- Collie River Flood Plain</td><td>
</td><td>▪ Inundation is predicted to be mainly within the foreshore reserve.
▪ Erosion lines may impact some residential properties.
– It is noted that a high-level study using policy setbacks provides no additional value to the planning and management of lands along the Collie River. Erosion lines along the mid- and upper Collie River streams were not mapped due to the dominant impact from inland processes (erosion primarily controlled by soil composition, river floods and vegetation growth). MU10 and MU11 should be managed in accordance with DWER foreshore management policies.</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

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APPENDIX A
STUDY AREA LOCALITY PLANS

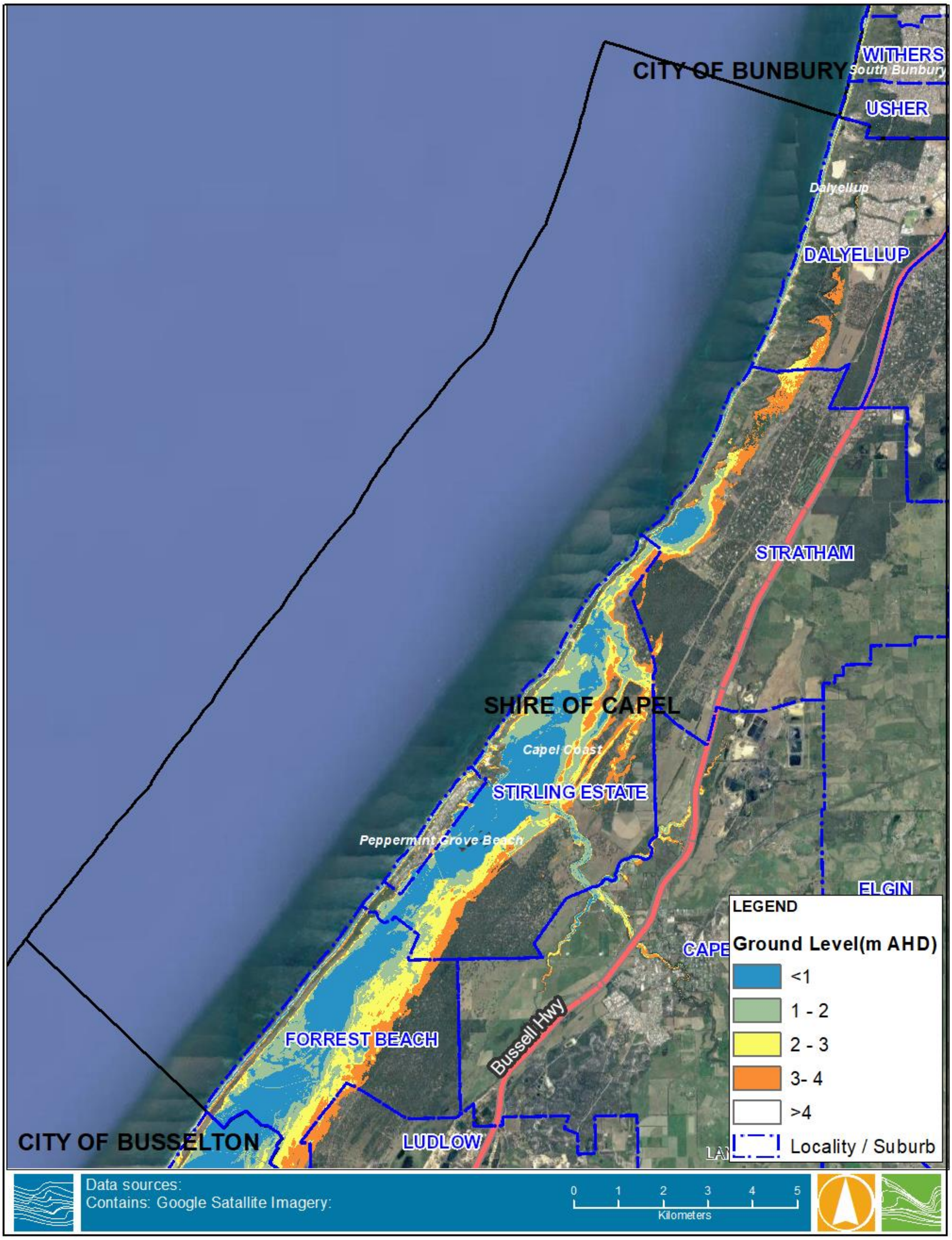


FIGURE A-1 SHIRE OF CAPEL PROJECT AREA (OVERLAYED ARE SUBURBS & ROADS AND GROUND LEVELS)

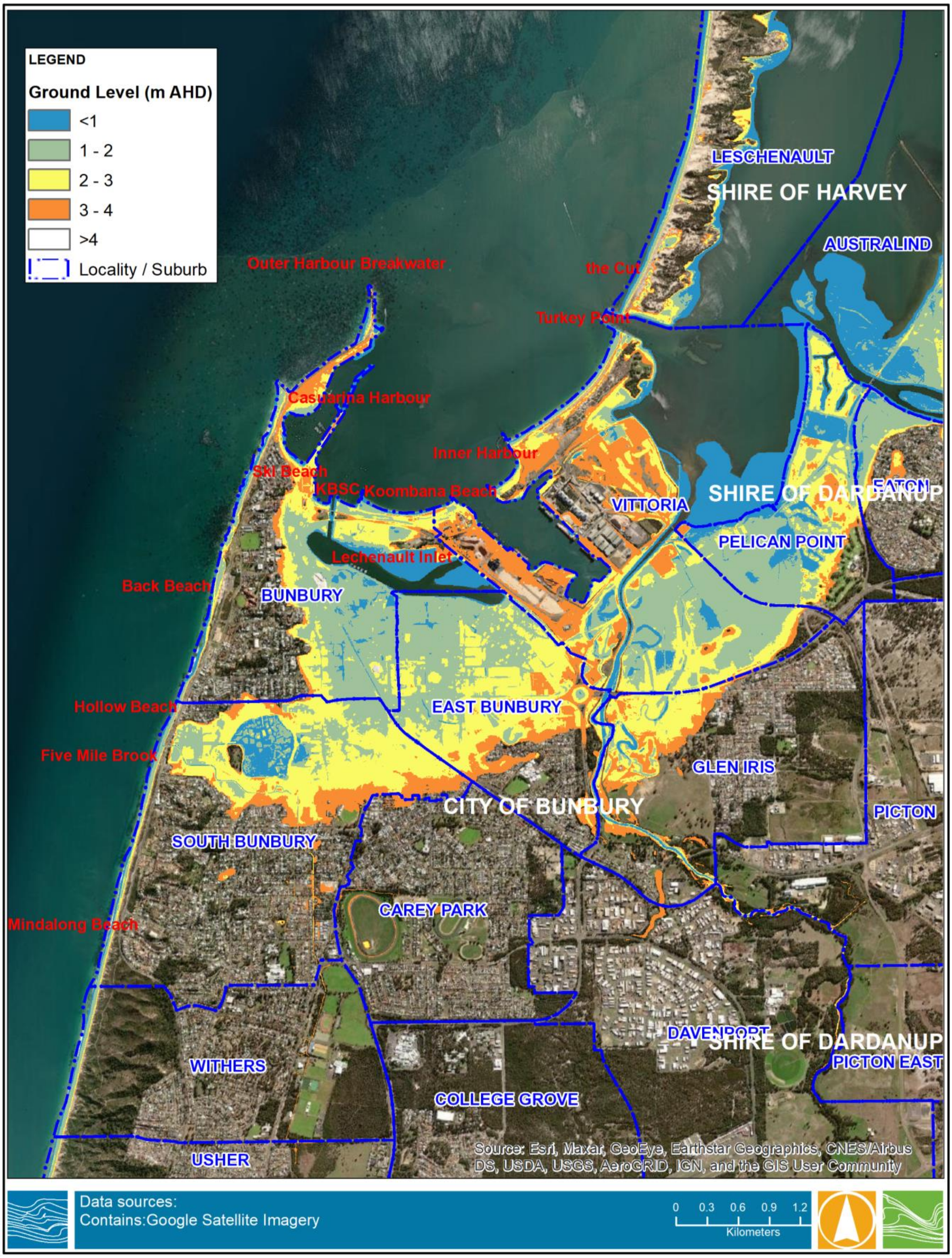


FIGURE A-2 BUNBURY PROJECT AREA (OVERLAYED ARE SUBURBS & ROADS)

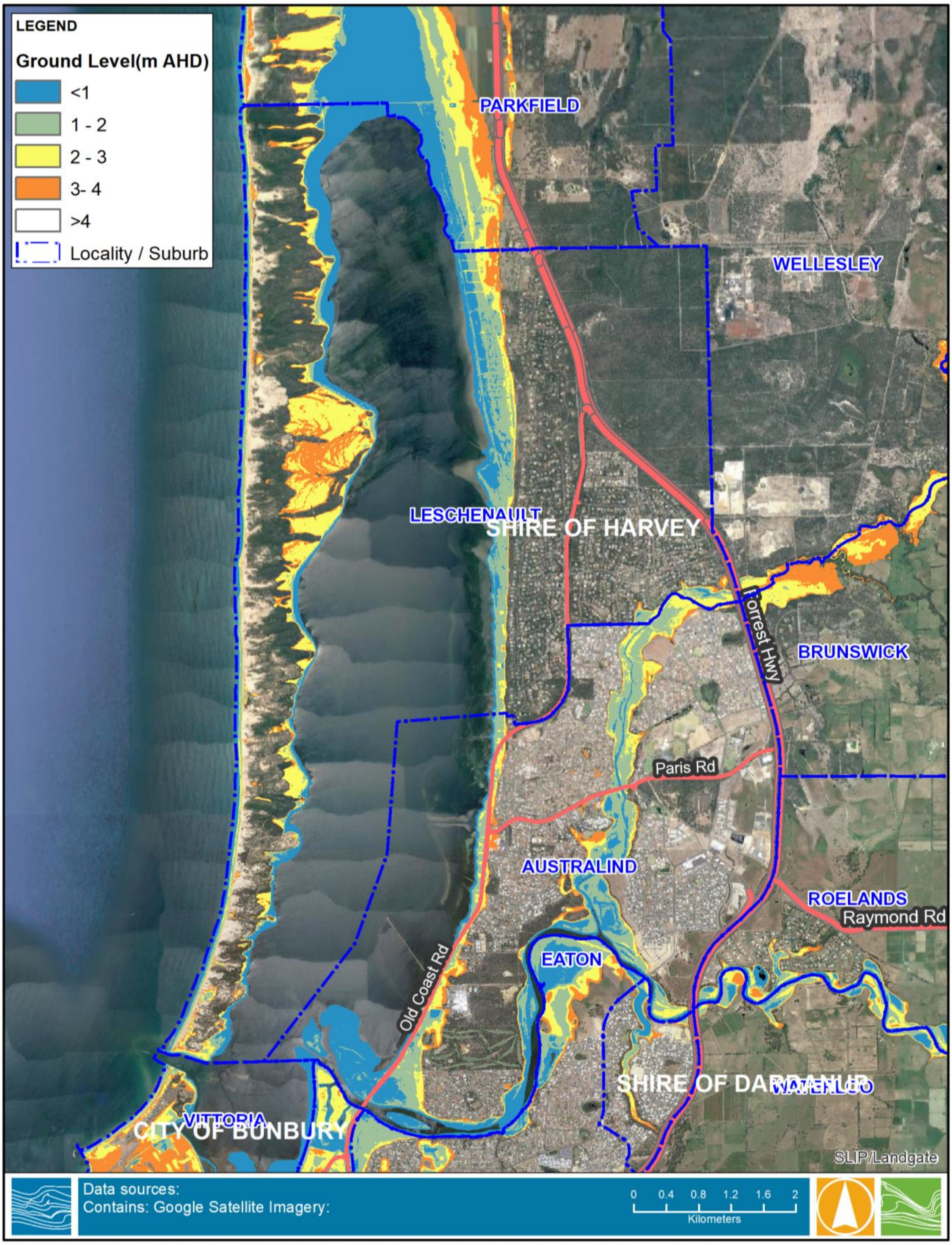


FIGURE A-3 SHIRE OF HARVEY PROJECT AREA (OVERLAYED ARE SUBURBS, ROADS AND GROUND LEVELS)

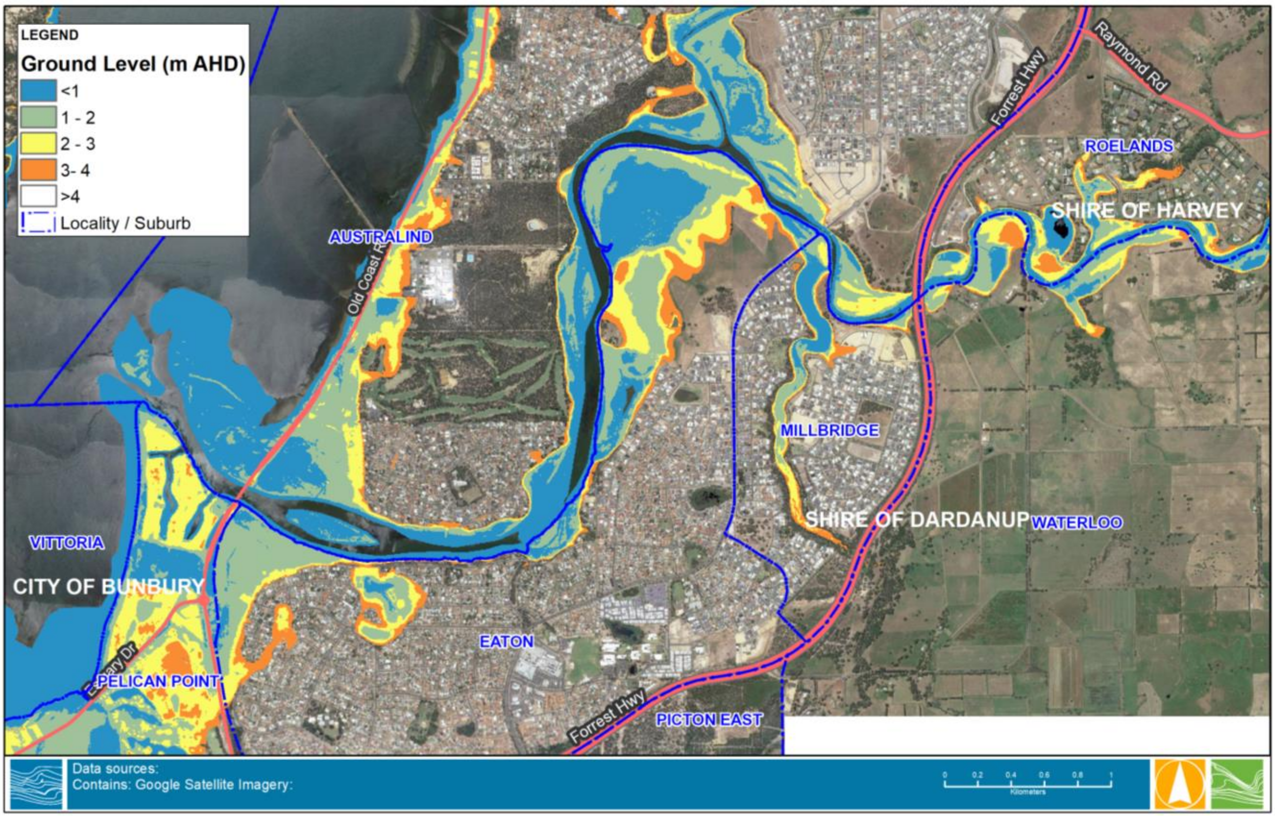
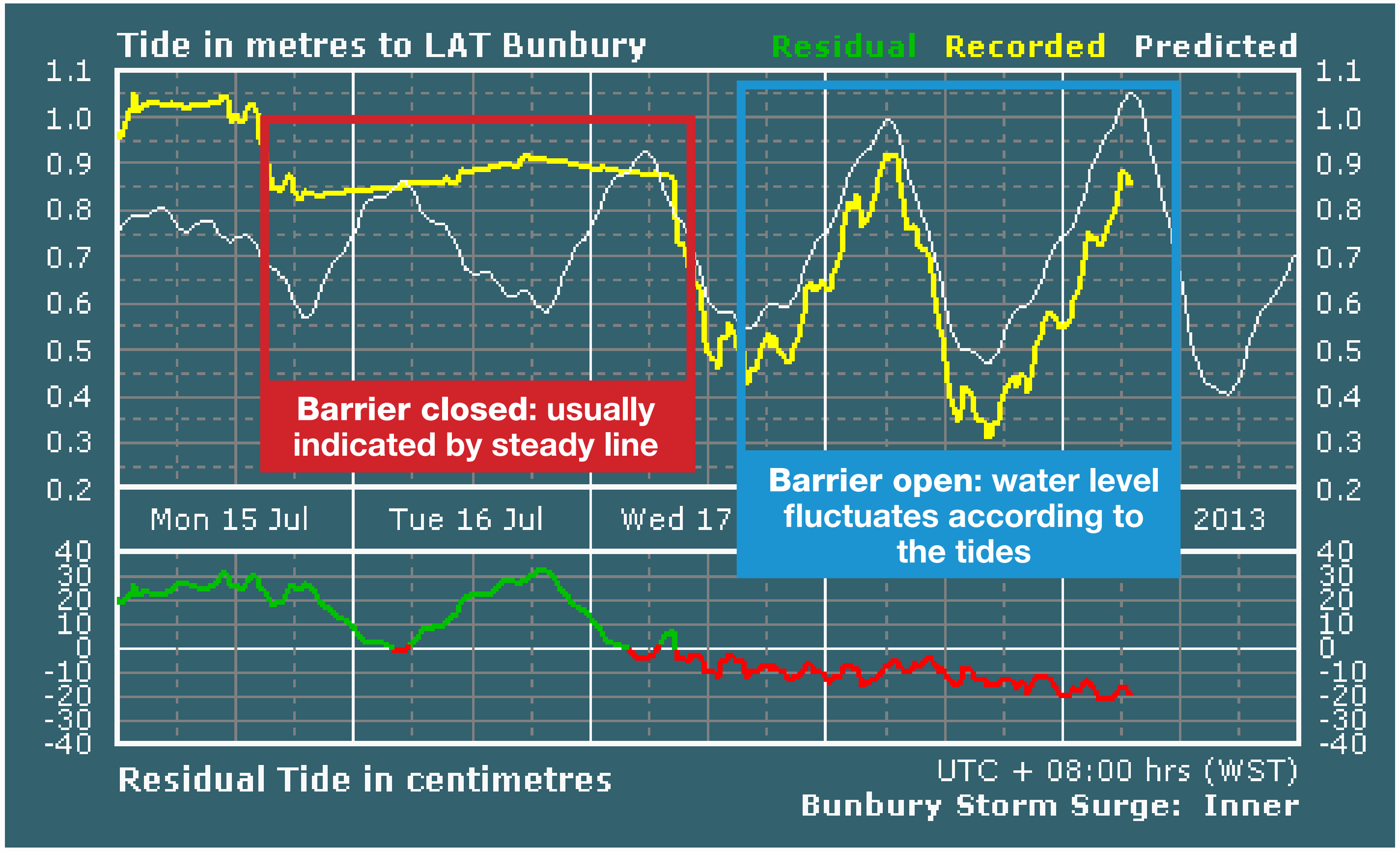


FIGURE A-4 SHIRE OF DARDANUP PROJECT SITE (OVERLAYED ARE GROUND LEVEL MAP, SUBURBS & ROADS)

APPENDIX B
STORM SURGE BARRIER DETAILS

Inner Storm Surge Barrier

Inside Leschenault Inlet



The graph is a plot of the actual water level (yellow line), predicted tide (white line) and the residual tide (green and red line: the difference between the actual water level and the predicted tide).

Before going boating on the Leschenault Inlet always plan ahead and check online at ***www.transport.wa.gov.au/imarine/ bunbury-storm-surge-barrier-tide.asp*** *if the barrier is closed or could be closed.*

Contact

Department of Transport
Coastal Management
Telephone: (08) 9435 7796
Email: bunburystormsurge@transport.wa.gov.au
Website: www.transport.wa.gov.au/imarine/ bunbury-storm-surge-barrier-tide.asp

August 2016 DoT 1484-36-01

Department of Transport

Bunbury Storm Surge Barrier

Purpose and Operation

Bunbury Storm Surge Barrier

The timely operation of Bunbury's storm surge barrier, at the western end of the Leschenault Inlet, is vital as it prevents flooding of Bunbury's low lying areas.

Location of the Bunbury Storm Surge Barrier.

Flooding of Bunbury, Cyclone Alby 1978.
Photo courtesy of The West Australian

The barrier was installed in 1980 following flooding of Bunbury townsite during cyclone Alby in 1978.

Today the barrier protects Bunbury's low lying areas from ocean flooding but careful consideration must be given to extended closure of the gates due to the threat of flooding from rainfall runoff.

Factors influencing operation

High ocean water levels are the main factor influencing the closing and opening of the barrier. High ocean water levels are caused by a combination of tide, wind and barometric pressure.

Significant high ocean water levels are most common from May to September during winter storms (low barometric pressure with strong winds) combined with high astronomical tides. However, high ocean water levels can also occur in summer associated with thunderstorms or ex-tropical cyclone events.

Based on analysis of water level information, drainage into the inlet, the duration the barrier may need to be closed, estimated rates of water level rise and damage to the City; the barrier should be closed at a maximum ocean water level of 1.2 metres above lowest astronomical tide (LAT).

Operation of the barrier

To prevent ocean and runoff flooding of Bunbury's low lying areas, the barrier may be closed before ocean water levels reach 1.2 metres LAT. When high ocean water levels are predicted, the barrier is closed to allow the CBD drainage network to fill the inlet without flooding. When high ocean water levels are predicted it is common for the barrier to be closed around 1 metre LAT.

It is rare for the barrier to be closed for extended periods; extended closure of the barrier is only likely during severe weather events.

Knowing when the barrier is closed

Two orange lights are located on the light post at the barrier and flash on and off when the barrier is closed.

The best way to find out if the barrier is closed is to check online at ***www.transport.wa.gov.au/imarine/bunbury-storm-surge-barrier-tide.asp***

Storm surge water levels can be viewed live online and can be interpreted to determine when the barrier is closed.

A	A-500	3-5-82	LUG FOR GATE RESTRAINING CHAIN ADDED	GRC	I.K.
	ZONE	DATE	REVISION	DR'N	APP'D
	SURVEY BOOKS			FILE No.	
				PW 1001/75	

GENERAL NOTES

1. UNLESS OTHERWISE SHOWN ALL DIMENSIONS ARE IN MILLIMETRES
2. THIS DRAWING TO BE READ IN CONJUNCTION WITH THE SPECIFICATION
3. STEEL: A.S. 1204-'72, GR 250 OR AS SHOWN. FABRICATION: AS. 1250-'75. WELDING: A.S. 1554 PT 1 & 2-'74
4. ALL WELDS 10 SEALED FULL CONTINUOUS FILLET UNLESS OTHERWISE SHOWN.
5. ALL CRS TO A.S. G18-'66 GRADE G18/EN 58 H, OR A.S. 1449-'79 GRADE 1449/316, AS APPLICABLE

SCALES AS SHOWN
MICROFILMED A
DATUM
ZERO ON THE TIDE GAUGE WHICH IS 0·640 m BELOW A H D

DESIGN CALC. MJT — BOOK & FILE II
CHECKED S.D.S. — BOOK 3
DRAWN W.A.S. — CHECKED I.K.
TRACED — CHECKED

SUBMITTED M.J. Tarca ENGINEER — DATE 4/9/79
APPROVED ENGINEER FOR DESIGN — DATE 5-9-79

PUBLIC WORKS DEPARTMENT — WESTERN AUSTRALIA

BUNBURY FORESHORE
LESCHENAULT INLET - STORM SURGE BARRIER
'U' FRAME & GATES, ARRANGEMENT & DETAILS

P.W.D., W.A. 51788-4-1 — REV'N A

APPENDIX C
MIKE HD AND SW MODELLING

C-1 Model Tools

DHI's MIKE21 Hydrodynamics (HD) and Spectral Wave (SW) model were used to investigate the coastal erosion and inundation hazards.

- The DHI MIKE 21 Hydrodynamic model resolves the Reynolds-averaged Navier-Stokes, depth-integrated hydrostatic equations and is capable of simulating hydraulic and environmental phenomena in oceans, lakes, estuaries, bays and coastal areas.
- The DHI MIKE 21 Spectral Wave (SW) model is a fully spectral wave model that simulate the growth, propagation, refraction and diffusion of wind waves.

DHI MIKE 21 HD and SW models can be run either in coupled or decoupled modes, depending on project applications and key coastal processes to be modelled.

In this study, coastal inundation hazard is investigated through a coupled HD/SW model with inclusion of cyclonic winds and radiation stress to account for impacts from wind and wave set up, as well as river discharge inputs to account for the impact of catchment flow.

For Collie River, the existing MIKE flood model (refer Section 3.5) has been used to evaluate the river flood impact in response to a combined effect of river flood and storm surge, as well as impacts from climate change.

For erosion hazard, MIKE SW model is used to simulate the process of erosive waves for identified design storms with results extracted as inputs for beach erosion modelling.

Model Grid and Bathymetry

Two sets of model mesh are used:

- For the HD model and inundation hazard assessment, a finer mesh was used with the model domain including the river courses as well as the land depressions along the SOC (Shire of Capel) coastline. The coverage of the model mesh and bathymetry are shown in Figure C-5. The model domain extends for about 100 km along the coast and about 60km offshore. The mesh is comprised of a combination of triangular and quadrangular elements (river channel). The grid size ranges from over 5 km offshore to less than 10 m in the river channels. Typically, 20-30 m elements are used to resolve the low-lying land at Bunbury.
- For the SW model and erosion hazard assessment, a coarser mesh was used with the model domain excluding the river courses due to their minimal impacts on wind wave conditions. The coverage of the model mesh and bathymetry are shown in Figure C-6. The model domain extends for about 100 km along the coast and about 60km offshore. The computational triangular mesh of the model is sufficiently sized (~30 m near project site) to resolve the detailed wave conditions inside the Koombana Bay and the estuary.

The bathymetry was developed using the LiDAR data (up to 30 m depth and on land) and hydrographic survey data (in water) supplied by the Department of Transport (DoT), and Australia Geoscience 250 m resolution bathymetry data to fill gaps wherever DoT LiDAR /hydrographic survey data are not available.

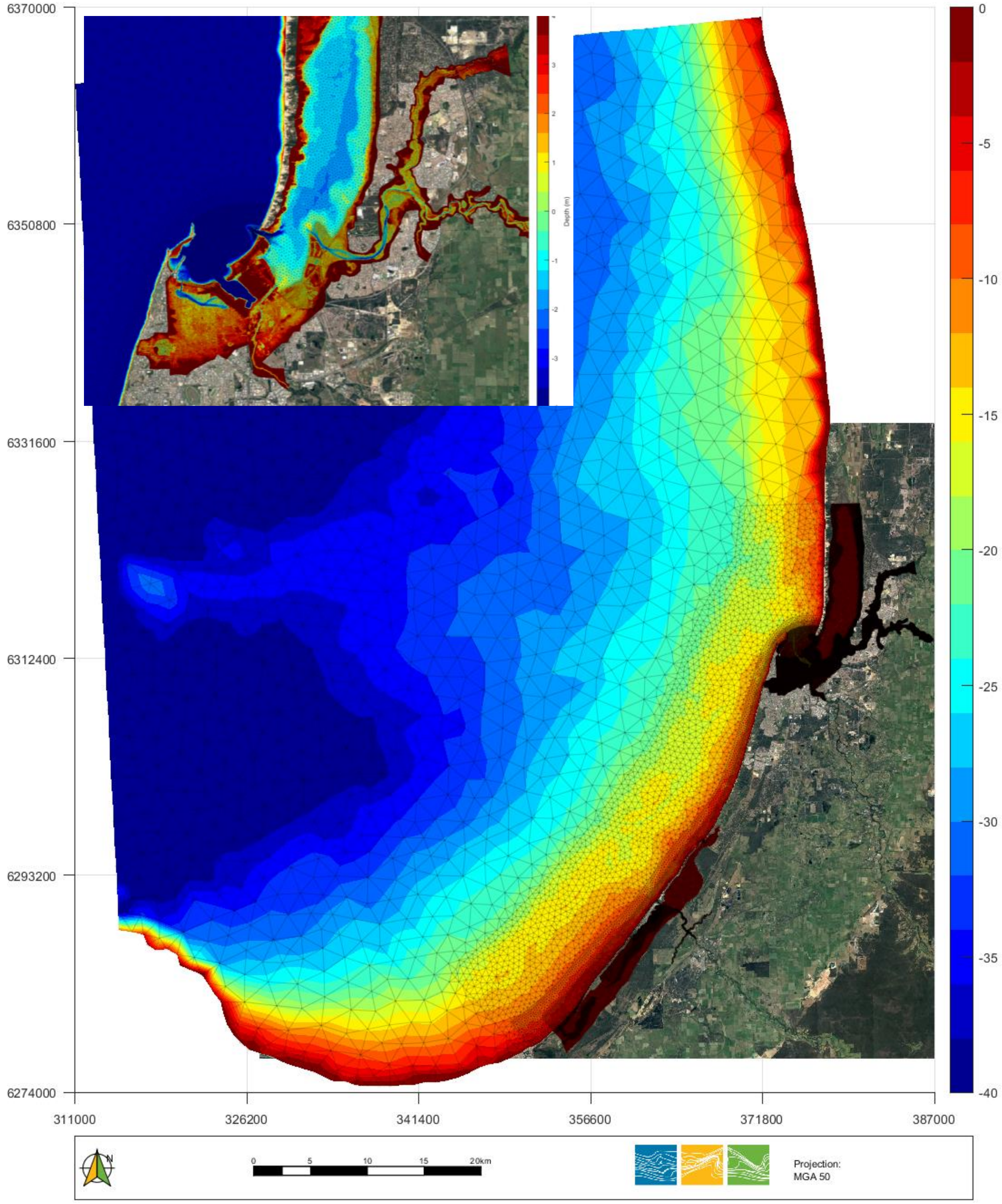


FIGURE C-5 HD/SW MODEL MESH AND BATHYMETRY FOR INUNDATION HAZARD ASSESSMENT

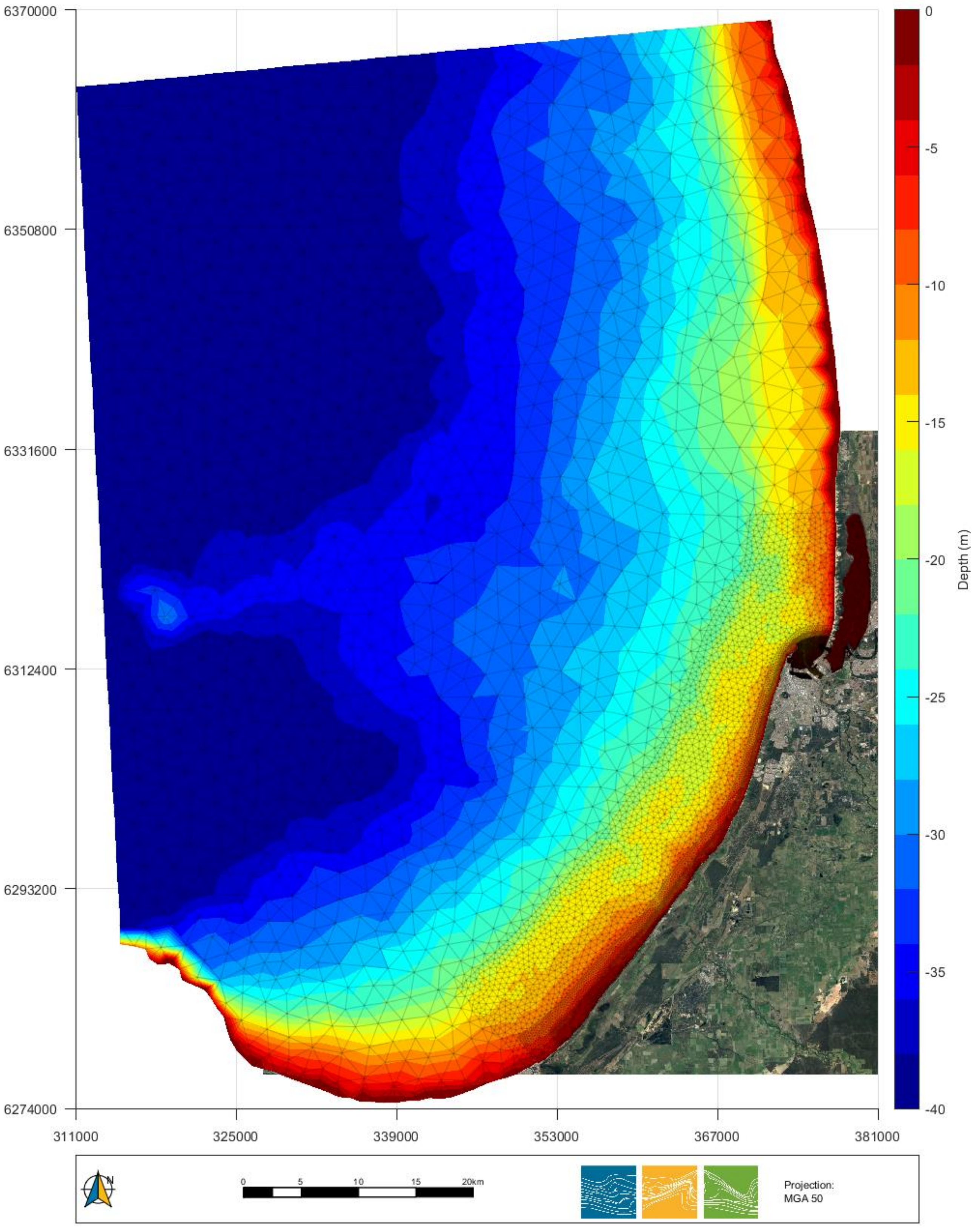


FIGURE C-6 SW MODEL MESH AND BATHYMETRY FOR EROSION HAZARD ASSESSMENT

C-2 Storm Surge Model

MIKE Storm surge model has been used to simulate the inundation extent in coastal zone from Capel to Leschenault estuary. The approach was proposed to account for the complexity of inundation process in Leschenault estuary and at land depression of Capel which cannot be accurately assessed by simple bathtub model (may overestimate the inundation risk). The model however does not attempt to replace the existing flood model along Collie River which has been carefully calibrated through inclusion of MIKE11 network, bridge network which are crucial inputs to simulate accurate river hydraulics.

Although our storm surge model includes all the river courses, model results along Collie River are trimmed to avoid confusion. River courses are included only to provide discharge input to the estuary so inundation extent within the reach of tide and SLR can be properly modelled. Inundation risk along the Collie River (for region beyond the impact of tide/SLR) is mapped directly from DWER flood model results.

Water Technology storm surge model has included structures over land to reduce the overflow of flood water across the riverbanks and roads due to limitation in 2D model resolution (~20 m). This has provided more reasonable prediction of flood over land that affected by roads and other structures, in the absence of higher resolution surface flood model.

Rainfall, infiltration, and evaporation are excluded from the model. It is not possible to simulate rainfall related urban flood without inclusion of urban drainage networks and rainfall/catchment analysis which was excluded from the scope of current CHA.

The MIKE storm tide simulates the dynamic process of coastal inundation in response to combined effects of storm winds, waves and tide. The approach is less conservative while more appropriate than the bathtub model which used a constant storm tide level everywhere to approximate the inundation risk which may overestimate the inundation risk in the estuary and at the land depression of Capel.

C-2-1 Model Inputs

Cyclone

The 500-year ARI storm is modified from the track information of TC ALBY which was suggested to have about 200-year ARI return period by Fountain, L., (2010). The track is shifted to the northeast by about 100 km, which generates a westerly cyclonic wind at Bunbury.

The modelled peak cyclone wind speed is in order of 30 m/s which is in line with the measured wind speed at Bunbury by BoM report (wind gust exceeding 36 m/s or equivalently hourly wind of 24 m/s of maximum scaled reading of the anemometer).

The maximum wind radius (MWR) of Alby near Bunbury is much larger at 50km than typical MWR in tropical region (<40km) due to extra-tropical transition and changes in Coriolis force from earth rotation. Similarly, the central pressure was higher at 930 hPa.

The modelled storm tide is about 2.8 m in Koombana Bay at peak storm which is in line with the value reported by previous studies (see section 2.2.1.3 & Table 2-2).

Overall, the approximated cyclone wind field for 500-year ARI storm is considered as appropriate for the purpose of this CHA.

Water Level

For the 500-year ARI storm, the water level boundary is taken from the tidal levels for the same period (April 1978) when TC Alby occurred.

For lower return period events, a typical tidal sequence is used with peak water level matched to the projected peak storm tide levels per Table 2-2. In this case, a storm process (four days duration) has been added over the regular tide signal. This has provided a more conservative storm tide boundary conditions for the simulation of inundation in coastal region and more importantly the attenuated impact in Leschenault estuary.

River runoff

River runoffs are sourced directly from DWER flood model inputs. The 1 yr. river runoff is scaled down from the 10 yr. river runoff sequence with factors estimated from analysis of peak river discharge projections. File Mile Brook discharge is taken from Water Technology existing model. Capel River discharge is composed from the peak river discharge projections and typical flood process of the river.

Review of historic flood events show that the peak river flood event is not correlated with severe storm tide events. Per DoW (2014), the most severe river flood event was in 1964 while the most severe coastal flood event was in 1978. TC Alby only brought a moderate and short rainfall compared to longer duration winter storms. In this study, the timing of river flood has been shifted to be in the same day as the maximum storm surge. This provides a more conservative estimate of coastal inundation where the river flood may elevate the water level in the estuary/coastal water, especially for area close to the river mouths.

Friction/ Roughness

Friction map over land and along the river courses is sourced from DWER existing model. The roughness of land/riverbed is represented by Manning's Number (m1/3/s). The land use type across the model area has been mapped and ground-truthed by the Water Science branch of the Department of Water. The land use map was simplified by combining different land use types that were expected to have a similar roughness coefficient.

Friction over the ocean basin is set as appropriate based on previous experience of the region (ranging from 30-60, depending on bottom type and depth). Model calibration has shown good results in storm surge modelling and little impact were found to be associated with configuration of bottom friction.

Structures

Main structures that may affect coastal flooding are implemented in the model including elevated roads, riverbanks, key culverts in potential coastal flooding zone. The model does not however include MIKE11 river networks, urban drainage networks, river survey profiles, culverts, bridge networks.

C-2-2 Model Calibration

Water levels were calibrated to Bunbury tidal gauge for the period during Tropical Cyclone (TC) Alby with results presented in Figure C-7. Overall, the model exhibits great performance in replicating the observed storm surge at Bunbury (black dash line). The hydrodynamic model was calibrated appropriately for primary parameters such as bottom friction and wind drag coefficient and deemed suitable for the purpose of this coastal hazard assessment.

As per conversation with DoT, the measured tidal Levels in 1978 were manually digitalised so there may be some uncertainty in the quality of data. The measured peak surge was however in line with information reported by post storm survey.

C-2-3 Model Sensitivity Test

Additional simulations are undertaken to evaluate the impact of cyclone intensity and track shifting.

Sensitivity test shows that 10% increase in cyclone intensity (centre pressure drop) only increase the storm tide level for 0.1-0.3 m, indicating a relatively moderate impact from cyclone intensity. The most significant impact is associated with track location changes which have increased the storm tide level from 1.8 m AHD to over 2.8 m AHD at Bunbury. This is because the original Alby track was about 100 km off the coast of Cape Leeuwin, for which the cyclone impact was attenuated.

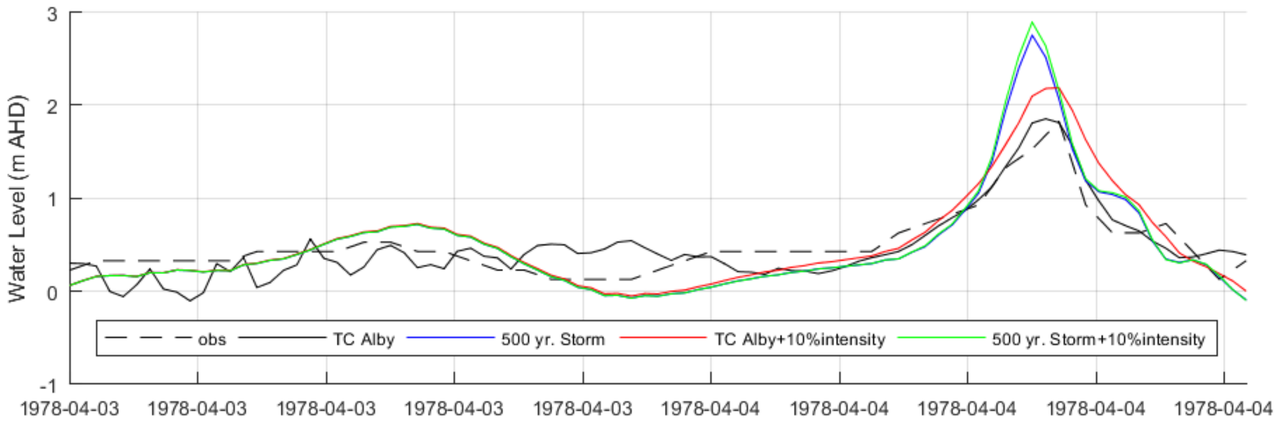


FIGURE C-7 WATER LEVEL CALIBRATION (BUNBURY TIDAL GAUGE, 1978)

C-2-4 Model Results Summary

The modelled peak steady water levels are extracted at locations shown in Figure C-8. Results extracted at are presented in Table C-1. An example of spatial distribution of modelled inundation levels (500 yrs. ARI) are shown in Figure C-9.

TABLE C-1 MODELLED PSWL (M AHD) FOR 1, 10, 100 AND 500-YEAR ARI EVENTS

Locations	Peak Steady Water Level (m AHD)															
	Present				2035				2050				2120			
	1 yr.	10 yrs.	100 yrs.	500 yrs.	1 yr.	10 yrs.	100 yrs.	500 yrs.	1 yr.	10 yrs.	100 yrs.	500 yrs.	1 yr.	10 yrs.	100 yrs.	500 yrs.
1	1.1	1.5	1.9	2.1	1.2	1.6	2.1	2.3	1.3	1.7	2.2	2.9	2.1	2.4	2.9	3.1
2	1.1	1.5	1.9	2.1	1.2	1.6	2.1	2.3	1.3	1.7	2.2	2.9	2.1	2.5	2.9	3.1
3	1.1	1.5	1.9	2.1	1.2	1.6	2.1	2.3	1.3	1.7	2.2	2.9	2.1	2.4	2.9	3.1
4	1.1	1.5	1.9	2.1	1.2	1.6	2.1	2.3	1.3	1.7	2.2	2.9	2.1	2.4	2.9	3.1
5	1.1	1.5	1.9	2.1	1.2	1.6	2.1	2.3	1.3	1.7	2.2	2.9	2.1	2.4	2.9	3.1
6	1.1	1.4	1.9	2.1	1.2	1.6	2.0	2.2	1.3	1.7	2.1	2.9	2.1	2.4	2.9	3.1
7	1.1	1.4	1.9	2.1	1.2	1.6	2.0	2.2	1.3	1.7	2.1	2.9	2.1	2.4	2.9	3.1
8	1.1	1.4	1.9	2.8	1.2	1.5	2.0	2.9	1.3	1.6	2.1	2.9	2.1	2.4	2.9	3.7
9	1.1	1.4	1.9	3.0	1.2	1.5	2.0	3.1	1.3	1.6	2.1	2.9	2.1	2.4	2.9	3.9
10	1.1	1.4	1.9	2.8	1.2	1.5	2.0	2.9	1.3	1.6	2.1	2.9	2.1	2.4	2.9	3.7
11	1.1	1.4	1.9	2.7	1.2	1.5	2.0	2.9	1.3	1.6	2.1	2.9	2.1	2.4	2.9	3.7
12	1.1	1.4	1.9	2.7	1.2	1.5	2.0	2.9	1.3	1.6	2.1	2.9	2.1	2.4	2.9	3.7
13	1.1	1.4	1.9	2.7	1.2	1.5	2.0	2.8	1.3	1.6	2.1	2.8	2.1	2.4	2.8	3.6
14	1.3	1.6	2.0	2.8	1.4	1.7	2.1	2.9	1.5	1.8	2.2	2.9	2.2	2.5	2.9	3.7
15	1.2	1.5	1.9	2.7	1.3	1.6	2.0	2.8	1.4	1.7	2.1	2.9	2.1	2.5	2.9	3.6
16	0.0	1.6	2.0	2.9	0.0	1.7	2.1	3.0	1.4	1.8	2.2	2.9	2.2	2.5	2.9	3.9
17	1.1	1.4	1.9	3.0	1.2	1.6	2.0	3.1	1.3	1.7	2.1	2.8	2.1	2.4	2.8	3.9
18	1.2	1.5	1.9	2.8	1.3	1.6	2.0	2.9	1.4	1.7	2.1	2.9	2.1	2.4	2.9	3.7
19	1.1	1.4	1.8	2.7	1.2	1.5	1.9	2.8	1.3	1.6	2.0	2.8	2.1	2.4	2.8	3.6
20*				1.2				1.3				1.9		0.6	1.9	2.6
21	0.0	0.0	1.1	1.7	0.0	0.0	1.1	1.8	0.0	0.0	1.1	2.4	0.0	1.2	2.4	2.3
22	1.2	1.6	2.4	2.7	1.2	1.7	2.4	2.8	1.2	1.7	2.4	2.8	1.5	1.9	2.8	3.2
23	1.0	1.2	1.5	2.3	1.1	1.2	1.5	2.4	1.1	1.2	1.6	2.4	1.2	1.5	2.4	3.4

* Storm surge barrier modelled as a DIKE, closed for all scenarios as storm surge is >0.7m AHD. For storm surge values <2.1 m AHD (the barrier level), water does not enter the inlet. For storm surge values >2.1 m AHD, a reduced volume flows into the inlet, due to the presence of the barrier in the model.

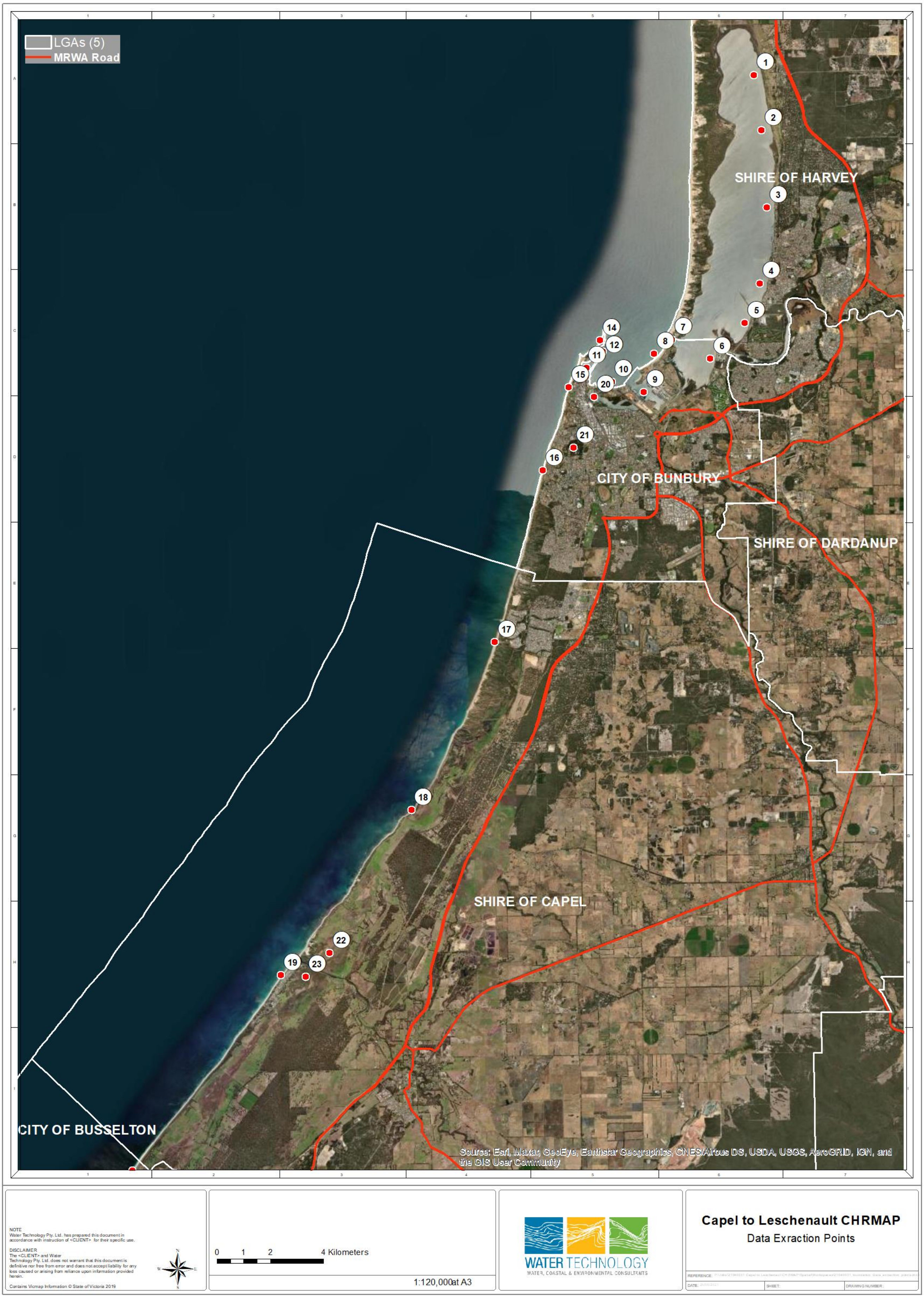


FIGURE C-8 DATA EXTRACTION POINTS

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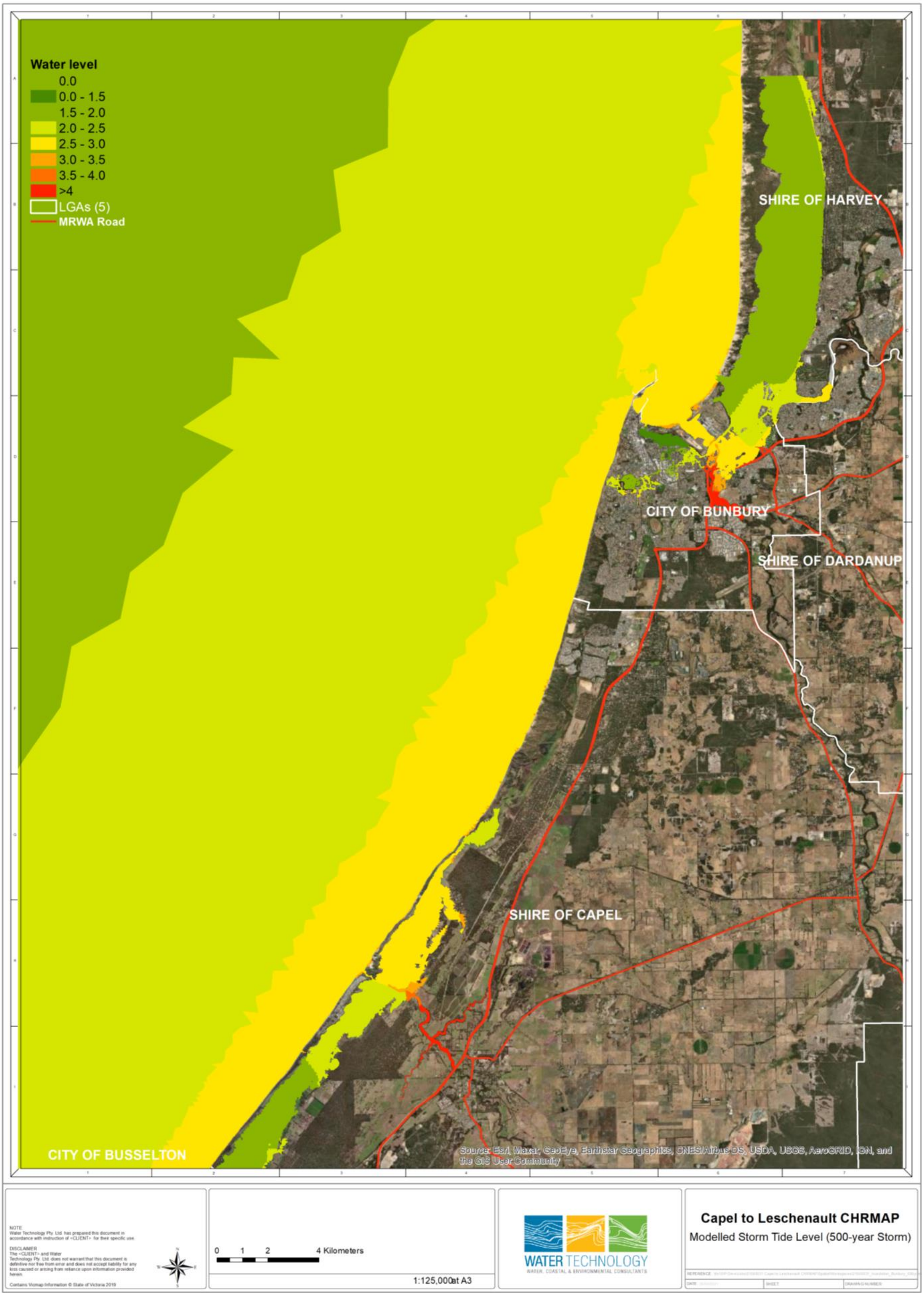

FIGURE C-9 INUNDATION EXTENT AND PSWL DURING A 500 YRS. STORM – 2120

C-3 Spectral Wave Model

C-3-1 Wave Calibration

The wave model was calibrated to measurements obtained at Bunbury Port Beacon 3 in 2015 (Figure C-10). Model results show very good agreement between modelled and observed waves. Key wave parameters e.g., Hs, Tp and Mean Wave Direction were all well simulated for both magnitude and timing of storm peaks.

The model configuration has been optimised to represent local conditions of the region. Applied wave-breaking parameters in the model are gamma = 0.8 and alpha = 1. Bottom friction is determined based on Water Technology's experience in the study area as well as friction map used by DWER Collie River flood modelling. Overall, modelling settings have been reviewed and considered suitable for the purpose of this coastal hazard assessment.

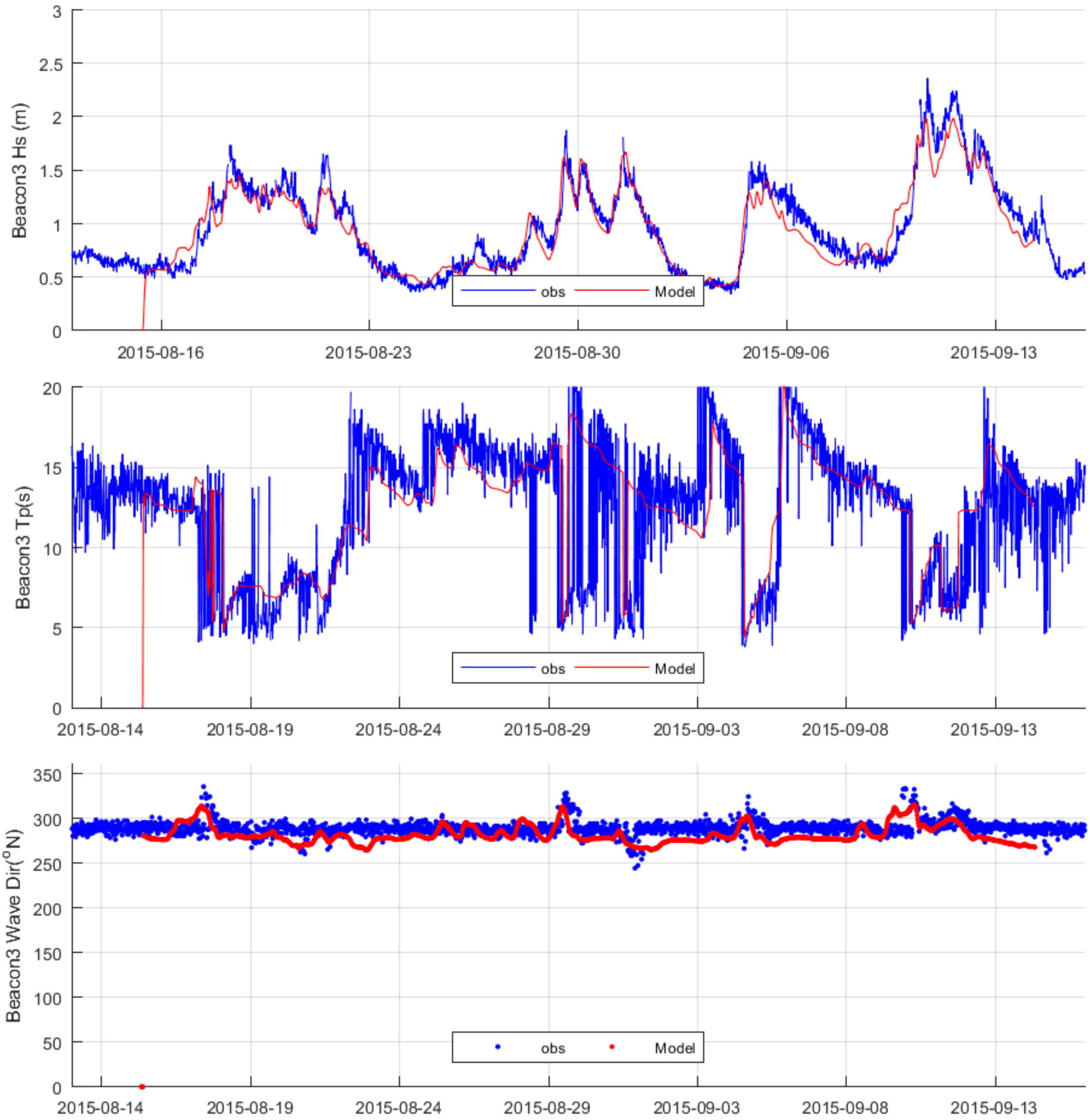

FIGURE C-10WAVE MODEL CALIBRATION (BEACON 3, 2015)

C-3-2 Model Results

Water Technology simulated the 100-year ARI event, selected based on its Total Wave Power and potential to cause coastal erosion; storm "a" was selected (MPRA 2018). The simulation was run in HD/SW coupled mode, to allow for water level feedback into the wave calculation. The model was forced with the supplied water level, wind and wave parameters at part of MPRA (2018). Figure C-11 shows the maximum of wave heights simulated during the 100-year ARI storm event. The modelled Hs ranges from over 3 metres nearshore to less than 1.5 m at Koombana Beach, less than 1 m near the entrance of Casuarina Harbour, less than 0.2 m inside the Casuarina Harbour/Leschenault Inlet and less than 0.8 m inside the Leschenault Estuary.

Model results are extracted to drive the SBEACH model for the erosion hazard assessment. Refer Appendix D below for time series plots of the key parameters from this storm.

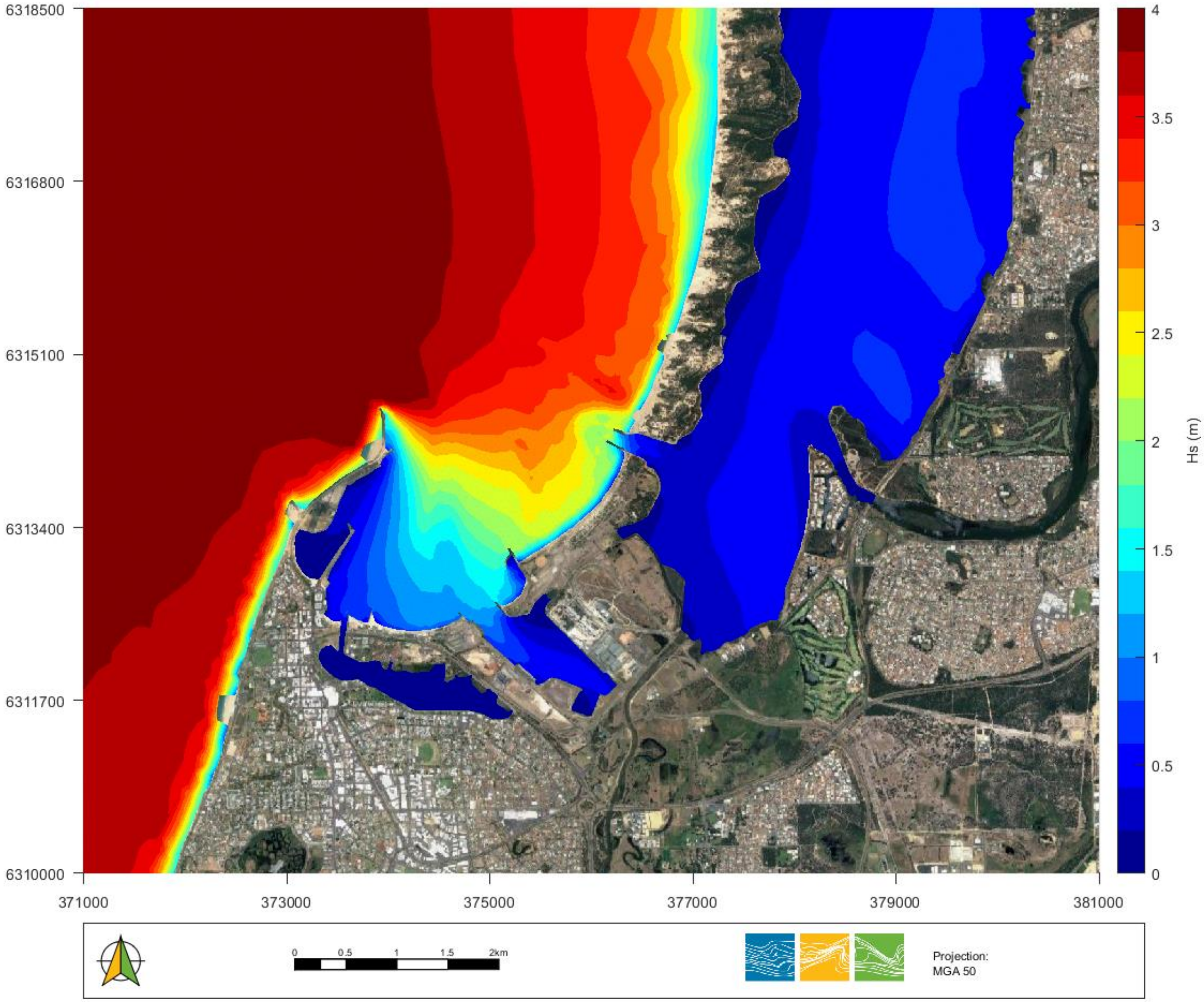

FIGURE C-11MAXIMIUM WAVE HEIGHT DURING THE 100 YRS. ARI STORM

APPENDIX D
EROSION HAZARD MODELLING

D-1 S1 – Acute Erosion Allowance

The potential for storm-induced erosion was assessed using the SBEACH numerical model. This model was developed to calculate short term wave induced erosion and has been utilised in a range of studies including numerous shoreline erosion/stability assessments in Western Australia.

A variable grid resolution (1 to 50m grid size) was applied extending from the landside of the dune system to the depth of closure. In the active zone, a 1 m resolution grid was applied. DoT Lidar (from ~-30 m contour landwards) and survey data (where available) have been merged to generate the nearshore seabed and beach face elevation for bathymetry inputs. Sediment grain sizes (Table D-2) are obtained from review of existing studies in this region (Seashore Engineering (2013), GHD (2019) and Semeniuk (2000)) as well as established knowledge of sediment along southwest coast of WA. Other model settings e.g., temperature, transport rate coefficient, transport rate decay coefficient, avalanche slope and surf zone depth etc are configured as appropriate and in line with the model manual.

Critical model inputs utilised include:

- Digital elevation data to maximum -10 m AHD contour offshore
- Time-series of water level for each design event (tide plus surge)
  - Extracted from the 100-year ARI Storm a simulation (described above in Section C-3-2)
- Time-series of significant wave height (Hs), Peak wave period (Tp) and Wave direction (Wdir) for each design event
  - Extracted from the 100-year ARI Storm a simulation
- Sediment size as presented in Table D-2 below.

TABLE D-2 SEDIMENT SIZE INPUTS FROM LITERATURE REVIEW

Point	1-19	20	21	22	23	24-28	29	30	31	32	33-35
D_{50} (mm)	300	400	360	180	250	225	125	500	250	125	250

D-1-1 SBEACH Profiles

The 35 SBEACH profile locations are presented in Figure D-12.

D-1-2 Storm Inputs

Storms representing open coast, Koombana Bay and the Leschenault Estuary are presented in Figure D-13 to Figure D-15 respectively. The open coast and Koombana Bay storms were extracted from the HD/SW simulation; a constant storm was applied within Leschenault Estuary, representing the worst conditions observed during the simulation.

D-1-3 Model Results

Model results for each profile are presented in Figure D-16 to Figure D-20.

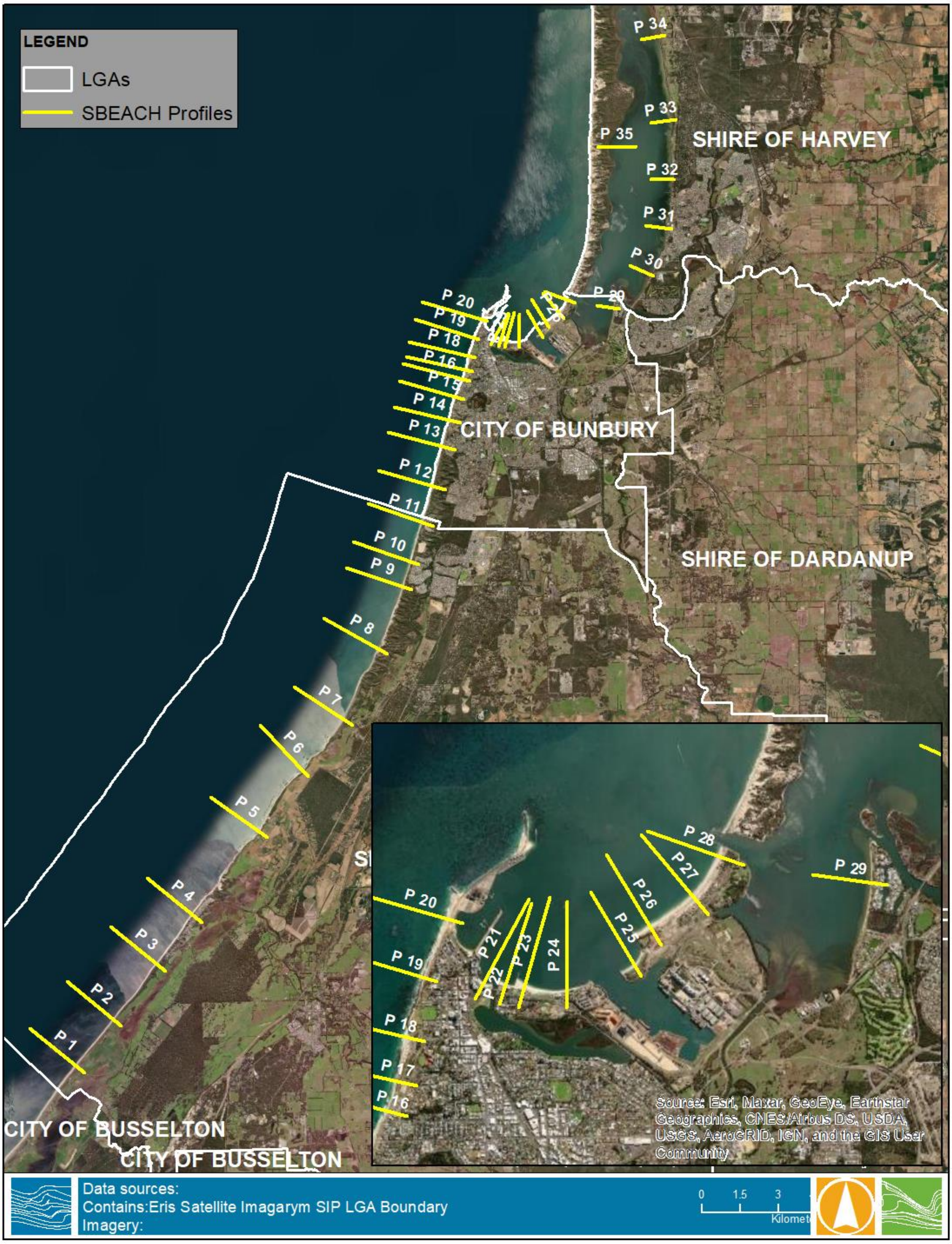

FIGURE D-12SBEACH PROFILES

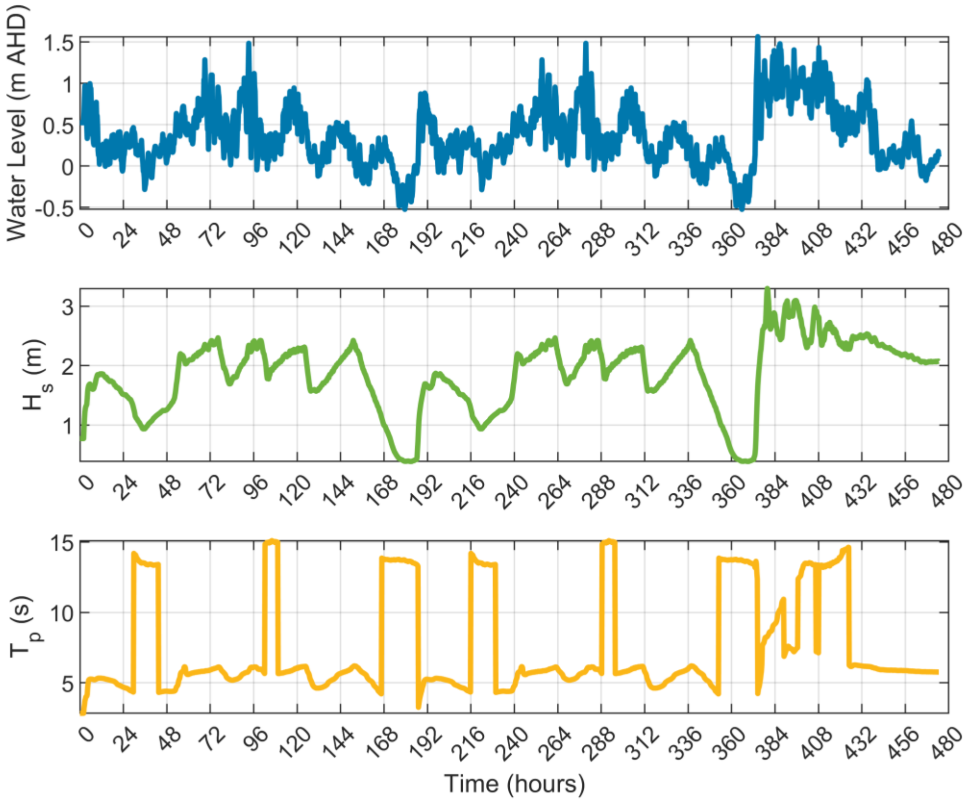

FIGURE D-13OPEN COAST SBEACH MODEL FORCING FOR 100 YRS. ARI STORM

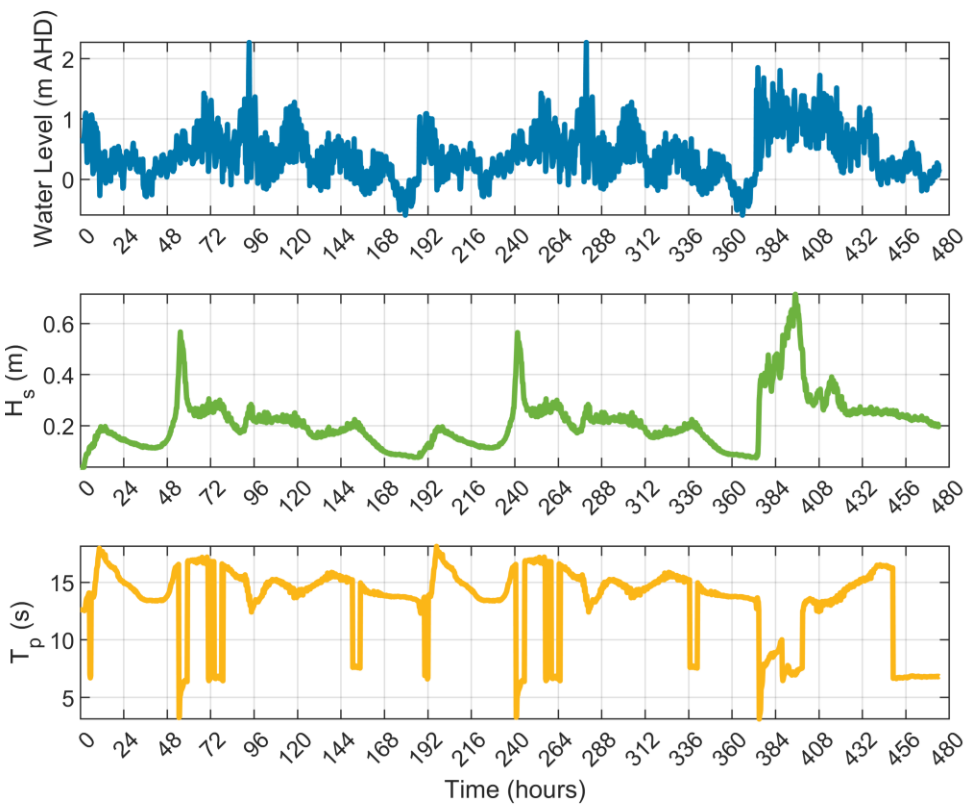

FIGURE D-14KOOMBANA BAY SBEACH MODEL FORCING FOR 100 YRS. ARI STORM

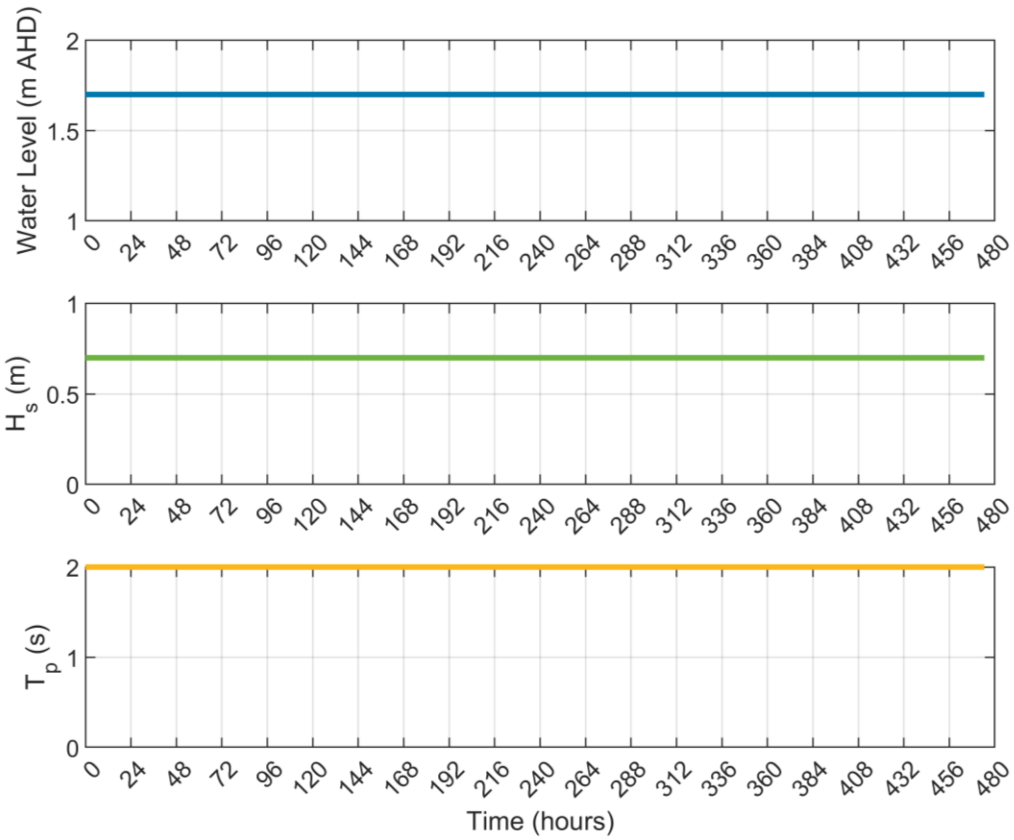

FIGURE D-15LESCHENAULT ESTUARY SBEACH MODEL FORCING FOR 100 YRS. ARI STORM

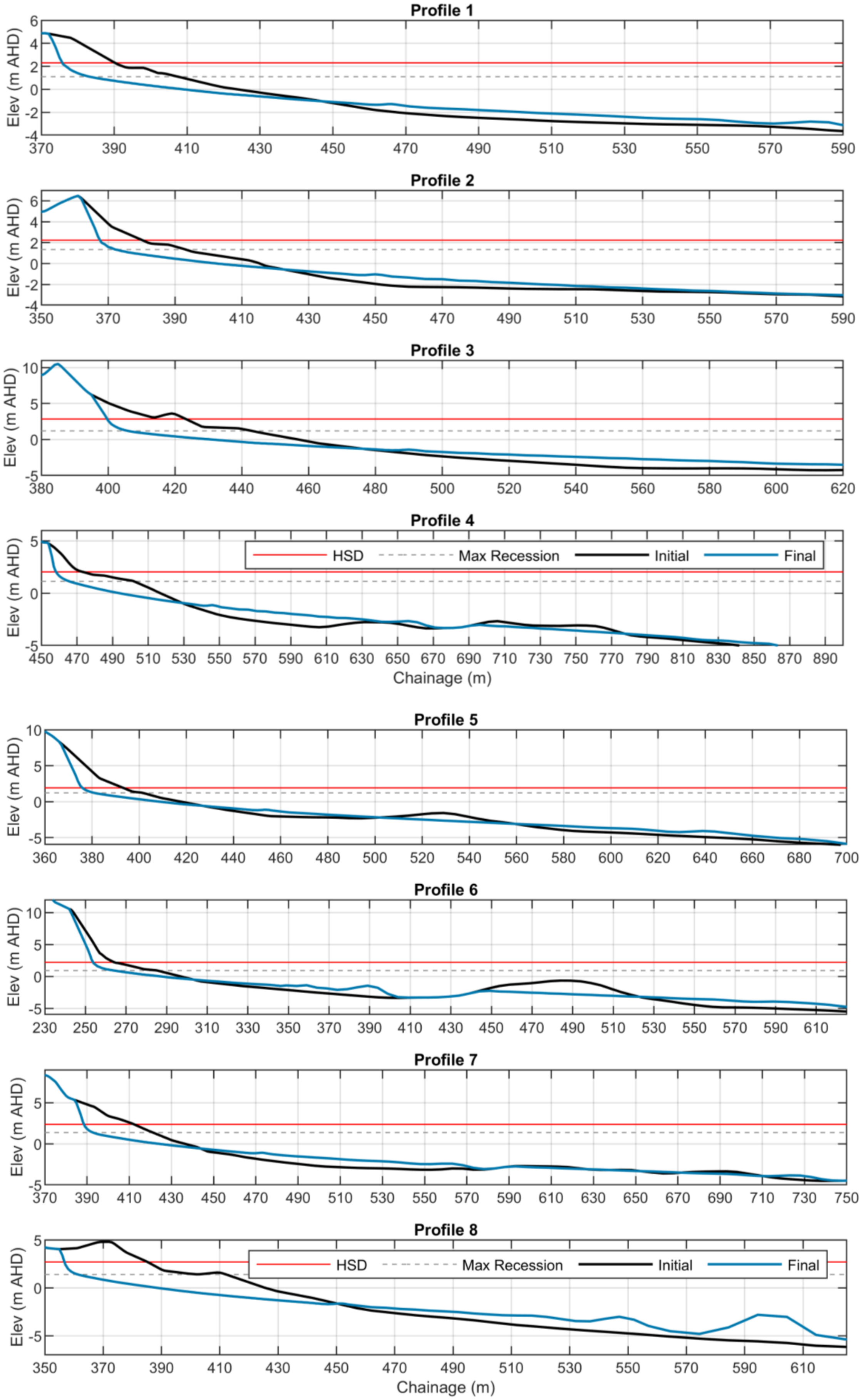

FIGURE D-16SBEACH MODEL RESULTS PROFILES 1 TO 8

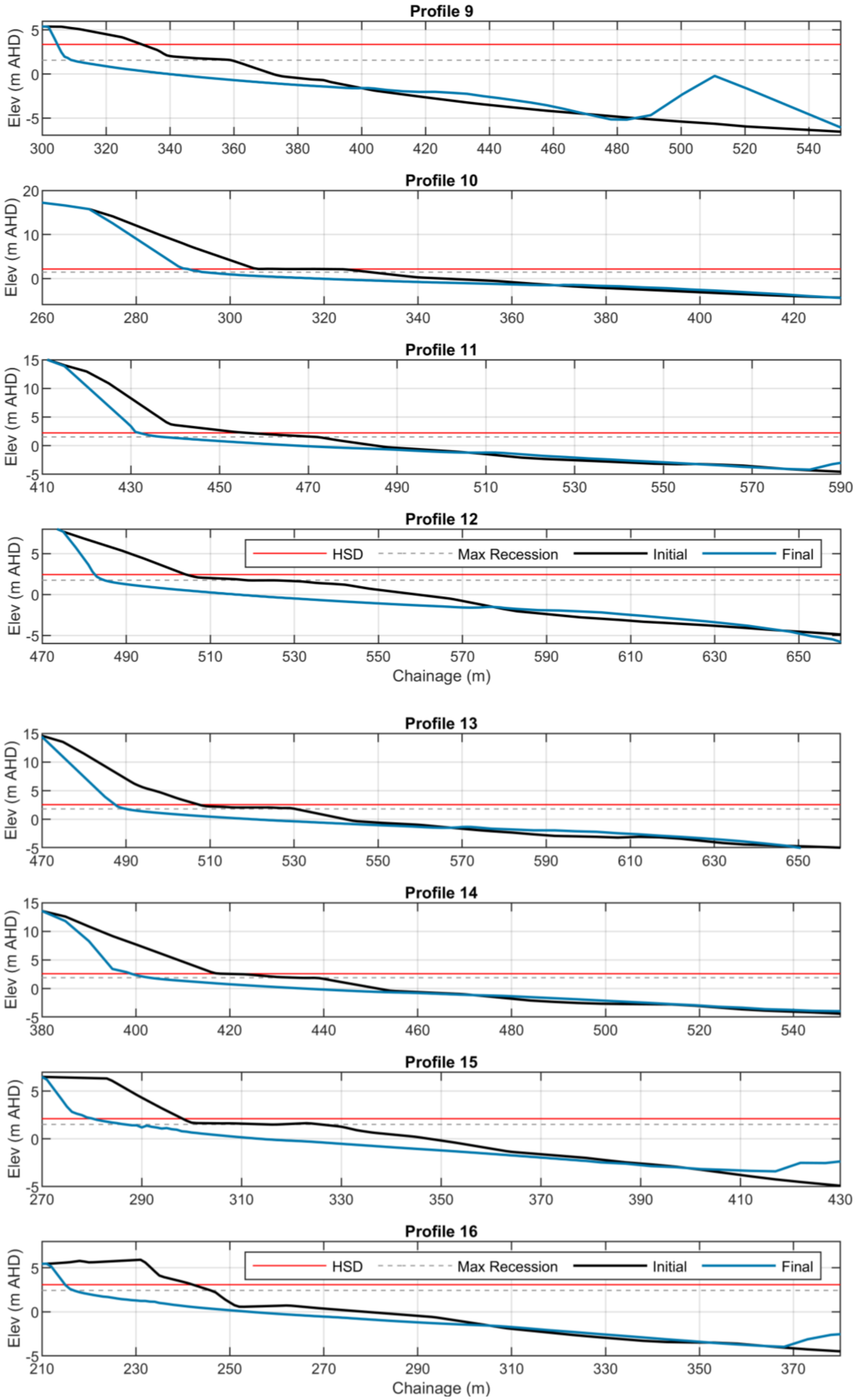

FIGURE D-17SBEACH MODEL RESULTS FOR PROFILES 9 TO 16

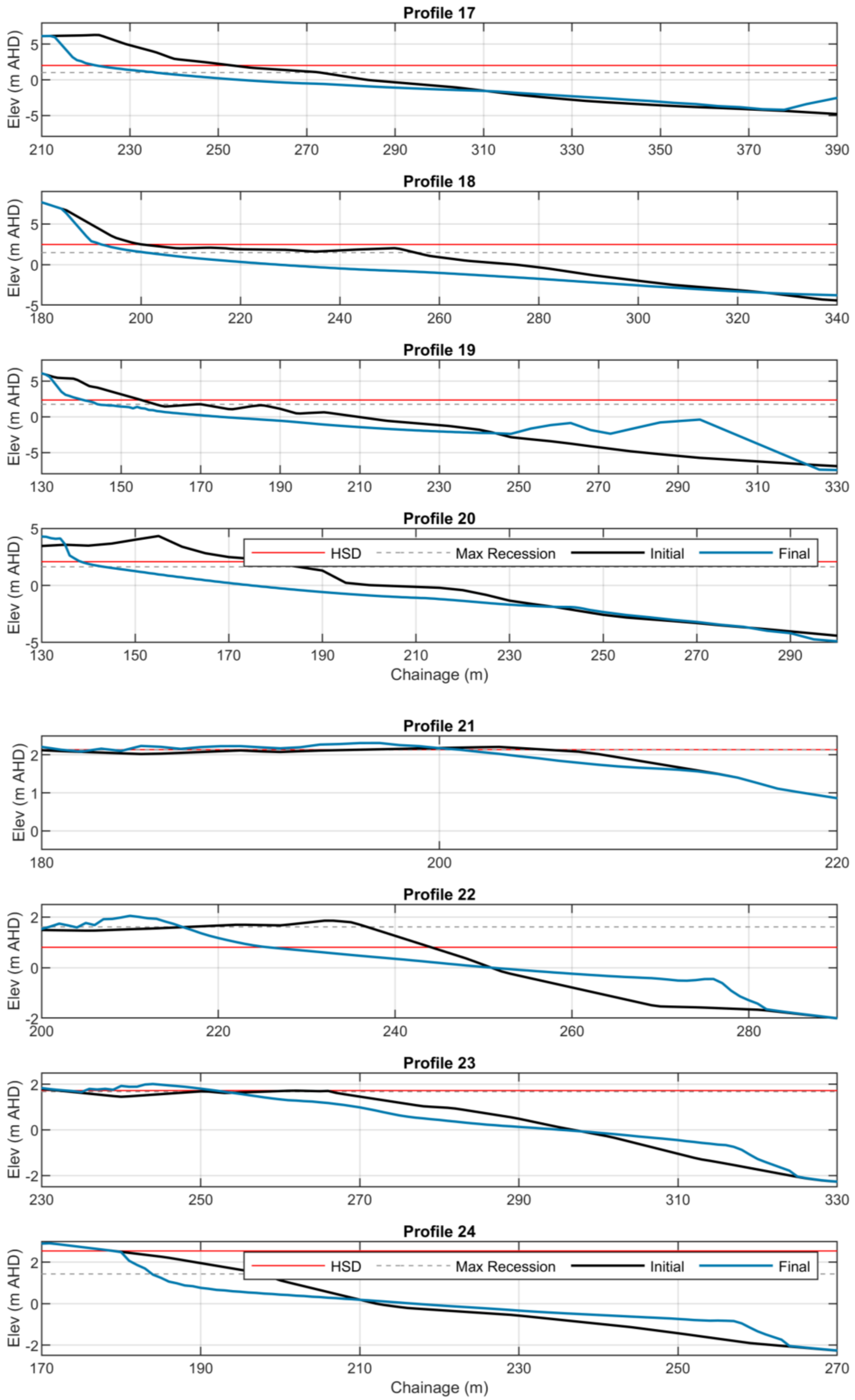

FIGURE D-18SBEACH MODEL RESULTS FOR PROFILES 17 TO 24

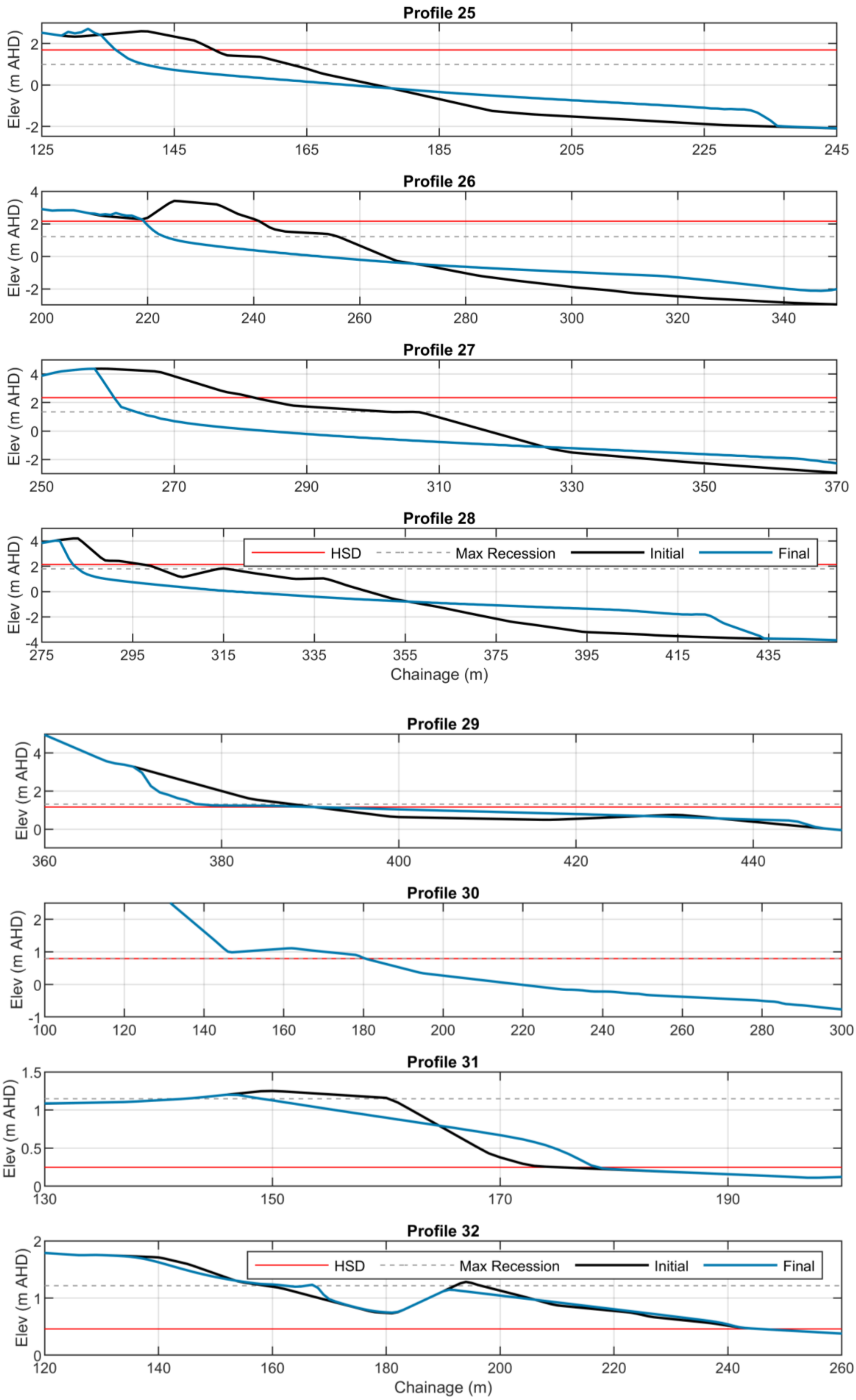

FIGURE D-19SBEACH MODEL RESULTS FOR PROFILES 25 TO 32

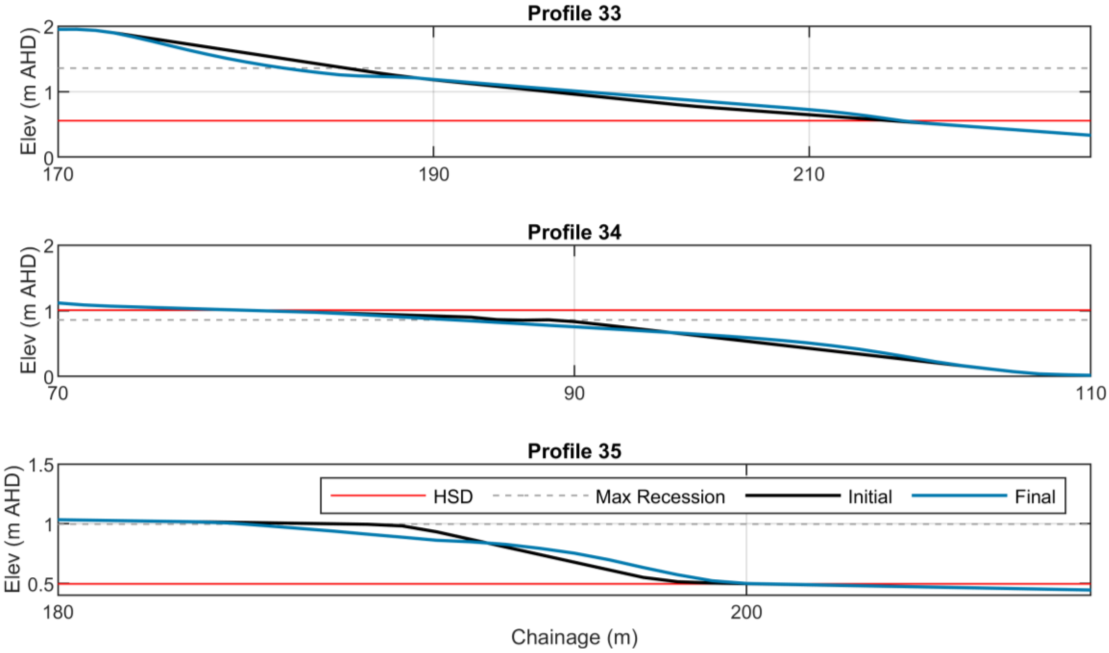

FIGURE D-20SBEACH MODEL RESULTS FOR PROFILES 33 TO 35

D-2 S2 – Chronic Historic Shoreline Movement

The historic shoreline movement trend is estimated through review of available historical shoreline changes. The approach is to analyse historical aerial imagery/vegetation lines and to use the horizontal change in the vegetation line as an indicator for historical shoreline changes. It is applicable on natural coastlines where vegetation is free to recede in response to erosion.

Analysis of historical vegetation line movements is undertaken with USGS Digital Shoreline Analysis System (DSAS 5.0) in ArcGIS. It is capable of generating beach transects and calculating shoreline movement trends based on transect crossings through historic shorelines.

Figure D-21 presents the DoT vegetation lines (from 1941 onwards) and DASA transects (250 m intervals along the Capel Coast, 100 m intervals in Koombana Bay) adopted to evaluate the shoreline movement rate along the coast of Capel to Bunbury. Historic shoreline movement within Leschenault Estuary is investigated separately, given the minimal reported movements over time and lack of vegetation lines to undertake a DSAS analysis.

Review of DoT vegetation lines shows some discontinuities where less than three shorelines are available for analysis. For these sections coast (e.g., South of Dalyellup, east of Koombana Bay), the DSAS model is unable to generate a meaningful shoreline movement rate modelling due to statistical insignificance.

FIGURE D-21S2 HISTORIC SHORELINE MOVEMENT MODELLING (DSAS MODEL PROFILES AND RESULTS)

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