Appendix C

Coastal Hazard

C.1 Coastal Hazard Report (Seashore 2021)

Appendix A

Coastal Hazard Report

A.1 Coastal Hazard Report (Seashore 2021)

Shire of Murray
Coastal Hazard Assessment

Seashore Engineering
August 2021

Report SE111-01-Rev 1

Prepared for
Shire of Murray

Executive Summary

Coastal hazards affecting the Shire of Murray foreshores have been assessed, to support development of a Coastal Hazard Risk Management and Adaptation Plan (CHRMAP). The Shire is located on the eastern sides of Peel Inlet and Harvey Estuary, with foreshore along the banks of the lower Murray and Serpentine Rivers. The Shire's foreshore is substantially undeveloped, with urban development at Yunderup along the lower Murray, including South Yunderup Canal Estate, and a low-density semi-rural development at Birchmont, adjacent to Harvey Estuary.

Evaluation has focused on the coastal hazards of erosion and inundation, which are the two principal hazards requiring assessment under the State Coastal Planning Policy SPP 2.6. General methods used for coastal assessment have been modified to account for the estuarine setting, including consideration of extremely low-lying land present in the lower Murray River and southern parts of Harvey Estuary. A further complication has been brought about due to opening of Dawesville Channel in 1994, which caused an abrupt change in estuarine water levels and consequently modified foreshore evolution. It is noted that the method is intended to provide 'best-estimate' hazard lines suitable for management triggers (i.e. CHRMAP application) rather than a conservative estimate of the coastal hazard zone, corresponding to Schedule One of SPP 2.6.

Erosion hazard has been assessed for 2020, 2030, 2050, 2070 & 2120 using:

- Modelling of cross-shore response to a severe storm, based upon the May 2003 storm, extrapolated to have extreme water levels and winds corresponding to a 100-year average recurrence interval (ARI).
- Extrapolation of shoreline trends based upon historical aerial imagery, generally from 2005-2017 to reduce the influence of Dawesville Channel opening. Shoreline change has historically been small, except in the vicinity of the Murray River delta, where the low-lying berms and islands have progressively folded landward into the wetlands behind them.
- Allowance for erosion in response to sea level rise, using the projected sea level curve described in Transport (2010). This includes an allowance of 0.5m per 0.01m of sea level rise for the whole foreshore, plus a geometric based allowance for low-lying areas where higher water levels will cause narrow foreshore features (berms and islands) to collapse landward. The latter process has been observed for parts of the Murray River delta after opening of Dawesville Channel.

These processes define an erosion hazard zone that varies around the Shire's foreshore, generally with a greater erosion hazard where there is low-lying land and smaller erosion hazard where the shore is higher. Erosion allowances vary from 70 to 120m by 2120.

Potential for an extreme erosion scenario has been identified in response to sea level rise, if tidal flows can cause substantial wetland infilling, with landward collapse of berms and islands up to 1.6km from the existing shore. This mechanism is not presently active, as demonstrated by the extensive intertidal wetland area, but tidal flows will increase with sea level rise. Local management of breaks through the foreshore berm may be used to mitigate the risk of significant sediment wetland infilling.

Total Erosion Allowance Along Shire of Murray Foreshore

Erosion hazard along channel margins for the lower Murray and Serpentine Rivers has been treated separately, acknowledging the differences in foreshore dynamics between the ocean, estuary, and river channels. Distinction has been made based on observed active processes, including 'switching' of channels experiencing flow within the Islands, and local influences of foreshore vegetation. In the absence of detailed measurements of channel change, allowances for erosion hazard have been based upon indicative setback requirements for estuary and river foreshores described in WAPC SPP 2.9 and DC 2.3. These have been distinguished for three sections, considering the likelihood of different erosion mechanisms being active:

- Channels within the Islands area have been defined with an erosion hazard of 50m by 2120, accounting for higher tidal flows and potential for channel switching.
- An erosion hazard allowance of 30m by 2120 has been defined where there is a single main channel for the Murray River (adjacent to Yunderup) and within the Serpentine River.
- Within the secondary channels and small lakes adjacent to the Murray River, an erosion hazard of 15m by 2120 has been defined. These waterbodies typically receive only a small quantity of flow, usually under extreme water level or flood overflow conditions.

Existing foreshore protection structures within Yunderup provide land retention, including canal estate walling and a bund around the man-made lake south of Yunderup. These features have been assumed to be maintained to provide the existing standard of protection. For canal walling, additional upkeep is likely required with higher water levels, but existing wall heights are sufficient for walling to provide protection against erosion. The bund around the man-made lake presently has a crest height of +1.1 to +1.5mAHD, which is likely to require enhancement prior to 2070 to prevent collapse due to frequent overtopping.

Inundation hazard has been identified through analysis of the Peel-Harvey tide gauge record, accounting for changes to flooding that have occurred since opening of Dawesville Channel. The upper limit of 'typical tides' is presently +0.6mAHD, defining wetland areas, and providing an effective limit for land-use. Wetland areas will increase with sea level rise, with a threshold of +1.5mAHD by 2120 based on a projected 0.9m sea level rise. The present-day 100-year ARI storm water level is estimated as +1.09mAHD, which will increase with sea level rise to +1.99mAHD by 2120.

The maximum extent of coastal inundation hazard has been evaluated through consideration of an extreme event based upon 'worst-case' impact of a tropical cyclone similar to TC Alby, but with +10% storm intensity and a track shifted to maximise flooding along the Mandurah coast, to approximate an event with 500yr recurrence. This scenario would produce a high water level of +1.44mAHD under present day conditions, increasing with sea level rise to +2.34mAHD by 2120. This upper limit level of flooding is similar to the potential flood risk area derived for the lower Murray River based upon 100-year ARI rainfall and 0.9m sea level rise.

Extreme Inundation Hazard for Present Day (+1.44mAHD)

Table of Contents

List of Figures

List of Tables

Limitations of this Report

Document Control

Index	Author	Date	Review	Date	Comment
Rev A	M.Eliot	18.12.2020	Baird	22.12.2020	Issued for Review
Rev B	M.Eliot	23.12.2020	DOT	22.02.2021	
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Rev 1	M.Eliot	09.08.2021			Address Public Comments

1. Introduction

This document summarises coastal hazards affecting the Shire of Murray foreshore, providing a contributing study for the Shire's Coastal Hazard Risk Management and Adaptation Plan (CHRMAP). The Shire of Murray is located along the eastern margins of the Peel-Harvey Estuarine System, which includes the mouths of the Murray and Serpentine Rivers.

The Shire's foreshore is substantially undeveloped, with predominantly rural land-use. Austin Bay Nature Reserve, Mealup Nature Reserve, Lake McLarty Nature Reserve and Kooljerrenup Nature Reserve occupy almost 25km of the Shire's foreshore, which includes narrow foreshore reserves in Austin Bay and at Birchmont (Figure 1-1). There are two existing communities, with urban development in Yunderup and low density semi-rural development at Birchmont. A third development area has been proposed for Point Grey (RPS 2009).

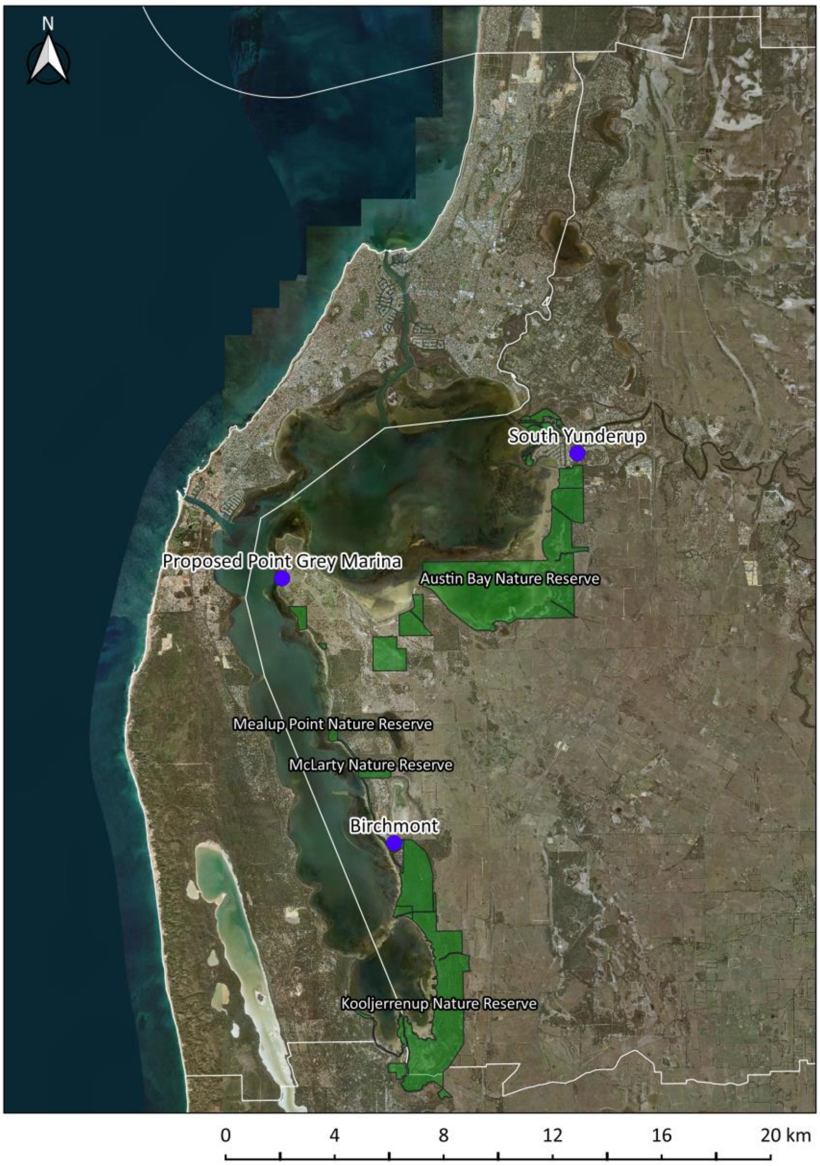

Figure 1-1: Location Diagram

1.1. COASTAL HAZARDS

Coastal hazards occur when coastal processes at the interface between the ocean (or estuary) and the adjacent land can provide physical, environmental, or social loss. For the most part, this is commonly associated with excursion of ocean waters (through waves, tides or storm surges) onto land area, particularly where it adversely affects land use. The two most investigated coastal processes are:

- Erosion, where oceans waters, including wave action, move sediment away from their existing position along the coast, removing a previous area of land.
- Coastal inundation, where land that was typically outside the influence of ocean waters, becomes submerged, typically for minutes to hours (i.e. typically excluding wave action).

Neither erosion nor inundation are a hazard unless they adversely affect an asset.

Management of coastal hazards is a key objective of the State Coastal Planning Policy SPP2.6 (WAPC 2013, 2020). This policy outlines a framework for management, combining land-use zoning and foreshore reserves as the primary tool for mitigation of coastal hazards. The policy recommends consideration of coastal hazards over a time frame of 100 years, including extreme events and projected impacts of climate change, such as sea level rise.

For areas where existing land-use may potentially be affected by coastal processes within the next 100 years, SPP 2.6 recommends development and implementation of a CHRMAP, for identification and ongoing management of coastal hazards. Guidelines regarding CHRMAP development have been published (WAPC 2019).

This coastal hazard assessment has been prepared as a step in the development of a CHRMAP for the Shire of Murray.

1.2. SUMMARY OF HAZARD ASSESSMENT APPROACH

The assessment has followed a conventional approach for forecasting coastal hazards, using observations to identify active processes, which are subsequently extrapolated, with consideration of extreme events and sea level rise (Figure 1-2). However, this is complicated by the Shire of Murray foreshore being located within the Peel-Harvey Estuarine System, which has been substantially modified by opening of Dawesville Channel in 1994.

The estuarine setting challenges the use of 'standard' interpretation of coastal drivers (e.g. waves & tides) and responses that are commonly used in coastal modelling, with the comparatively low-energy setting altering the relative significance of waves, tides and river flows (Harris & Heap 2002) with the structure of each estuary being affected by its origins and degree of infilling (Ryan *et al*. 2005). Consequently, estuarine morphology has been used to supplement interpretation of active processes.

The effect of Dawesville Channel complicates interpretation of active processes, as it represents a secular change in conditions, with a comparatively large increase in tidal range. Because of the low-energy conditions within the estuary, its impacts can potentially affect observed trends for decades. Although these are permanent changes, the effect of 'step changes' needs to be considered carefully when extrapolating trends for the next 100 years.

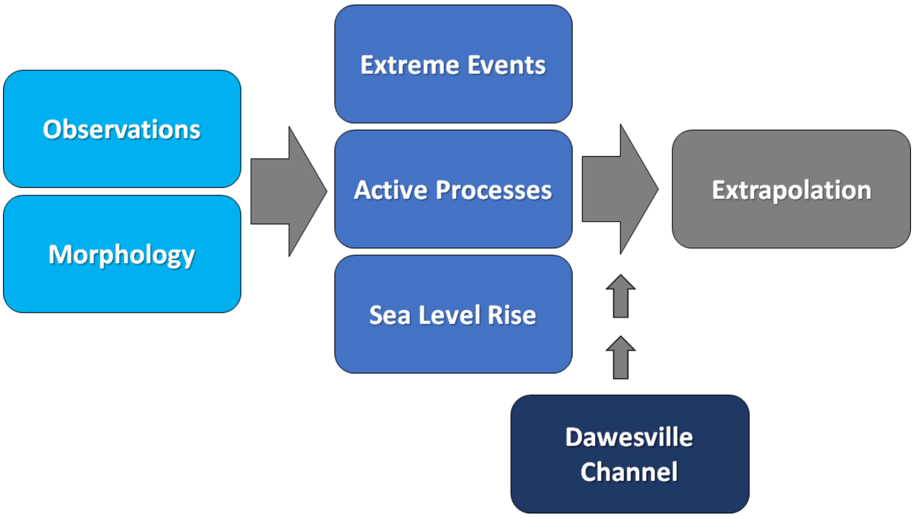

Figure 1-2: Framework of Assessment Approach

Evaluation of inundation hazard has been based upon analyses of extreme water level records and modelling for south-west Western Australia (e.g. Haigh *et al*. 2010; Eliot 2012), including the derived relationship between water levels inside and outside Peel-Harvey system (Eliot & McCormack 2019). Components of the inundation assessment include evaluation of estuary water levels, modelling of ocean extreme events and transfer of the ocean signal through to the estuary using a spectral admittance function.

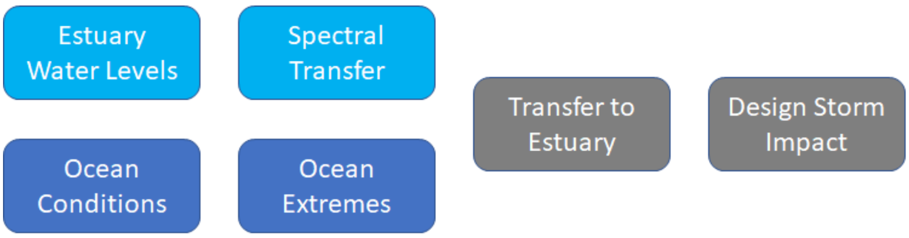

Figure 1-3: Components of Inundation Assessment

The assessment approach for the Shire of Murray foreshore dynamics has been built from previous evaluations in the southwest of Western Australia (Eliot *et al*. 2006; Damara WA 2008, 2009, 2016, 2019; Travers *et al*. 2010), within the wider context of estuarine and low-energy beach literature (Nordstrom & Roman 1992, Jackson *et al*. 2002; Ton *et al*. 2020). For the main basin of the estuaries, foreshore dynamics are strongly related to the directional wave climate and water level variability. Components of the assessment consequently involve directional analysis of winds, fetch analysis based on the estuarine structure and wave hindcasting (Figure 1-4).

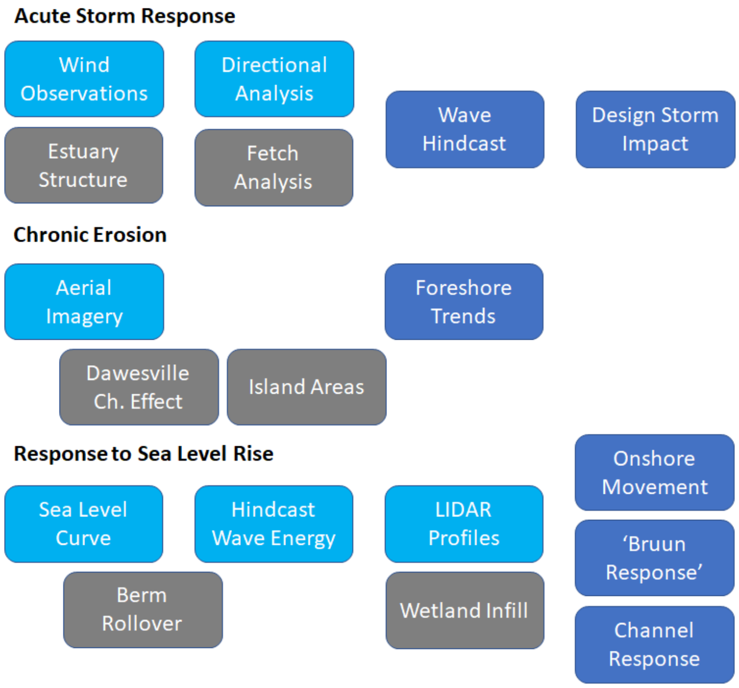

Figure 1-4: Components of Erosion Assessment

2. Peel-Harvey Foreshore Dynamics

2.1. EXISTING ORIGINS AND STRUCTURE

Peel-Harvey Estuarine System is a large waterbody, comprised of two shallow basins, the elongated Harvey Estuary, and the more rounded Peel Inlet, with input from the Harvey, Murray and Serpentine River systems, along with local catchment drainage. The estuarine system is a geologically modern feature on the greater Swan coastal floodplain, which has developed its modern form over the last 2,000 years, when sea levels have remained approximately constant, declining 1-2 m (Wyrwoll *et al*. 1995). Land surrounding the estuary has correspondingly been shaped by coastal, alluvial or lagoonal processes (Figure 2-1):

- Coastal features are prevalent on the west side of the estuarine system, with a narrow strip of dunes along the east side of Harvey Estuary.
- Alluvial features mark the previous limit of estuarine processes, which intuitively suggest an approximate limit of expected foreshore response to sea level rise up to the level of the previous highstand.
- Lagoonal deposits are present along the east and south side of Peel Inlet, along with the south end of Harvey Estuary. These include sediment supply from the Murray and Harvey Rivers, with reworking through estuarine foreshore dynamics. There has apparently been low sediment supply from the shallow grade Serpentine River.

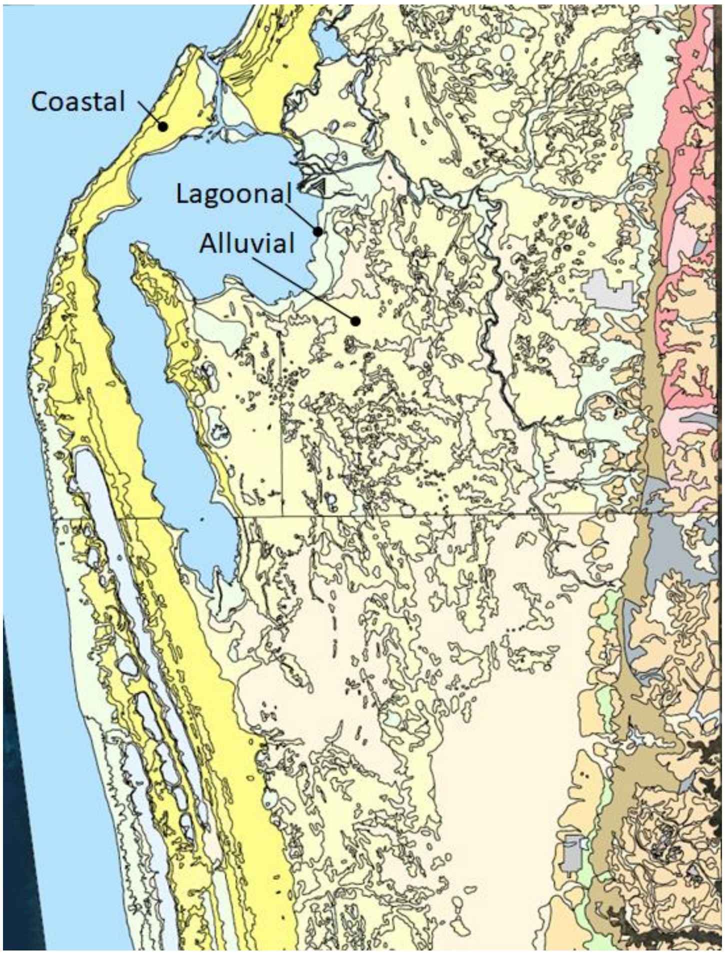

Figure 2-1: Extract from 1:50,000 Surface Geology (GSWA)

The mix of land forming processes has created several different morphotypes along the Shire of Murray foreshore (Figure 2-2). These indicate active processes and influence pathways by which the foreshore can potentially change over time.

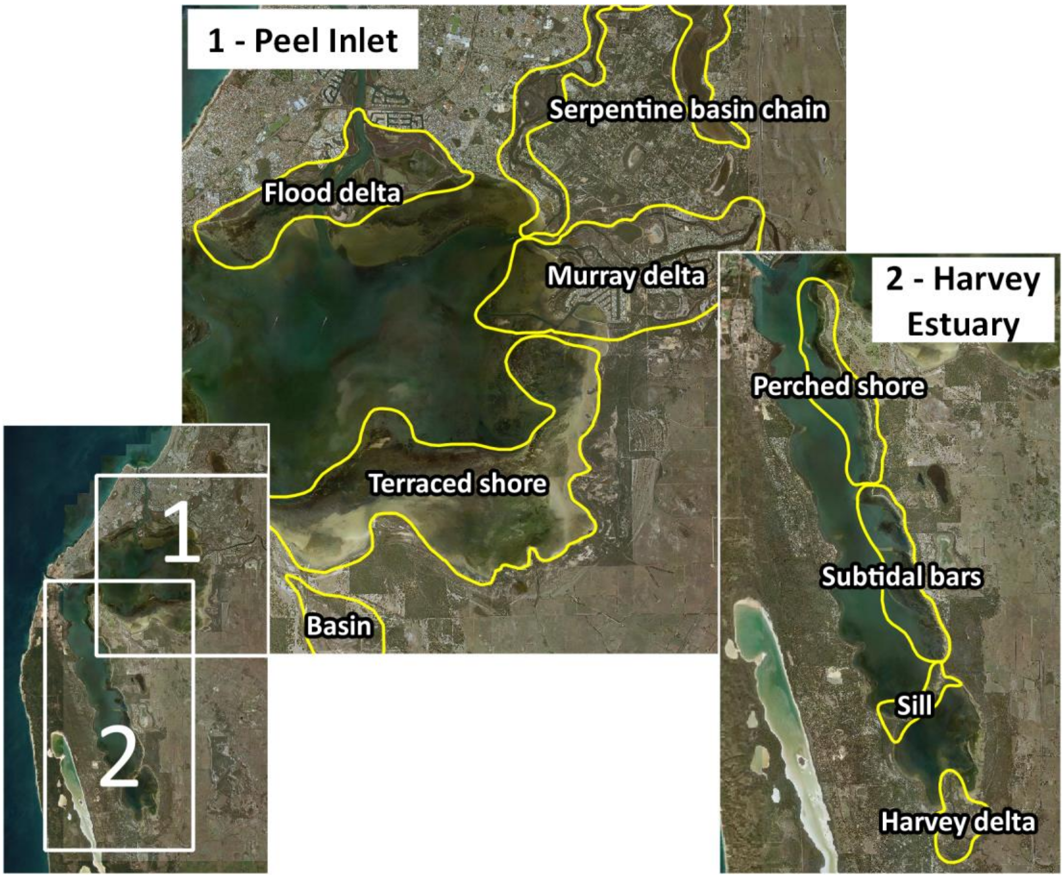

Figure 2-2: Major Foreshore Features

Active and future behaviour can be distinguished between the foreshore of the estuary basins, which is strongly influenced by wave conditions, and foreshore along channel margins, which are affected by flows and sediment supply (Table 2-1). Separate approaches have consequently been used to estimate erosion hazard in Section 4.

Table 2-1: Active & Future Processes Indicated by Key Features

Feature	Active Processes	Future Processes
Flood Delta	Historic marine sediment supply	Increased tidal exchange
Serpentine Basin Chain	Limited river sediment supply Tidal exchange	Increased tidal exchange
Murray Delta	Historic river sediment supply	Increased tidal exchange
Terraced Shore	Shallow depth limits waves	Reduced sheltering (wave)
Perched Shore	Rock control	Reduced control (wave)
Subtidal Bars	Alongshore transport	Modified transport (wave)
Sill	Tidal exchange / overwash	Increased overwash
Harvey Delta	Historic river sediment supply	Increased overwash

2.2. MORPHODYNAMICS

Identification of foreshore dynamics has been undertaken through evaluation of aerial imagery, including comparison of shoreline change, and measurement of bathymetric change, based upon hydrographic surveys. Aerial Imagery suitable to assess dynamics of the Shire of Murray foreshore is available from:

• 1974 (Sep)	North Peel Inlet only	City of Mandurah
• 1975	Peel Inlet only	Department of Transport
• 1979 (Sep)		Department of Transport
• 1985 (Jun)	Peel & North Harvey	City of Mandurah
• 1994 (Apr)		Department of Transport
• 1995 (Feb)		City of Mandurah
• 2000		City of Mandurah
• 2001		City of Mandurah
• 2002		City of Mandurah
• 2004		City of Mandurah
• 2005		City of Mandurah
• 2006		City of Mandurah
• 2007		City of Mandurah
• 2008		City of Mandurah
• 2009		City of Mandurah
• 2010		City of Mandurah
• 2011		Shire of Murray
• 2012		Shire of Murray
• 2013 (Jan)		City of Mandurah
• 2014 (Feb)		City of Mandurah
• 2015 (Feb)		Shire of Murray
• 2015 (Nov)		Shire of Murray
• 2016		Shire of Murray
• 2017 (Feb)		City of Mandurah
• 2017 (Apr)		Shire of Murray

Assessment of historic behaviour provides an evidential basis for the estimation of future shoreline trends. Initial interpretation of foreshore change was conducted through comparison of oldest and most recent imagery (generally 1979-2017). This indicated that much of the estuary foreshore has experienced limited net change of vegetation line, including areas that are geomorphically considered highly sensitive, such as birdsfoot delta formations (Figure 2-3). The Murray delta area provided a marked exception, with some areas of significant change.

Subsequently, historic imagery was used to evaluate foreshore processes and project future shoreline trends. Although there is almost 40 years of aerial imagery, projection of future trends based on historic behaviour is complicated by construction of Dawesville Channel. Shoreline adjustment to higher tidal range after 1994 suggests pathways of response to higher sea levels, and therefore is a useful indicator of expected response to sea level rise, particularly over the next 20-30 years.

Figure 2-3: Observed Change at Austin Bay Birdsfoot Delta

Periods 1994-2005, 2005-2011 and 2011-2017 (reported in Appendix C) were used to check the relative influence of Dawesville Channel on shoreline trends, using the logic sequence shown in Figure 2-4. Overall behaviour is indicated by Figure 2-5, noting there is little difference between the 2005 shoreline (black dash) and the 2017 shoreline (imagery) except at the Murray River delta. Low-lying areas are indicated where the 2017 HSD (pink) is set back from the 2017 shore, in the Murray River delta and along the southern shore of Peel Inlet.

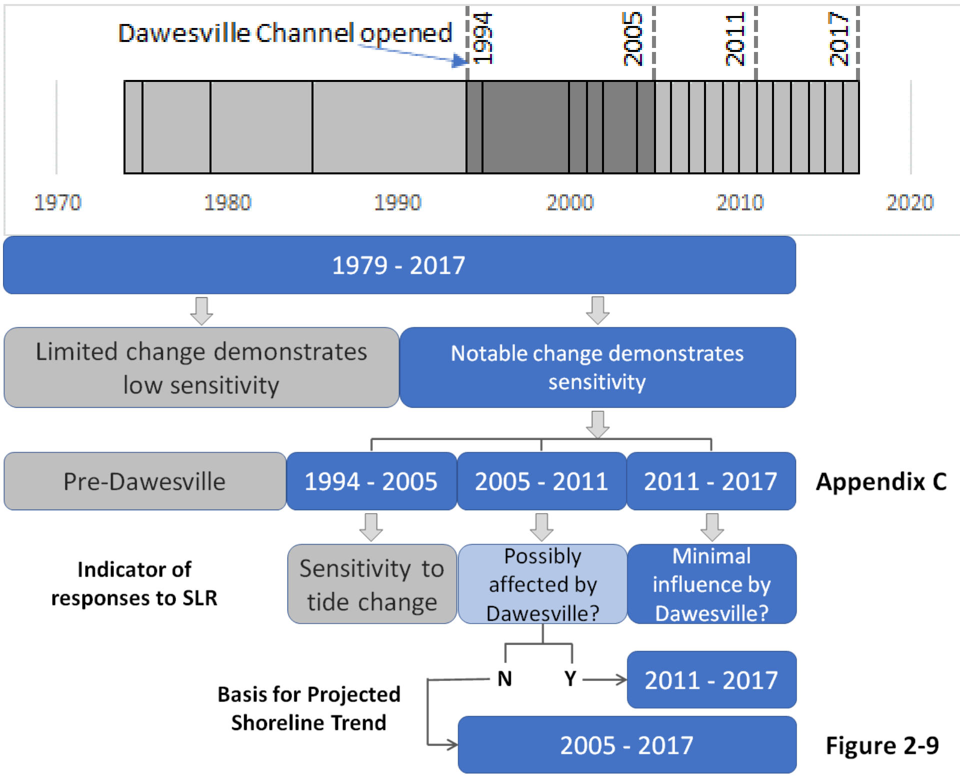

Figure 2-4: Available Imagery Dates and Flow-Diagram to Estimate Shoreline Trends

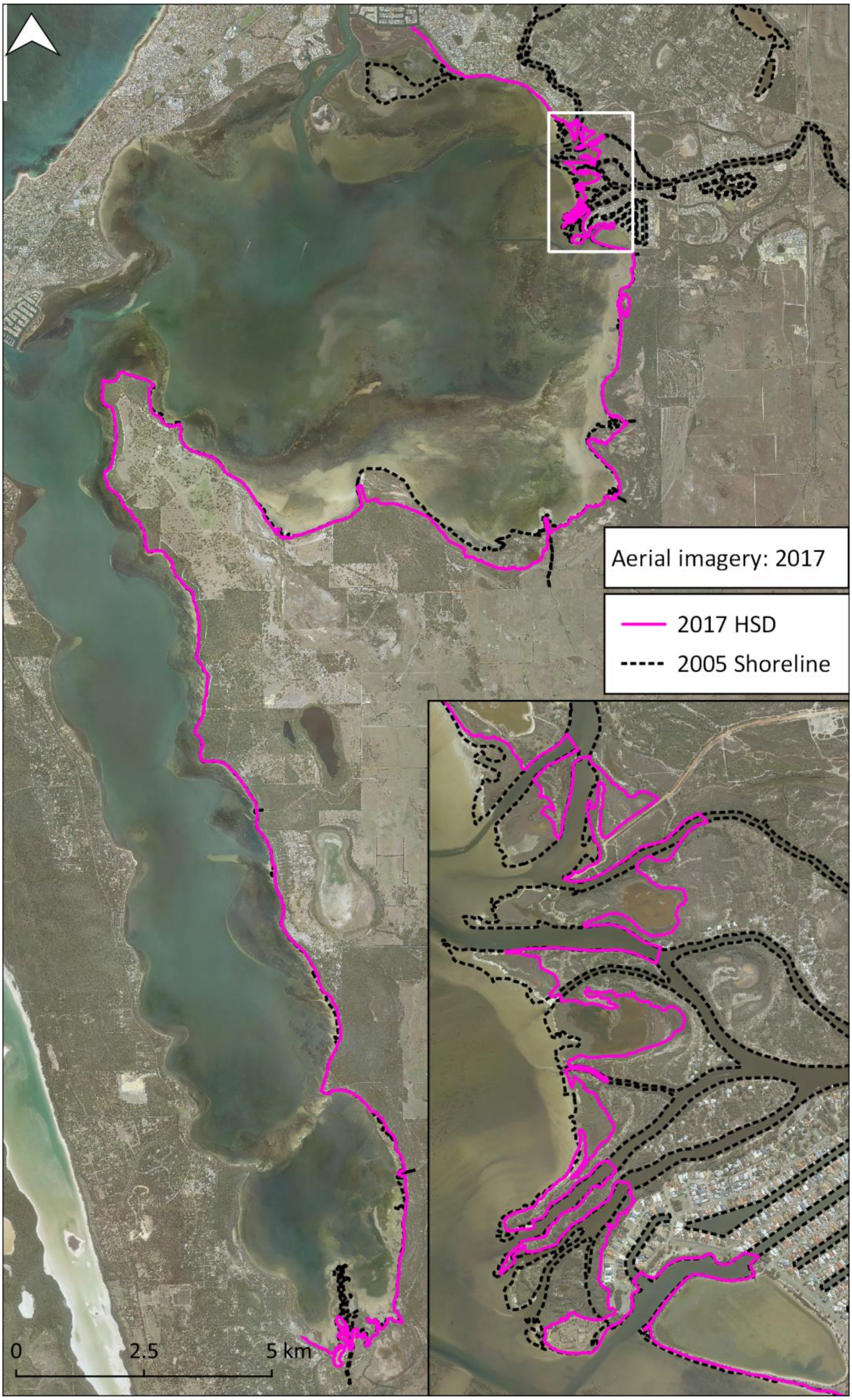

Figure 2-5: Areas of identified vegetation line change (2005-2017)

The full time series was examined for areas where substantial change had occurred, to help identify driver-response patterns, particularly if several alternative mechanisms for change were evident.

Examined at a local scale, movement of the vegetation line has been significant, particularly at the northern end of Meeyip Island (Figure 2-6). However, the nature of change has been the landward collapse of ridges and spits, with spits developed through flood deposition gradually collapsing back on to the islands (Figure 2-7). Consequently, this is not erosion (sediment volume loss) *per se*, although this movement needs to be considered in the definition of erosion hazards. Consequently, evaluation of foreshore trend has considered the change to island areas (Figure 2-8), averaged along the active foreshore length. This gives a rate of erosion of 0.5 to 1.6 m/yr, increasing from the Murray River mouth to the north, greatest at Meeyip Island.

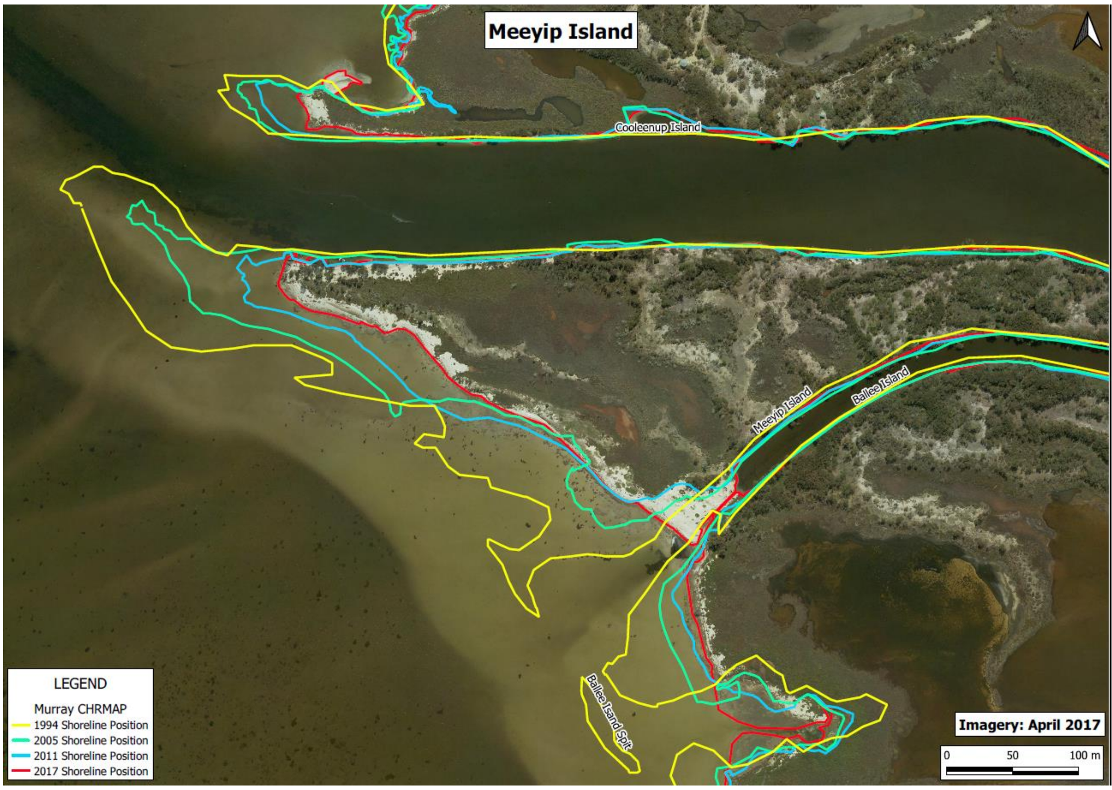

Figure 2-6: Meeyip Island Vegetation Line Change

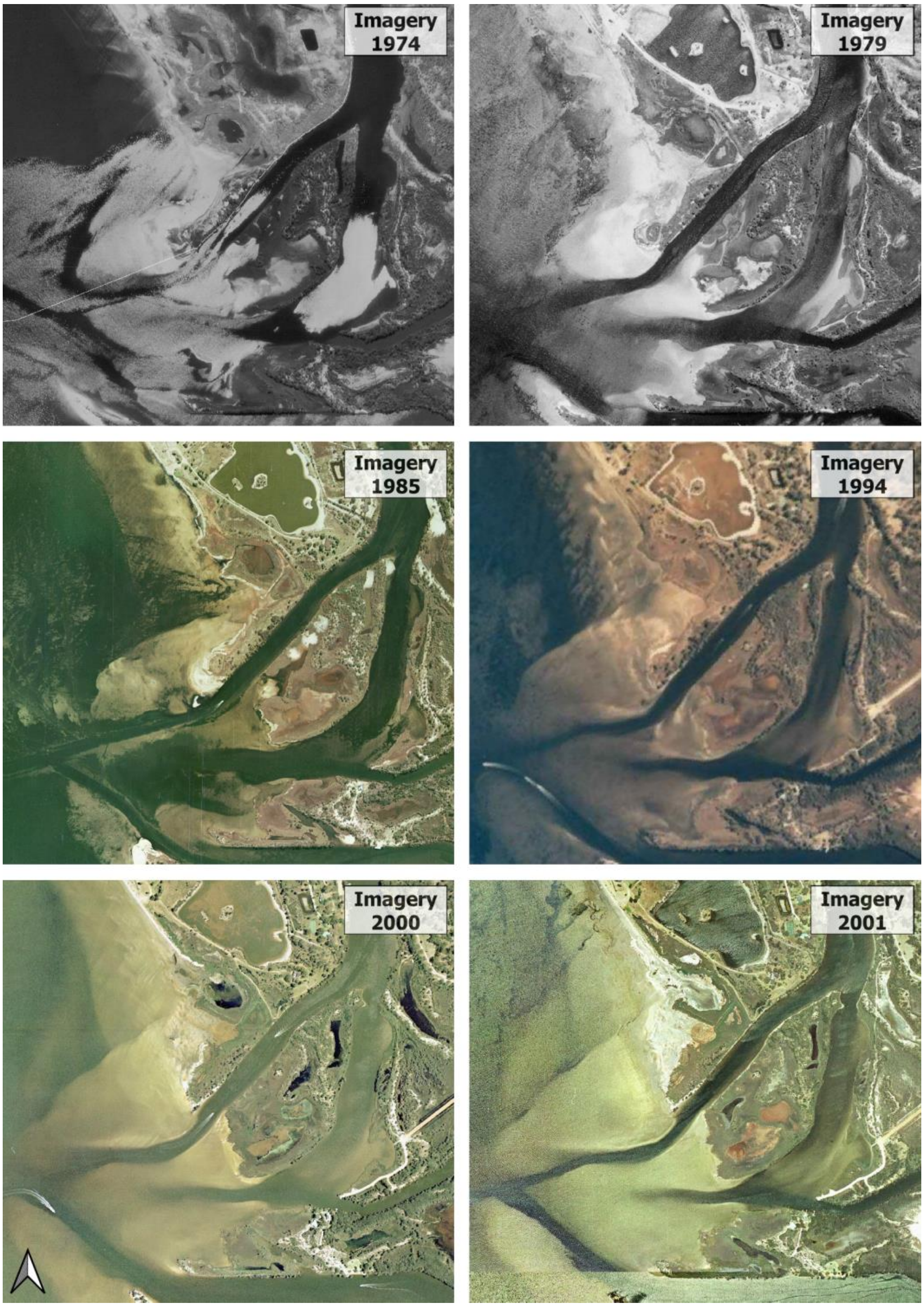

Figure 2-7: Imagery Sequence 1994-2001 for Murray Delta Area (North)

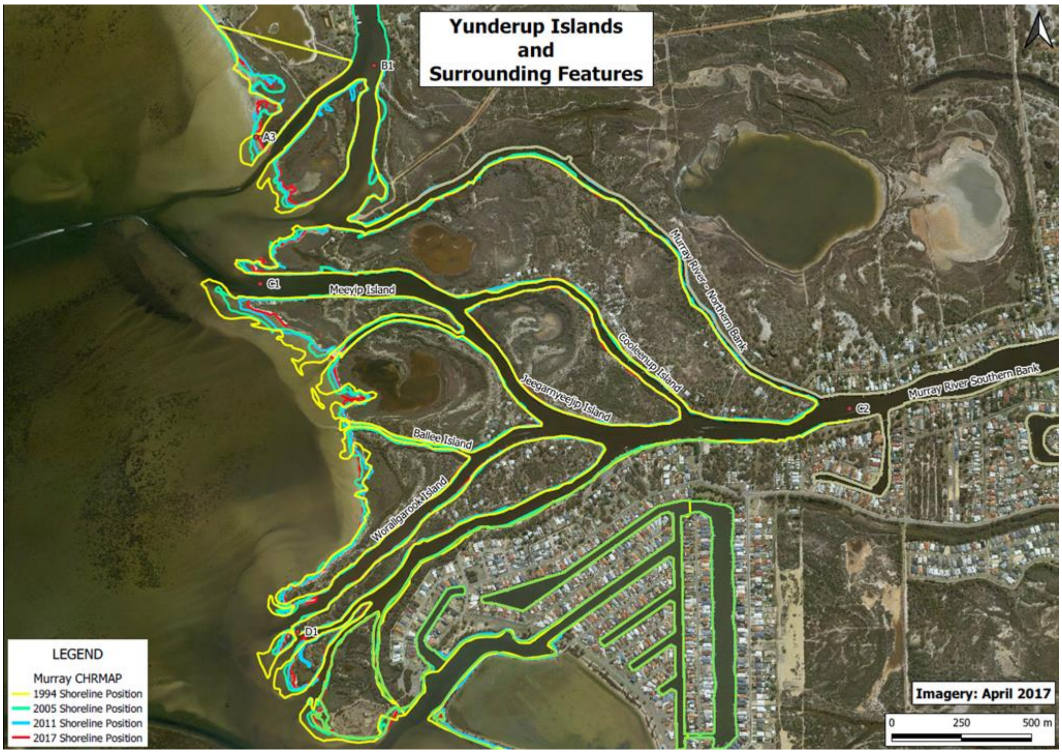

Figure 2-8: Vegetation Line Changes for Murray Delta 1994-2017

Complex foreshore dynamics were also identified at Harvey Estuary Sill, toward the southern end of Harvey Estuary. Significant disruption of the sill and adjacent transverse bars occurred following opening of Dawesville Channel, with associated ‘straightening’ of the shore north of Herron Point. However, substantial change was delayed until around 2012, which corresponded to a period of elevated mean sea levels during strong La Niña conditions. Changes included increased coverage of benthic vegetation, development of a single main tidal channel through the sill, further breakdown of the sill sand bar chain and degradation of the transverse bars. Local shoreline erosion is mainly a consequence of losing feed from the bars, and therefore has not been extrapolated as a future trend.

However, other sections of shore have also been subject to variability of beach and benthic conditions, without corresponding change to the shoreline itself. This is illustrated along the shore south of Point Grey, with fluctuations in beach width, nearshore bars and terrace structure (Figure 2-9). This has occurred with negligible change to the vegetation line position.

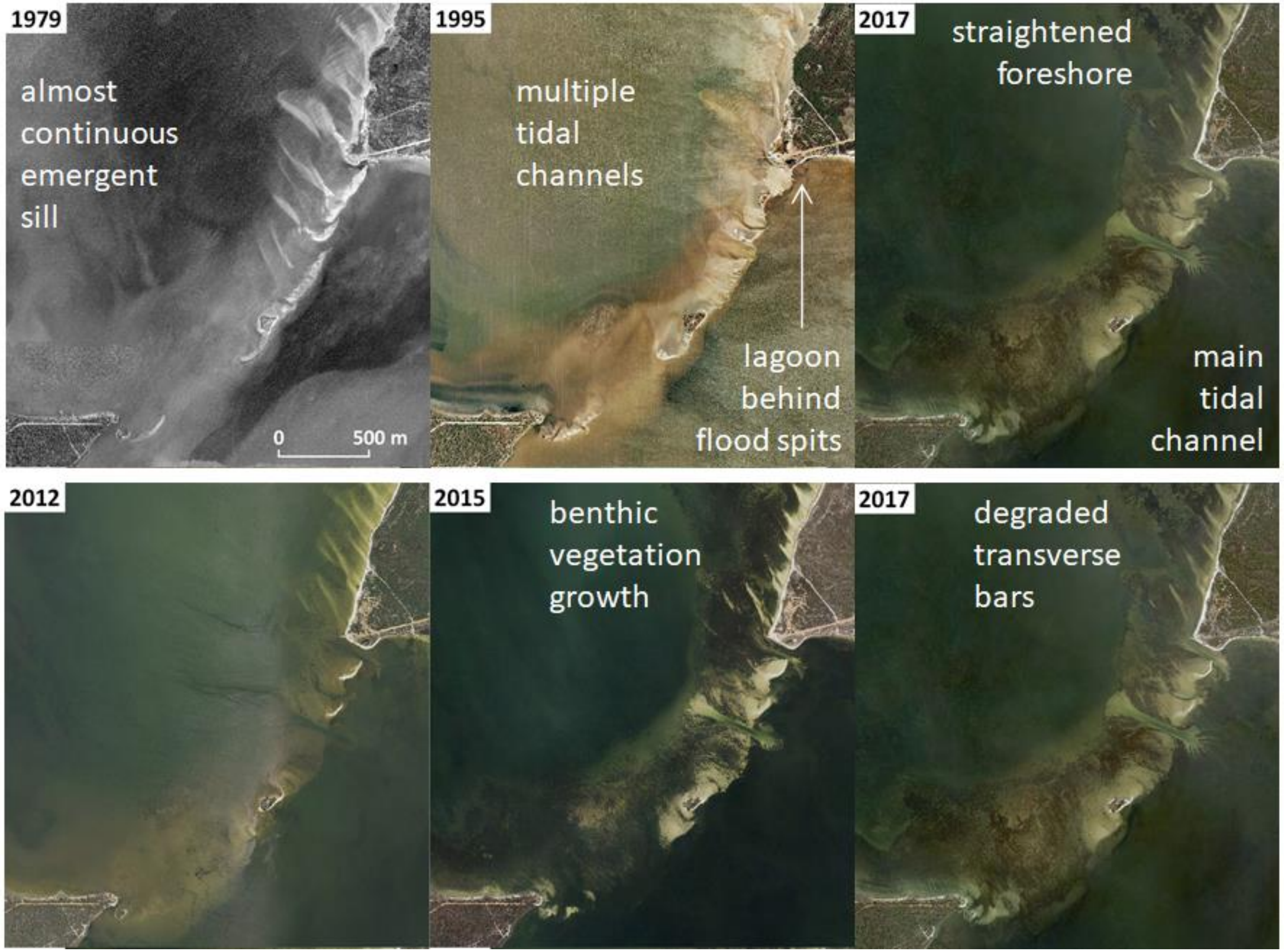

Figure 2-9: Dynamics of Harvey Estuary Sill (1979-2017)

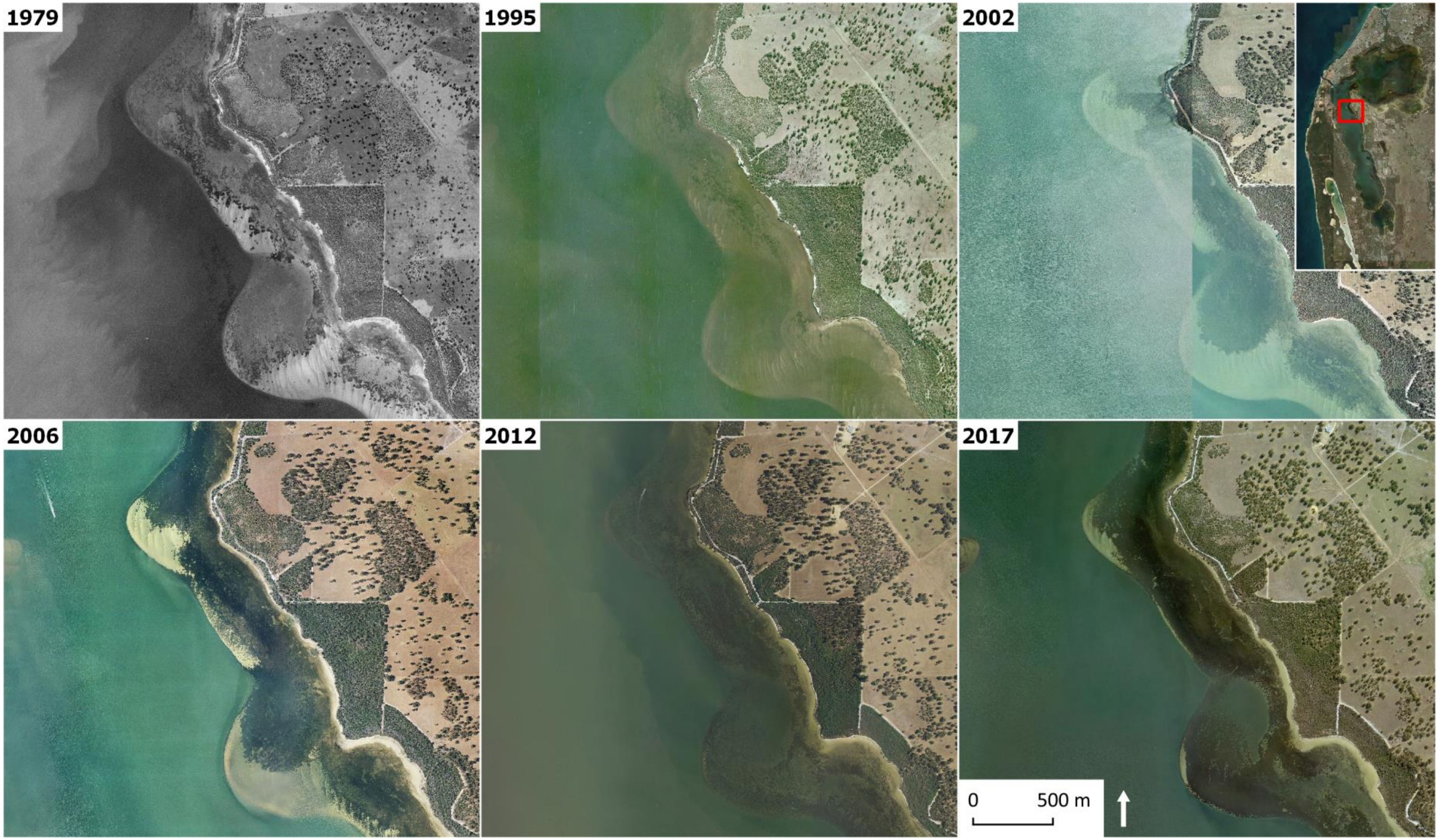

Figure 2-10: Beach and Benthic Variability on Stable Shoreline South of Point Grey

3. Inundation Hazard

Inundation hazard has been considered based upon previous studies of extreme water levels in the southwest of Western Australia (Haigh *et al*. 2010; Eliot 2012, 2018). These have identified that the relative role of different storm types in the generation of high water levels:

- Mid-latitude storms occur all year round but are most frequent and severe during winter months. Coincidence of storms with high mean sea level and the winter solstice tidal peak determines that high water levels mainly occur between May and July (Eliot 2012).
- Tropical storms occur in northerly latitudes mainly between December and March. These storms are highly mobile and occasional late season storms pass into southerly locations, where they may experience extra-tropical transition, interacting and eventually merging with extra-tropical systems. These storms can generate large surges, but they typically occur during a period of low mean sea level and moderate tides, reducing their capacity to generate extreme water levels (Eliot 2010).
- Thunderstorms occur throughout Western Australia. The local pressure drop associated with thunderstorms can generate a travelling surge that can, when travelling at certain speeds and directions, be amplified by the resonant characteristics of coastal bathymetry (Pattiaratchi & Wijeratne 2014). This provides opportunity for high amplitude but rapidly oscillating surges.

Historically, the tide gauge records of almost all southwest stations show that the most frequent cause of high water levels is developed by mid-latitude winter storms. However, the highest total water levels are typically associated with either tropical cyclones or meteotsunami. The most significant event on record was caused by TC Alby in April 1978, which caused extensive flooding from Mandurah through to Busselton (MacPherson *et al*. 2011).

Evaluation of water levels within the Peel-Harvey system has demonstrated that the estuary acts like a spectral filter, with the channel and basin structure modifying how tides, storm surges and other ocean sea level signals are transferred through into the estuarine systems (Eliot & McCormack 2019). This analysis has shown that tide is reduced to 70-90% of the ocean signal and mean sea level variation is unchanged. The effect on surges is variable, according to the time scale of the surge process, with 85% of 'typical' storm surges passing through, with reduced transfer for shorter duration signals.

The likelihood of inundation for events below 100-year ARI has been estimated based upon data from the permanent tide gauge established in Peel Inlet since 1985 (Figure 3-1). A sub-set of the dataset has been used, considering only data since April 1994, following opening of Dawesville Channel.

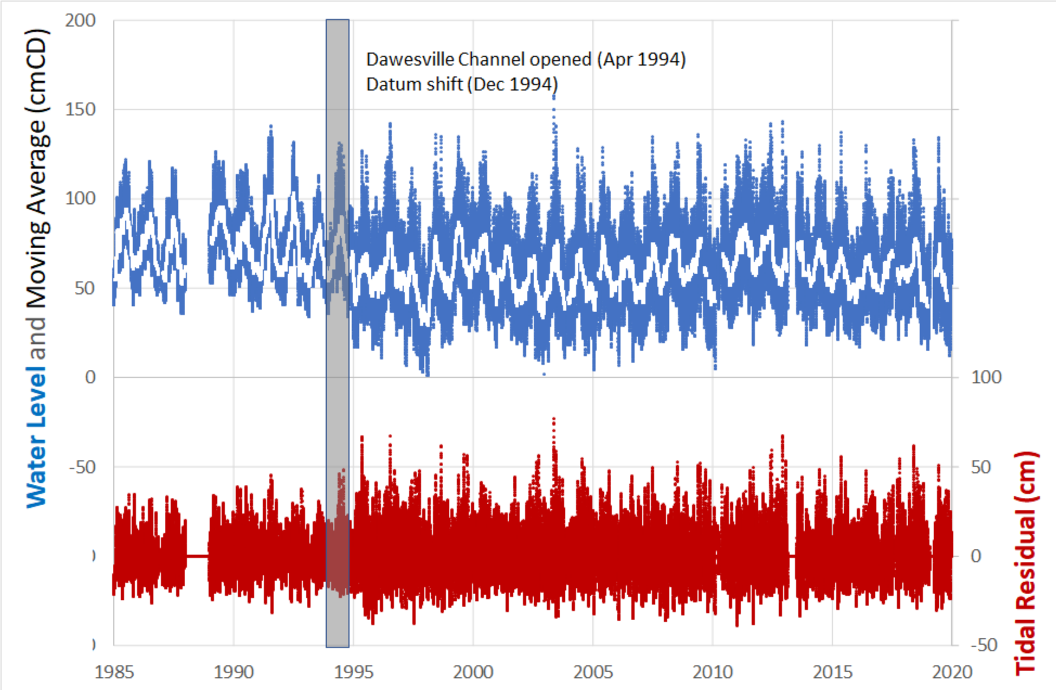

Figure 3-1: Peel Inlet Tide Gauge Observations & Residuals 1985-2019

Evaluation of inundation hazard has been based upon ground levels derived from the 2009 LIDAR land surface, captured by Fugro, on behalf of the Department of Water. It is noted that although LIDAR has capacity to collect topography with fine vertical and horizontal resolutions, there was limited vertical datum control available within the Shire of Murray (John Mullally, DOT Senior Hydrographic Surveyor, pers comm.). Hence, it is estimated that ground levels might have systematic errors in the order of 0.3m, which represents a substantial change in relative flooding incidence. Despite this potential limitation, checking of broad-scale patterns did not identify inconsistencies, and the LIDAR topography has been considered the most accurate available information for use in this assessment.

For land-use planning, water levels are distinguished between those causing ‘tidal inundation’ and higher levels producing ‘flood inundation’. Tidal inundation occurs frequently, limiting the vegetation able to survive, and is typically characterised as wetland. The limit of present-day tidal inundation is approximately level of +0.6m (Figure 3-2), which will increase with sea level rise. Wetland areas are generally unsuitable for typical 'land-use' requiring consideration of inundation, potential erosion hazard and effects of salinity. Identification of adaptive mitigation principles is an objective for the overall CHRMAP supported by this document. Rising tidal inundation is also associated with increased salinisation of the wetlands fringing the Murray River, causing changes to the riparian vegetation, which may locally affect foreshore stability.

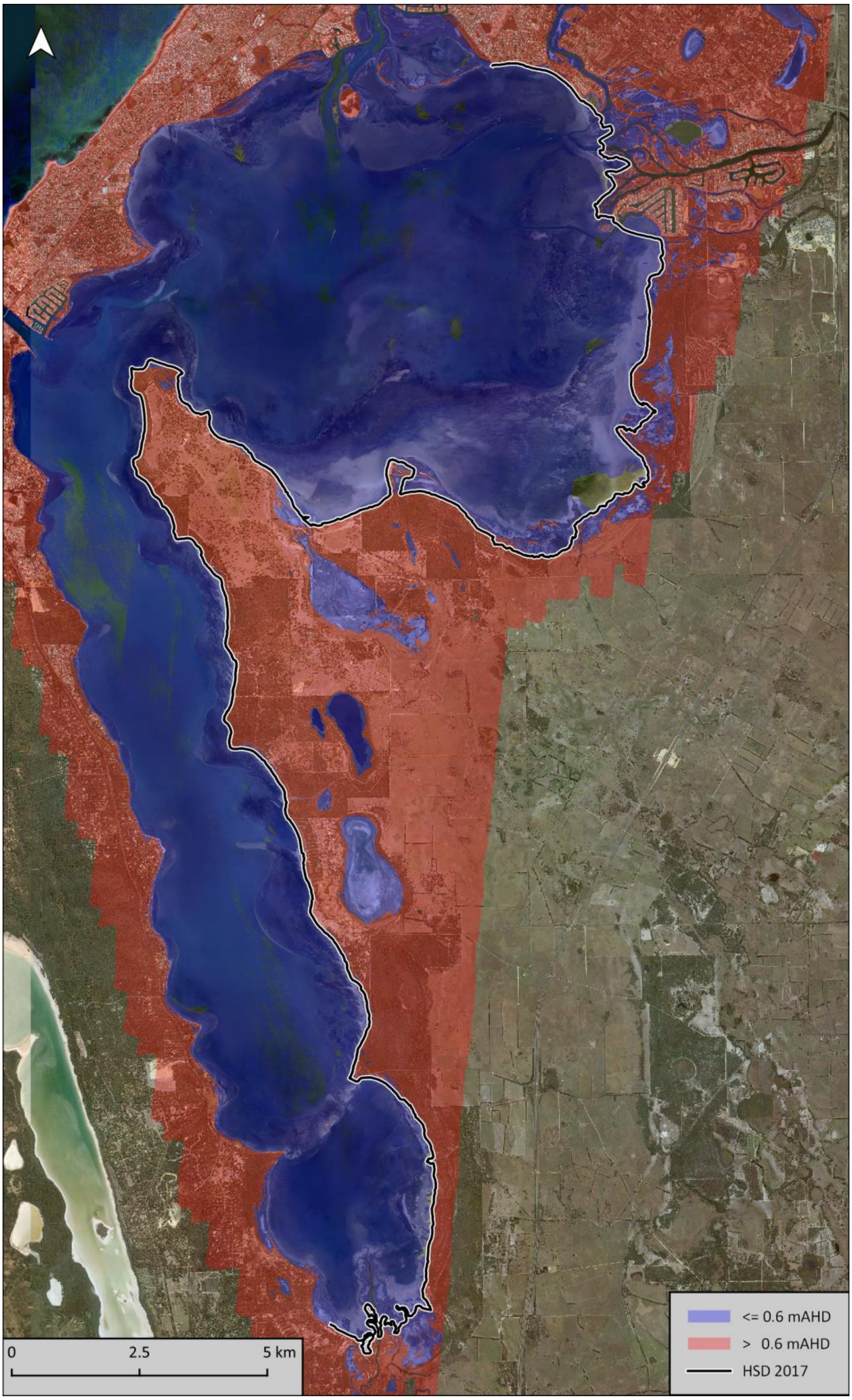

Figure 3-2: Areas Below 0.6mAHD

Note: HSD2017 is defined in front of wetland areas below 0.6mAHD where a largely continuous barrier has been identified.

Exposure of parts of the Shire of Murray foreshore to relatively low levels of inundation is demonstrated by flooded areas observed from satellite imagery, as assessed by Digital Earth Australia (Mueller *et al*. 2019). The south and west fringes of Peel Inlet is suggested to be inundated 5-20% of the time (Figure 3-3), including a large wetland connected to Roberts Bay through a narrow channel. Wetlands adjacent to Harvey Estuary (Lake McLarty and Birchmont) are not directly connected, with inundation patterns suggesting influence of near-surface groundwater (Figure 3-4).

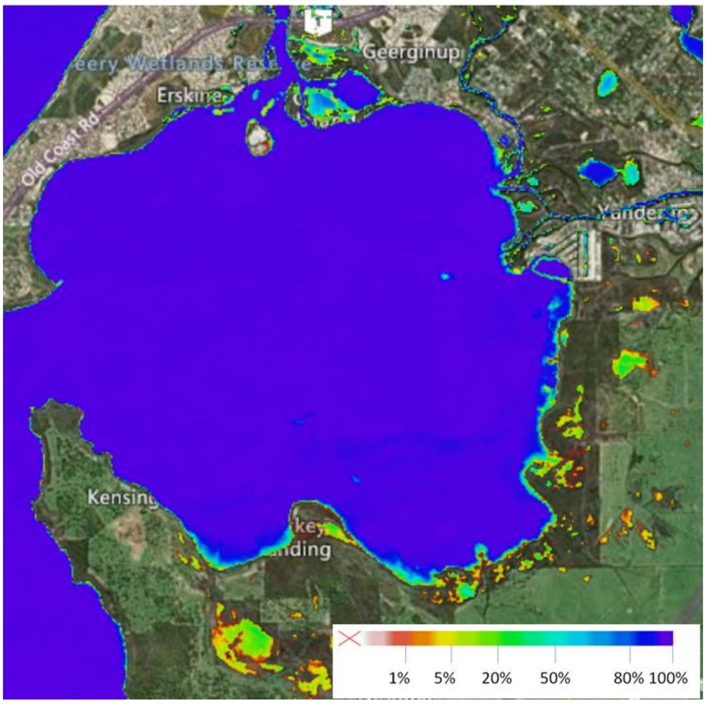

Figure 3-3: Inundation Frequency of Wetlands Fringing Peel Inlet

Flood inundation occurs with lower frequency for high levels. The impacts of flooding depend on the type of land-use, with tolerably rare flooding usually considered nuisance flooding. Incidence of tolerable flooding usually varies from once per year (affecting ground covers) to 1% likelihood per year (possibly tolerable for housing). Flood inundation levels will increase with sea level rise.

Characterisation of flood recurrence was undertaken by identifying maxima, with a minimum window of two days between events, to avoid including the same storm event twice. The highest 24 events within the data set (i.e. approximately 1 per year of data) were then ascribed ranking positions, following the method of Petrauskas & Aagard (1971). Fitting of alternative extreme distribution curves suggested a best fit with Weibull k = 1.1, which is nearly equivalent to a log-linear fit (Figure 3-5 and Table 3-1).

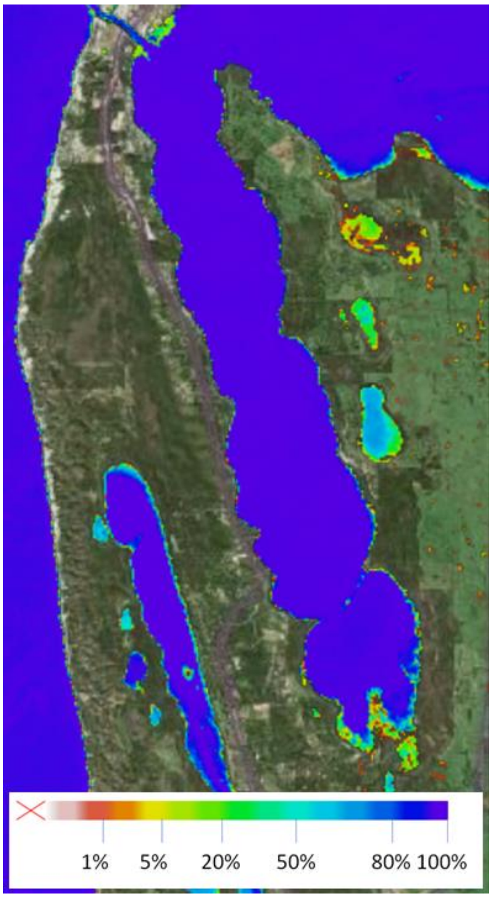

Figure 3-4: Inundation Frequency of Wetlands Fringing Harvey Estuary

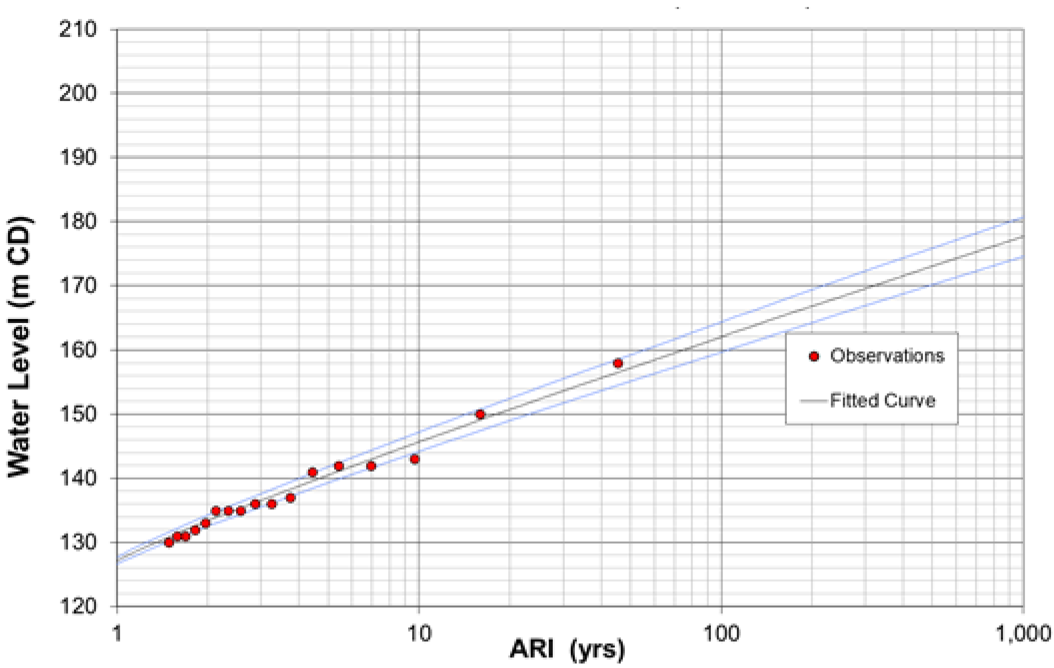

Figure 3-5: Peel Inlet Extreme Water Level Best Fit
Derived from 1994-2020 tide gauge data

Event Recurrence	2 yr ARI	5 yr ARI	10 yr ARI	20 yr ARI	50 yr ARI	100 yr ARI
Water Level (mCD)	1.33mCD	1.42mCD	1.46mCD	1.51mCD	1.59mCD	1.64mCD
Water Level (mAHD)	0.78mAHD	0.87mAHD	0.91mAHD	0.96mAHD	1.04mAHD	1.09mAHD

Table 3-1: Peel Inlet Extreme Water Level Best Fit

The potential for higher water levels associated with passage of a tropical cyclone was evaluated as an 'upper limit' estimate for inundation, following the State Coastal Planning Policy SPP 2.6 (WAPC 2013). Two design storm scenarios were developed, based upon historic events from TC Alby (April 1978) and TC Ned (March 1991).

Following the design storms approach, the storm events were modified through track shifting and varying storm intensity, to achieve a combination that approximates a 500-yr ARI event. For TC Alby, this involved increasing intensity by 10%, and shifting the storm passage such that the radius of maximum winds passed over Mandurah.

Modelling of ocean water levels at the mouth of Mandurah Channel indicated that the surge peak associated with the Alby-based design storm has a relatively short duration of approximately 18 hours (Appendix I). Based upon spectral admittance, the surge within Peel inlet was estimated to be within 60-80% of the ocean surge (Figure 3-6). It is recognised that the level of damping observed during TC Alby was substantially greater with negative surges observed in parts of the estuary. However, opening of Dawesville Channel has significantly increased the opportunity for ocean surges to enter the estuary, and the damping response observed during TC Alby will not occur for the present configuration.

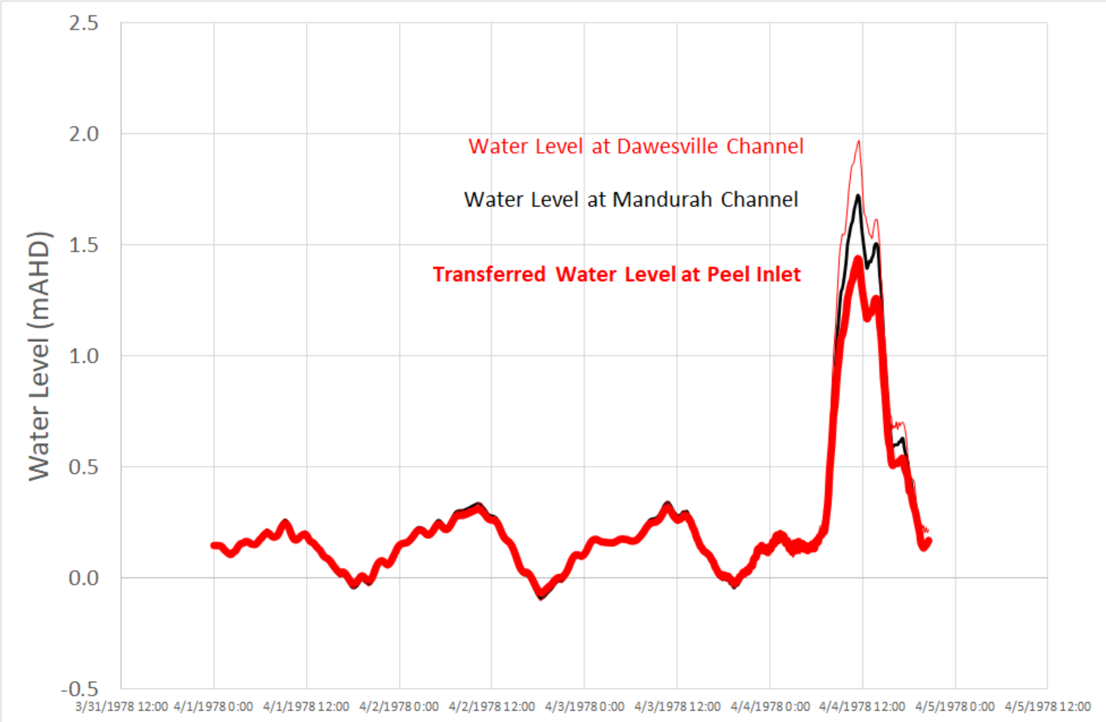

Figure 3-6: Simulated Ocean and Estuarine Water Levels for Design Storm

Using the upper limit of tide and surge transfer rates, the estimated maximum water level associated with the design storm was +1.44mAHD. This extreme storm has synoptic and tidal characteristics approximating a 500-year ARI storm event. The extent of flooding, using a bath-tub approach, covers wide areas of wetland (Figure 3-7), significantly reducing the influence of wave runup, which has consequently been neglected.

Figure 3-7: Extent of Foreshore below Design Inundation Level

The effect of projected sea level rise is to increase all levels of flooding hazard, with a recommended curve for coastal planning in Western Australia (Figure 3-8). The change to flooding levels with sea level rise has been assumed as additive (Table 3-2).

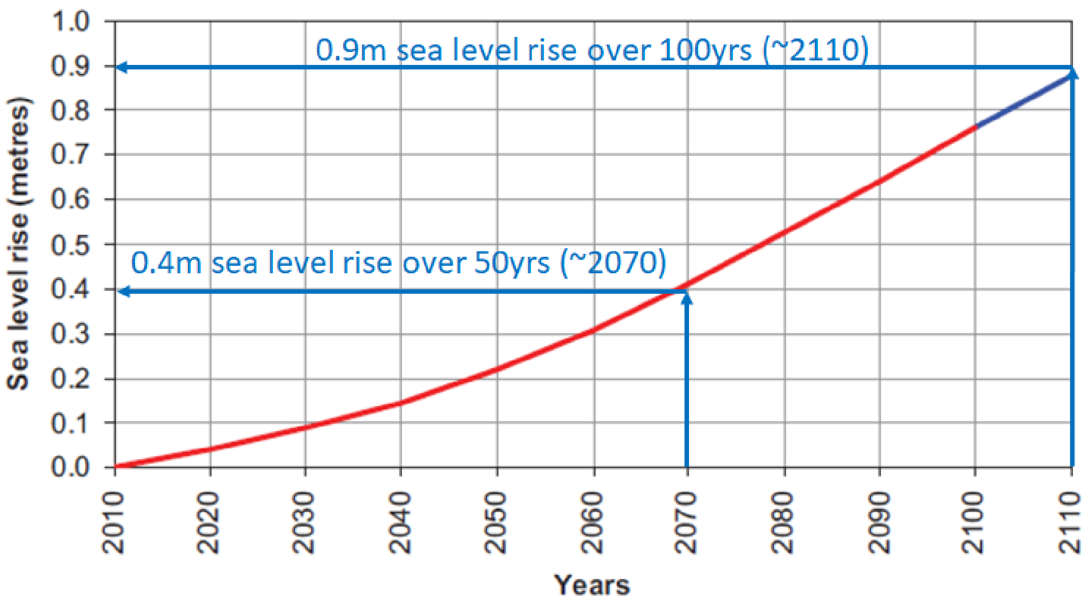

Figure 3-8: Sea Level Forecast Curve Used for WA Coastal Planning (Transport 2010)

Table 3-2: Change to Inundation Levels with Projected Sea Level Rise

Year	Projected Sea Level Rise	Tidal Inundation Limit	10yr ARI Coastal Flooding	100yr ARI Coastal Flooding	Extreme Coastal Flooding
2020	0.0m	+0.60mAHD	+0.91mAHD	+1.09mAHD	+1.44mAHD
2030	+0.07m	+0.67mAHD	+0.98mAHD	+1.16mAHD	+1.51mAHD
2050	+0.15m	+0.75mAHD	+1.06mAHD	+1.24mAHD	+1.59mAHD
2070	+0.50m	+1.10mAHD	+1.41mAHD	+1.59mAHD	+1.94mAHD
2120	+0.90m	+1.50mAHD	+1.81mAHD	+1.99mAHD	+2.34mAHD

Use of a projected sea level curve for modelling of future coastal change is a simplification. The historic record of water levels from Fremantle demonstrates that south-west Western Australia experiences significant inter-annual variability, including the effects of storminess, oceanographic variability (ENSO-related) and tidal modulation (Eliot 2012). These components determine that effects of sea level rise may be felt sooner or later than projection time frames, increasing importance of using adaptive management, which is part of the CHRMAP framework.

The relative significance of changes due to Dawesville Channel is indicated by increase of the 10yr ARI flooding level by 0.37m from pre-1994 to post-1994, acknowledging that around 0.1-0.2m of this difference is due to variability of storminess and higher mean sea level during the 2011-2013 La Niña phase (Eliot & McCormack 2019).

4. Present-day Erosion Hazard

Evaluation of erosion hazard has followed the general form of schedule one of SPP2.6 (WAPC 2013), varied to account for apparently different mechanisms causing response to sea level rise (see Section 4.4). Erosion hazard components are therefore comprised of:

- Acute Storm Erosion Allowance
- Chronic Erosion Allowance
- Response to Sea Level Rise Allowance

4.1. COASTAL EROSION POLICY

SPP2.6 requires a coastal hazard zone to be identified for greenfield development sites using 'Schedule One', which includes allowances for acute erosion (S1), chronic shoreline trend (S2) and response to sea level rise (S3). There is an additional factor for inundation (S4) which does not represent an erosive process. Although erosion allowances are similar to processes evaluated in this section, the required approach differs, as erosion hazard definition under SPP2.6 is prescriptively defined, with an objective to conservatively estimate the area subject to future foreshore change. In contrast, erosion allowances presented in this report are based on 'best-estimate' values, simulating active and projected geomorphic processes to predict change, supporting their use to guide management triggers within a CHRMAP.

4.2. ACUTE STORM EROSION ALLOWANCE

The prescribed approach for evaluating storm erosion is to model the impacts of a severe storm, with an approximate 100-year ARI recurrence. For coastal settings, this is typically undertaken using a profile-based storm response model, plus allowance for alongshore response where there are headlands, protective structures, or changes in shoreline orientation. However, validation for profile models has typically been developed for ocean coasts, where a significant mechanism for erosion is developed by the transition from spilling to plunging waves, with flattening of the beach face resulting in offshore transfer of sediment. In contrast, wave conditions within estuaries rarely experience this transition, and often remain spilling under storm conditions – erosion response is more typically associated with (i) an expansion of the hydraulic zone or (ii) alongshore sediment transfer. Application of a profile model along the Shire of Murray foreshore was therefore expected to require validation and interpretation.

4.2.1. Process Validation Event

A severe storm event occurring on 24 May 2020 provided an opportunity to evaluate the applicability of the SBEACH profile model for the Shire of Murray foreshore. This storm caused strong winds (Figure 4-1) and occurred near to the annual peak predicted tide, resulting in the second highest water level on record inside Peel Inlet.

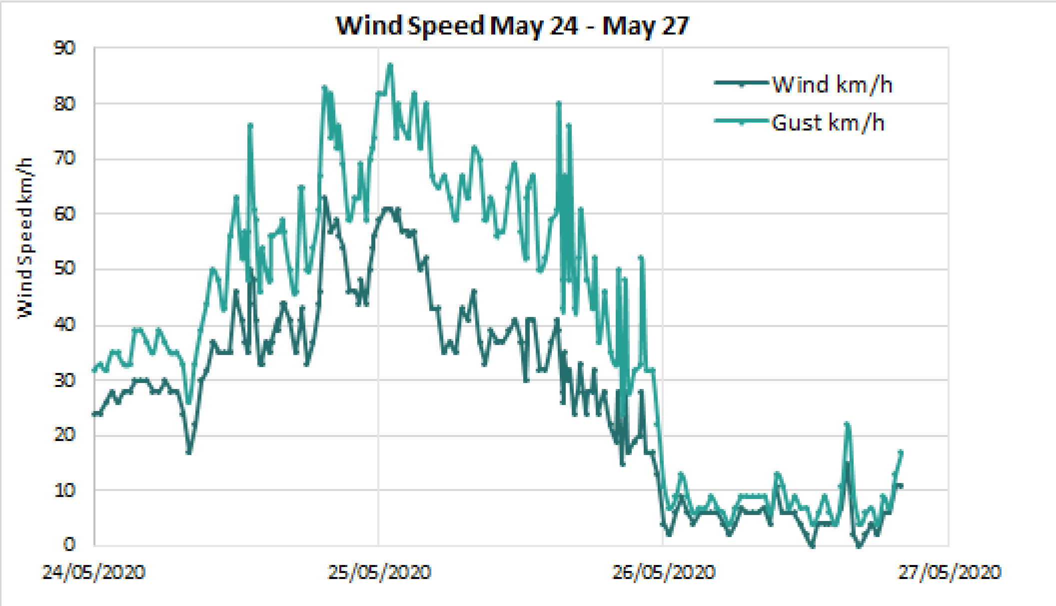

Figure 4-1: May 2020 Storm Wind Record

During site visit in June 2020, impacts to the Murray River delta foreshore were observed, which included foreshore retreat and development of storm bar to landward. This corresponds to the foreshore rollover sequence described by Davidson-Arnott (2015).

Figure 4-2: Observed Response to May 2020 Storm at Old Mill

SBEACH modelling was conducted using a hindcast derived from the wind record, combined with the measured water levels. A median sediment size of 0.15mm was assumed, although field assessment using visual grading indicated highly variable sizing. Model outcomes suggested landward transfer of a similar volume of material, although the depositional structure was steeper, with a sharp back-slope. This response is a consequence of SBEACH's formulation, which includes an empirical estimate of cross-shore sediment transport rates but does not include the process of overwash (Larson & Kraus 1989). Consequently, the total cross-sectional area of change derived from profile response modelling was converted to a horizontal erosion allowance.

4.2.2. Design Storm Definition

Development of a design storm to examine acute erosion involved evaluation of previous storm events. The storm of 16 May 2003 was identified as an outstanding event, with the highest water level on record in Peel Inlet (Figure 4-3) and sustained strong winds for nearly two days. Wind and water levels have been used to hindcast wave conditions for the 2003 and 2020 storms.

A synthetic design storm was developed, by scaling up the 2003 storm winds and water levels to correspond to 100-year ARI levels (Figure 4-4), with hindcast outputs developed for each of 73 profiles (Figure 4-5). The design storm was then applied as a sequence of three storms – this approach was applied to cater for potential underestimation of cross-shore transport rates simulated by SBEACH.

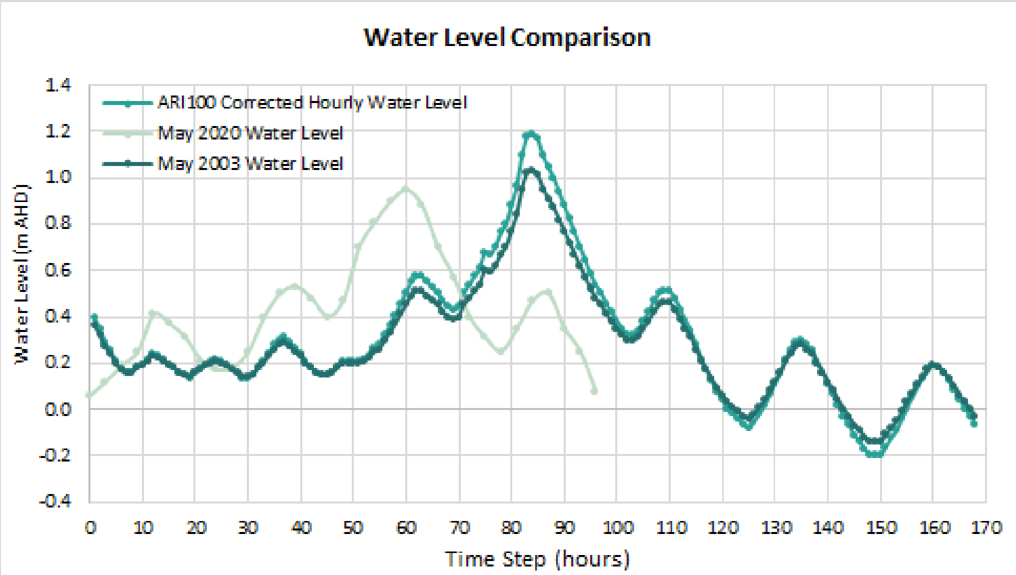

Figure 4-3: Water Levels for 2003 & 2020 Storms & Synthesised 100-year ARI Storm

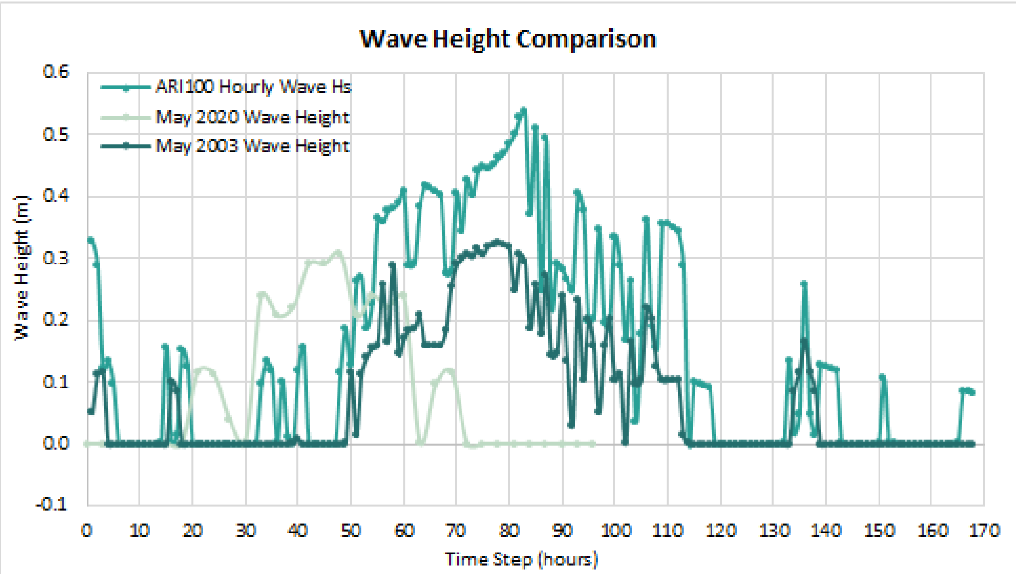

Figure 4-4: Hindcast Wave Heights for 2020, 2003 and 100-year ARI storms

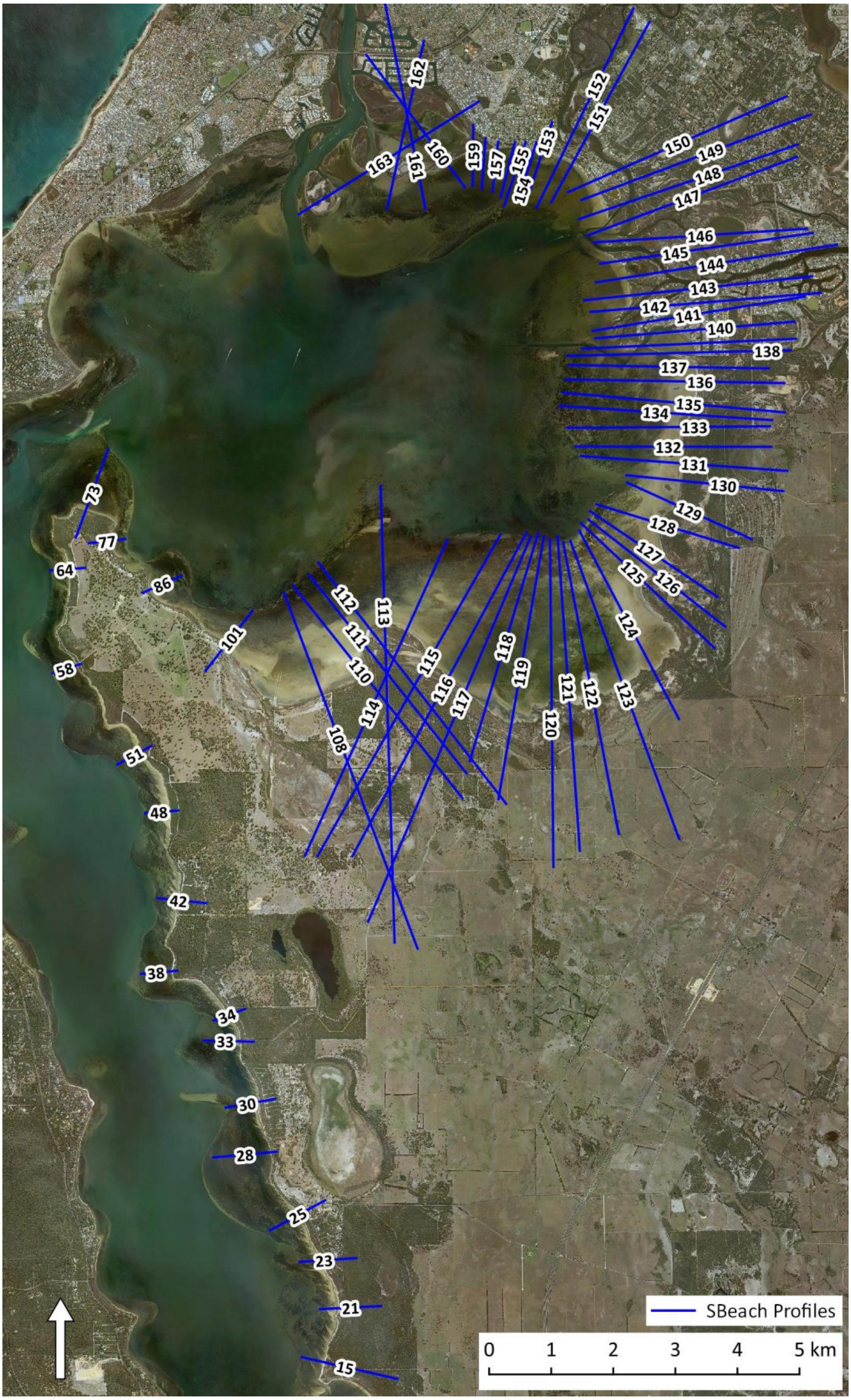

Figure 4-5: Profile Lines used for SBeach Modelling

4.2.3. Profile Response Modelling

SBEACH modelling was conducted for all profiles along the Shire of Murray foreshore (Figure 4-5). As had been suggested by trial modelling for the May 2020 storm, use of the semi-empirical model SBeach is challenged by the low elevation of the foreshore profiles, with profile change modelled to occur wherever a steep gradient is subject to wetting (Figure 4-6). At the shoreline itself, predicted profile change more typically corresponds to the main process used within SBEACH, which is movement toward an 'equilibrium profile' (Figure 4-7).

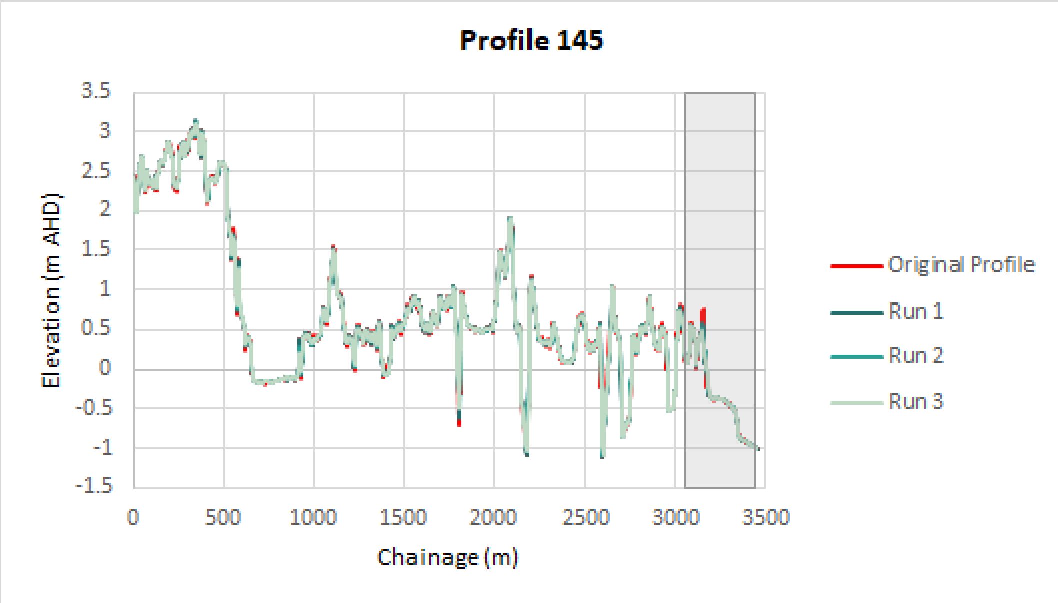

Figure 4-6: SBeach outcomes over full profile

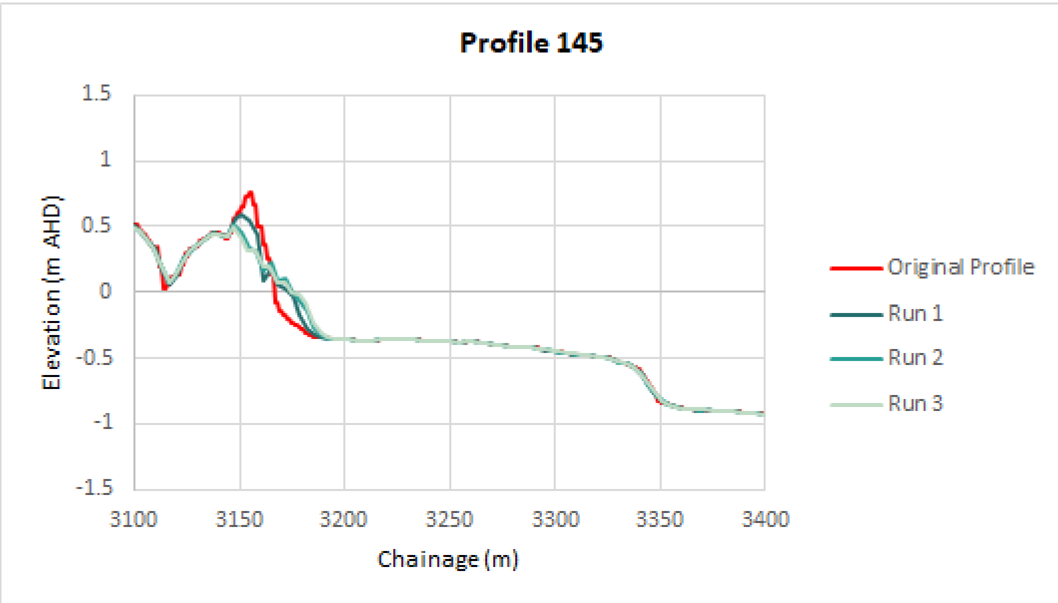

Figure 4-7: SBeach outcomes over part-profile

Estimated erosion response to a storm was developed by summing cross-section change over the whole profile, and then applying this change solely to the front face of the profile. This provided outcomes ranging from 4m to 22m erosion response, with the largest response modelled at Roberts Bay wetlands (Figure 4-13). Variation of response occurs through a range of factors, including the width of the subtidal terrace (causing damping), the beach face gradient and the elevation of the nearshore land.

Riparian vegetation can also substantially modify the foreshore response, with well-established vegetation able to resist short-term erosion pressure from waves up to 0.3-0.5m (Shafer *et al*. 2003). This resistance has not been incorporated in the SBEACH modelling.

4.3. CHRONIC EROSION ALLOWANCE

Observations of foreshore change, summarised in Appendix C, demonstrated that much of the estuary foreshore has been subject to small changes, with the clear exception of the Murray River mouth and the Islands. However, these islands have demonstrated 'roll over' behaviour (see Section 4.4.1), where low elevation spits and berms are gradually pushed landward, rather than the processes of offshore or alongshore loss which cause loss of sediment volume and are more typically considered as 'erosion'.

Determination of a chronic erosion allowance used the overall change in area for the Islands, divided by the active foreshore length, to calculate a trend. For other locations, although some variability was identified, changes were not characteristic of trends. Following SPP 2.6, a rate of 0.2m/yr was used as the minimum allowance for potential future change, which allows for the 'uncertainty' associated with shoreline trend estimation (Figure 4-13).

4.4. PROJECTED EROSION DUE TO SEA LEVEL RISE

The effect of projected sea level rise is to modify wave energy distribution along the estuary shore, causing reconfiguration of existing foreshore landforms. Response may occur through a number of pathways (Figure 4-8), including offshore, onshore or alongshore sediment transport, as well as shift in the foreshore profile.

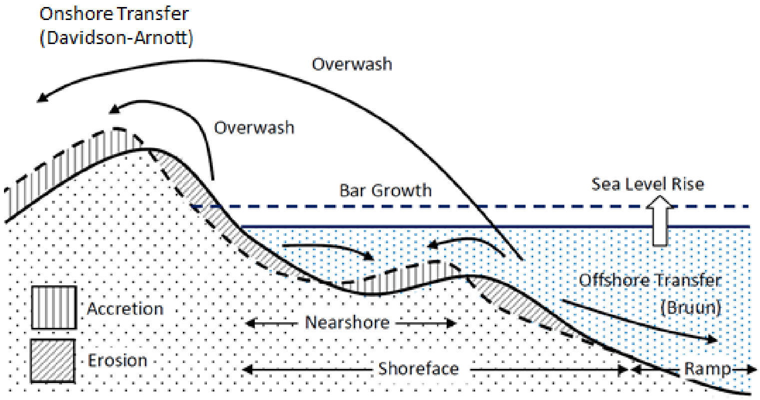

Figure 4-8: Typical Models of Cross-Shore Response to Sea Level Rise
Diagram adapted from Dubois (1992)

Localised response to sea level rise is also expected where coastal landforms facilitate sediment supply or storage. Estuaries will generally experience increased marine sediment influx, however if this is insufficient to keep up with sea level rise the estuary will 'drown' (Leuven *et al*. 2019). For the Peel-Harvey system, there is limited opportunity for marine sediments to enter the estuarine basin, with the ebb-delta occupying only a small part of Peel Inlet's northwest shore. Consequently, most of the estuary is expected to respond at a local scale, where adjustment is caused through foreshore rollover and transfer to the adjacent shore.

Areas of low-lying foreshore provide enhanced opportunity for onshore sediment movement. Occurrence of this mechanism is indicated by the topography, with a low berm providing a narrow barrier to extensive wetland located to landward (Figure 4-9).

SPP2.6 describes a simple allowance for response to sea level rise on the open coast, using 1m horizontal erosion per 0.01m sea level rise. This is often considered to occur through offshore loss (described by Bruun). However, a uniform treatment would not capture the enhanced erosion hazard along low-lying sections of the Murray foreshore. It was consequently determined to determine erosion response to sea level rise by combining a derived erosion allowance for onshore sediment movement with a fixed erosion allowance for offshore or alongshore sediment transfer.

Figure 4-9: Complexity of Low-Level Topography

4.4.1. Onshore Sediment Transfer

Shoreline adjustment through onshore sediment transfer is affected by the topography formed along the shore. Where mild conditions occur, which is consistent alongshore and subject to limited disturbance under ambient conditions (e.g. seasonal variability of alongshore transport), a small berm is created along the shore with a gently sloped back face (Figure 4-10 top). This requires a moderate amount of sediment to build, which must be supplied from the shore, creating retreat. A smaller amount of sediment is required if the back slope of the berm can be steeper, such as a constructed dune, or a vegetated berm.

Response of a low-berm foreshore to sea level rise occurs through two mechanisms:

- *Berm Rollover*, where mild overtopping of the berm causes it the crest to move landward. Erosion from the front face of the berm enables the crest height to rise.
- *Wetland infill*, where large overtopping or tidal currents through a breach cause sediment to dispersed through the wetland area behind the berm.

A considerably larger amount of sediment is required if wetland infill occurs over the entire area behind the berm, which may occur if a storm-built berm becomes unstable. This sequence has been illustrated on the Murray delta islands.

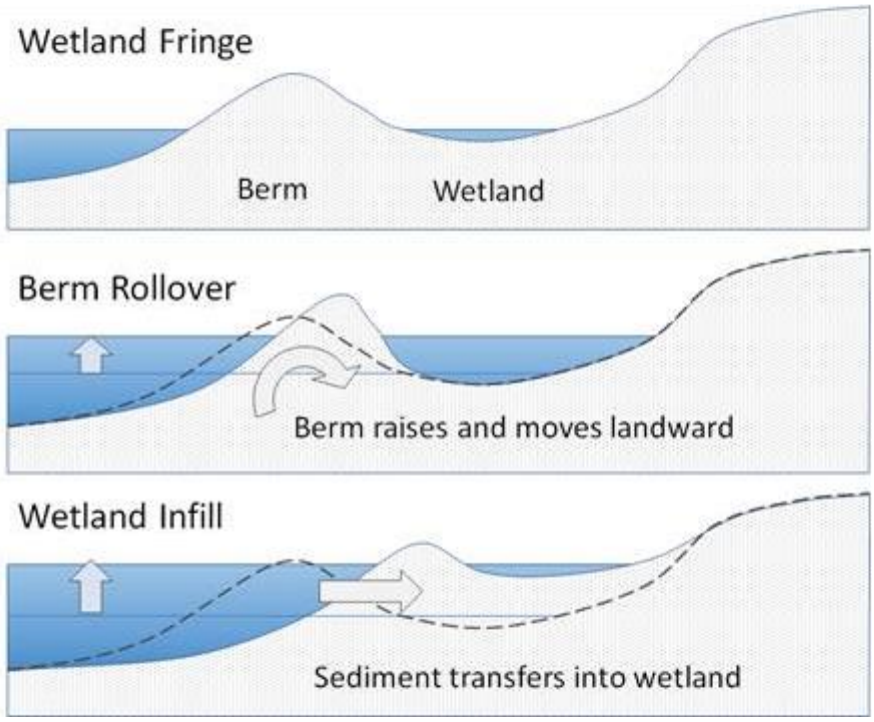

Figure 4-10: Definitions of Rollover and Infill

Instability of berm features increases the higher the berm is above the adjacent land level, with a general progression from occasional overwash, foredune building and then berm collapse and infilling. This results in an exponential increase in sediment demand and shoreline retreat with sea level rise.

Evaluation of potential erosion along the Murray foreshore has been conducted using profiles extracted from LIDAR survey (Appendix E), with aggregated behaviour considered within each of the foreshore segments. Estimation of the potential for wetland infill was calculated for each profile by the cross-sectional area below SLR + 0.6mAHD (i.e. +1.5m AHD by 2120, after 0.9m sea level rise). This provides a significant sediment demand, which has the potential to cause substantial erosion, in the order of 1800m for the Murray River delta area and approximately 400m for Roberts Bay (by 2120).

However, individual profiles highlighted significant low-lying areas, where a narrow berm prevents complete infilling. This suggests that wetland infill is not presently active widely, and that berm rollover is the most likely response to sea level rise, at least in the next 10-50 years. Because berm rollover requires a substantially smaller quantity of sediment, the potential erosion response to sea level is strongly linked to berm stability.

Evaluation of berm rollover was undertaken considering typical profile changes modelled under the design storm, compared with associated storm wave energy, parameterised by the sum of H^2T over the storm period. However, wave energy is only capable of causing overtopping when it occurs simultaneous to high water levels (relative to the berm crest). The long-term hindcast (Appendix B) has been used to derive a cumulative distribution of wave energy with water level (i.e. a berm crest at +0.3mAHD will experience all wave energy for conditions exceeding +0.3mAHD, but will have negligible wave energy input during lower water level conditions. Equating the modelled rate of berm rollover to the available wave energy, potential infill rates for different berm crest levels have been estimated (Figure 4-11). These demonstrate a substantial increase for lower berm levels, with negligible rollover for berm crest levels typically identified along the Murray foreshore of +0.6mAHD to +1.0AHD.

Response to sea level rise has been considered as equivalent to having a lower(ing) berm. This suggests that existing rates of berm rollover will remain relatively low for the next 10-30 years but have the capacity to substantially accelerate with greater sea level rise. In addition to the influence of wave energy, low-lying areas behind foreshore berms are subject to tidal influences, with increasing opportunity for berms to collapse as the difference between the estuary water level and the bed level of the landward basin increases, potentially creating the mechanism of wetland infill.

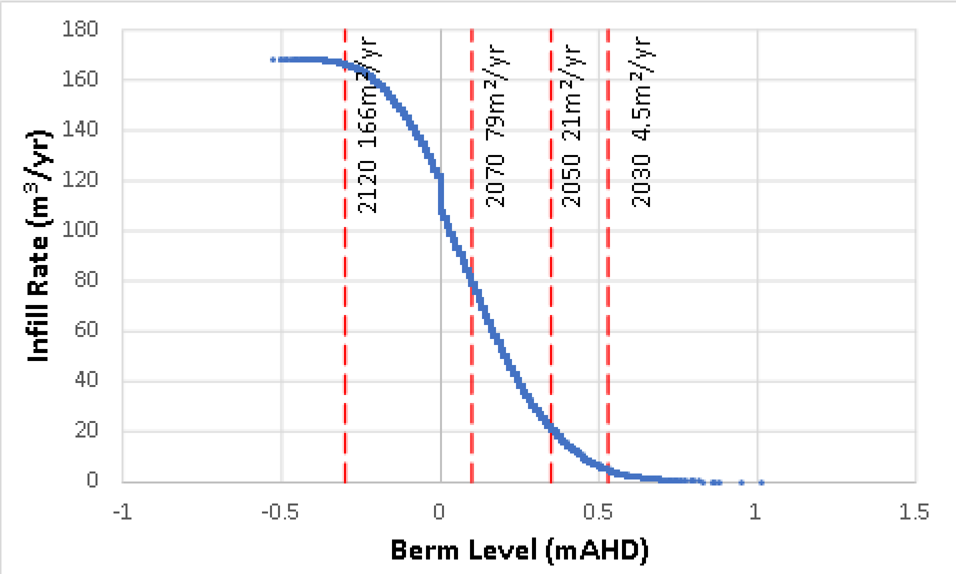

Figure 4-11: Berm Rollover Rates due to Wave Energy and Sea Level Rise

Evaluation of the potential foreshore erosion associated with sea level rise has been conducted – with a ***critical assumption*** that berm rollover will remain the major mechanism for foreshore change. The high alongshore variability results in large differences between nearshore processes – to correct for spatial connectivity, a moving average has been used to estimate the allowance for response to sea level rise.

A small response to sea level rise is expected along the majority of Harvey foreshore due to the height of the existing foreshore. Larger responses are expected towards Herron Point and Roberts Bay, where their lower profile topography is modelled to experience greater rollover. Modelled response to sea level increases from Austin Cove towards the Murray and Serpentine. A small amount of response is estimated for the section of City of Mandurah foreshore where a revetment has been built and the foreshore has been raised above +1.6mAHD.

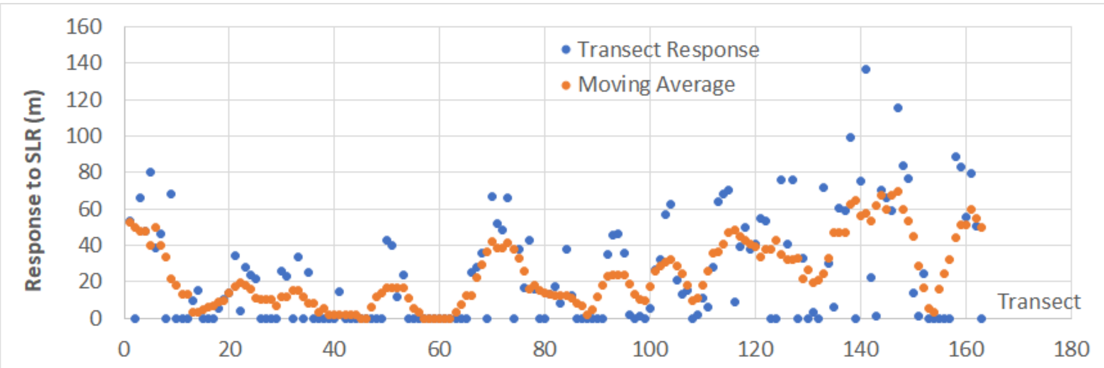

Figure 4-12: 2120 Berm Rollover Estimates by Profile (Locations in Figure 4-5)

The mechanism of wetland infilling is critical to the long-term foreshore dynamics for the Yunderup area. If the foredune berms are unable to keep pace with sea level rise, the intertidal area of the wetlands has a potential infill volume that is an order of magnitude greater than the volume required for a foreshore berm. Implicitly, this means that the projected response to sea level rise could increase to the scale of 1-2 kilometres.

4.4.2. Offshore or Alongshore Sediment Transfer

Although onshore sediment transfer has potential to be extremely significant for parts of the Shire of Murray foreshore, response to sea level rise may also occur through other transfers, including offshore or alongshore sediment transfers. It is expected that offshore loss is likely to occur where the foreshore is perched, such as near Point Grey, and alongshore loss is likely to occur where existing features suggest alongshore transport, such as north of Herron Point. However, as identified by aerial imagery, these areas have experienced small foreshore change over the historic period, limiting the capacity to project future response.

A fixed allowance of 50m has been assumed as a response to offshore or alongshore sediment transfer for all of the estuary foreshore.

4.5. TOTAL ESTUARINE FORESHORE EROSION ALLOWANCES

Influences of storm erosion, chronic change and response to sea level rise have been added horizontally to develop erosion allowances for the Shire of Murray foreshore for time frames of 2030, 2050, 2070 and 2120 (Figure 4-14). Erosion allowances for 2120 are also presented as a table according to foreshore segments (Table 4-1). Erosion distances have been mapped by buffering the erosion distances landward from a nominal shoreline at +0.6mAHD, which was treated as a horizontal setback datum (HSD) using the terminology of SPP 2.6. This is the approximate upper level at which present-day shoreline erosion is observed.

Erosion allowances are comparatively small along the Harvey Estuary foreshore, including the Birchmont area (Figure 4-15), where the relatively higher foreshore resists substantial response to sea level rise and limited historic shoreline change has been observed.

Larger erosion allowances have been determined for Austin Cove and in the vicinity of the Murray and Serpentine Rivers (Figure 4-16), developed mainly due to the low-lying topography and projected response due to sea level rise.

It is reiterated that the process of wetland infilling, which has not been incorporated in derived erosion allowances, has the capacity to massively increase the response of the foreshore to sea level rise.

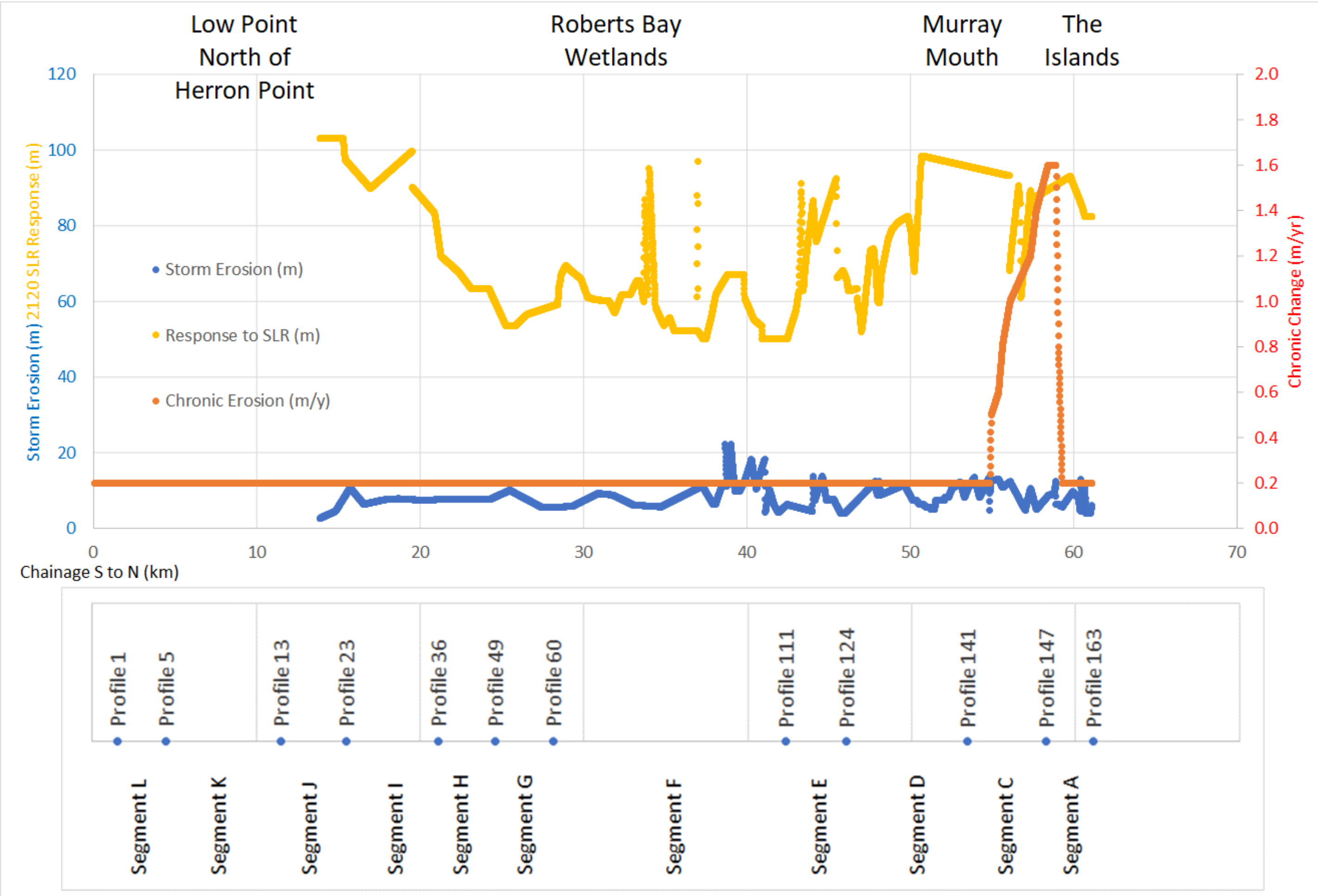

Figure 4-13: Modelled Profile Responses to Design Storm, Chronic Trend and SLR

Note that 'spikes' in the response to sea level rise occur where there is a local low point

Table 4-1: Total Erosion Allowances Table for 2120

Segment	Profiles	S1 (m)	S2 (m/yr)	S3 (m)	Total (m)
A	148-163	4-13	0.2-1.6	54-100	78-261
C	142-147	5-14	0.2-1.5	95-118	139-256
D	125-141	4-12	0.2	70-112	95-141
E	112-124	4-14	0.2	61-93	87-123
F	61-111	4-22	0.2	50-98	76-139
G	50-60	6-10	0.2	50-67	75-97
H	37-49	7-8	0.2	50-97	78-125
I	24-36	6-11	0.2	54-95	81-122
J	14-23	3-9	0.2	54-69	76-97
K	6-13	2-3	0.2	54-100	76-122
L	1-5	2-3	0.2	90-102	112-125

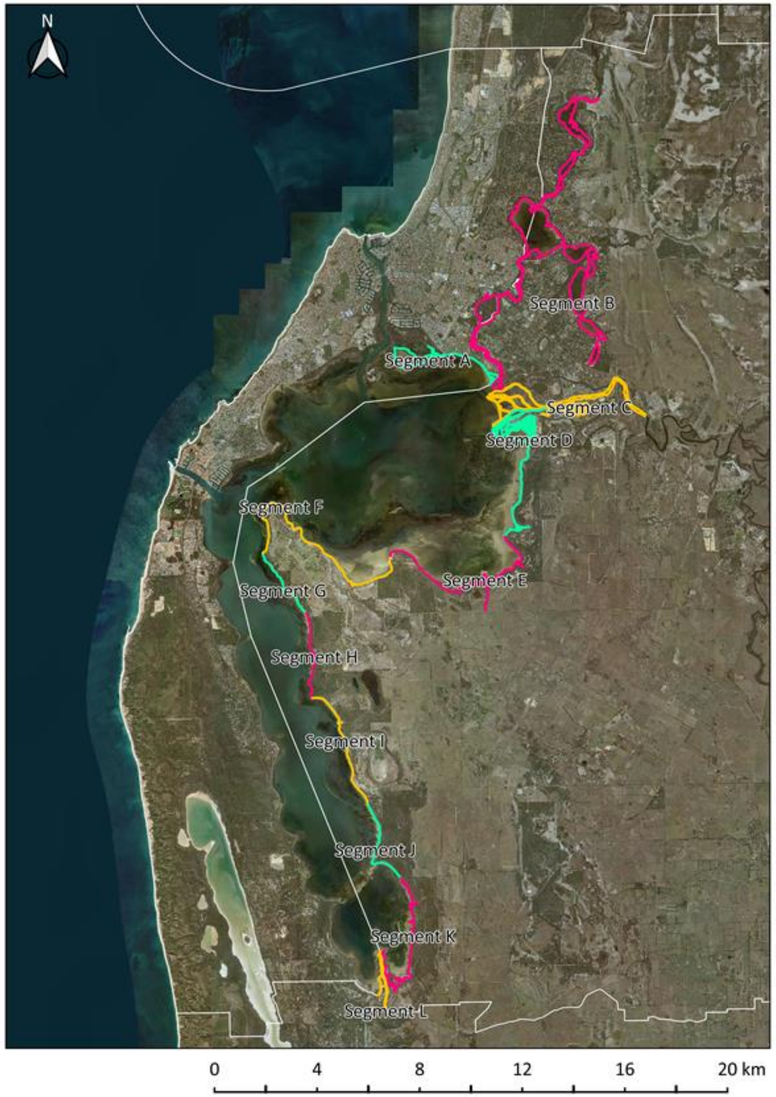

Figure 4-14: Total Erosion Allowances (Whole Foreshore)

Figure 4-15: Total Erosion Allowances (Birchmont Area)

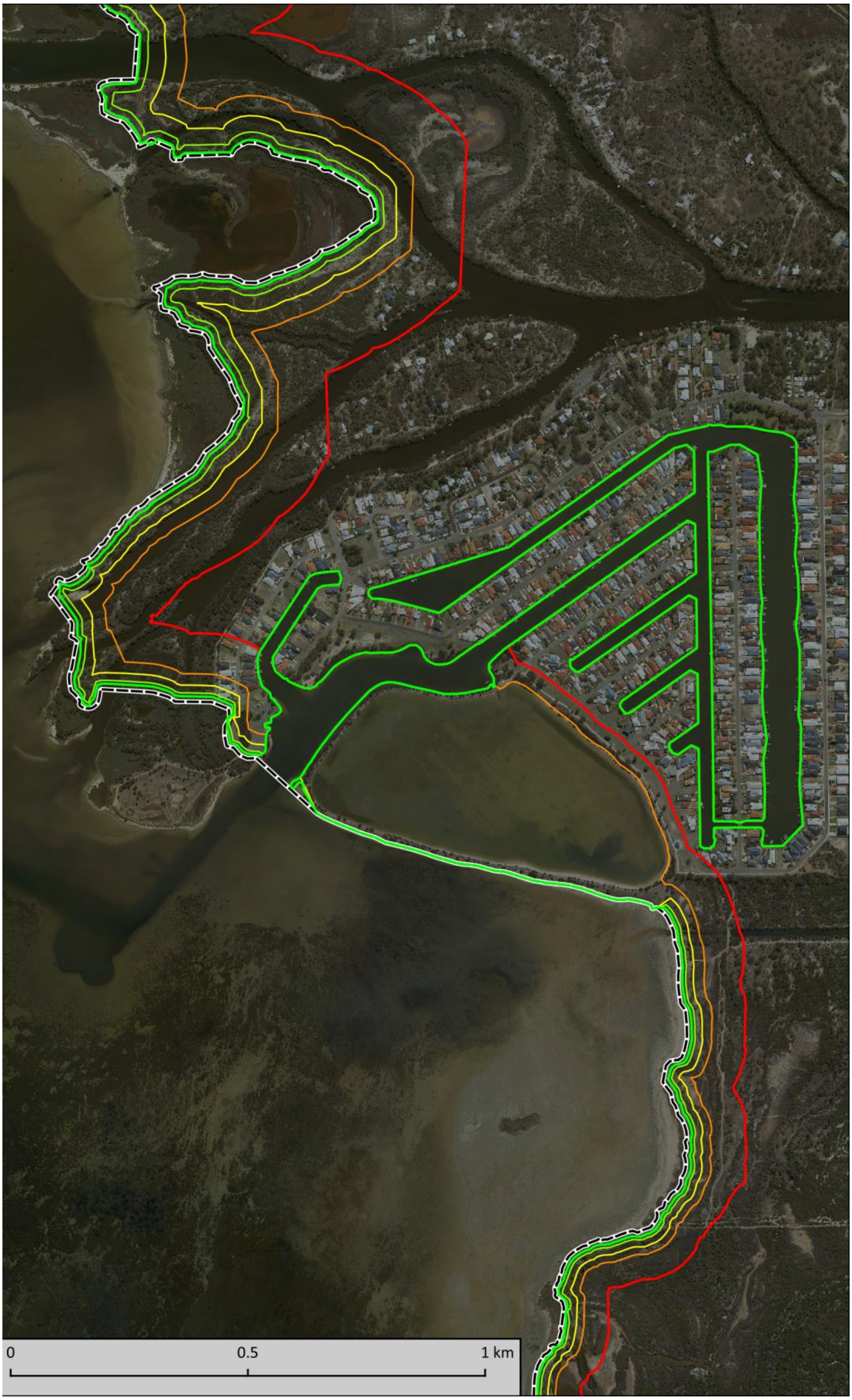

Figure 4-16: Total Erosion Allowances (South Yunderup Area)

4.6. CHANNEL EROSION ALLOWANCES

Erosion pressure has been identified along river channel sections in the lower Murray and Serpentine Rivers (Syrinx Environmental 2019). Sensitivity to erosion hazard is high along the lower Murray River due to active recreational and residential use, substantial presence of foreshore infrastructure and occurrence of high water mark freehold titles. Small scale erosion can cause jetties to disconnect from shore, or the undermining or riparian vegetation, which are perceived as substantial impacts, often prompting reactive works.

Erosion pressure has perceptibly increased due to large-scale hydraulic changes (currents and water levels) after opening of Dawesville Channel. However, the lower section of the river channels also has a history of natural channel evolution, and there have been extensive examples of local transfers of erosion pressure due to foreshore infrastructure. Erosion pressure is expected to increase further due to sea level rise.

The ability to suitably project future erosion hazard (i.e. to define foreshore setbacks) is challenged by a diversity of potential contributing mechanisms (Table 4-2). There is a limited evidence base with which to distinguish between mechanisms or parameterise the scale of response to each mechanism. The PNP Regional Coastal Monitoring Program (Damara WA 2016) provides a recommended monitoring framework for estuaries that may assist with future distinction of active drivers.

Table 4-2: Potential Erosion Mechanisms for Lower Murray River

Erosion Mechanisms	Monitoring	Distinction
Macro-scale:		
• Channel avulsion[1]	Channel widths	Different channels expand/contract
• Dawesville Channel impacts	Channel widths	After 1994, all channels responding
• Sediment supply variability	Flow record	Following flood / low flow periods
Meso-scale:		
• Hydraulic variability	Tide record	All channels responding
• Siltation / deposition	Hydrosurvey	Widespread bed shallowing
• Bed mobility	Hydrosurvey	Adjacent to known bed features
• Boat wakes	Visual inspection	Wide impact
• Channel migration	Thalweg	Local bed deepening
• Bank undermining	Visual inspection	Nearshore deepening
Micro-scale:		
• Instability of riparian vegetation (e.g. trampling)	Visual inspection	Local impact
• Erosion pressure transfer from structures	Visual inspection	Updrift trapping / downdrift erosion

[1] Avulsion is the process where hydraulic flows are redistributed between two or more channels. Typically this involves expansion of one channel and corresponding contraction of another.

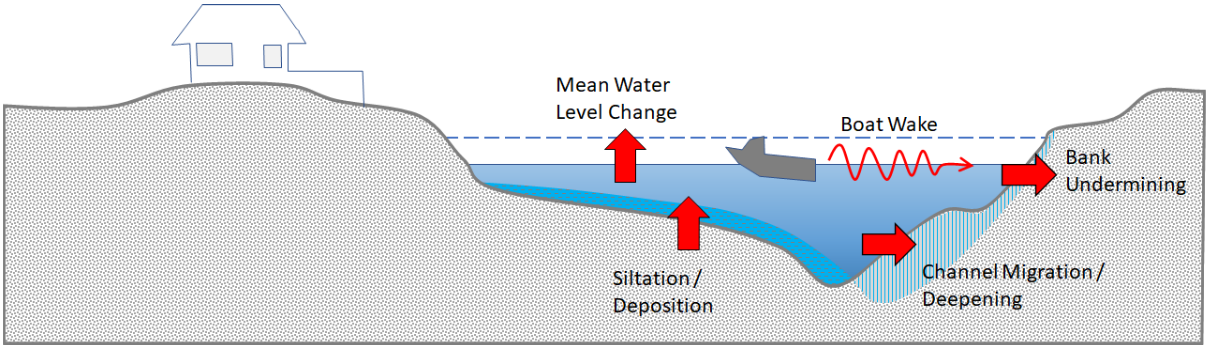

Figure 4-17: Schematic Indicating Meso-scale drivers of Channel Foreshore Change

Identification of erosion hazard along the most developed section of the lower Murray River is partly challenged by a limited ability to measure foreshore change using remote-sensing techniques commonly used for erosion assessment. In particular, the transition from a well-established riparian foreshore through to a degraded foreshore (Figure 4-18) is often obscured by tree canopy. In many cases, the root mass of trees is capable of resisting erosion stress for a considerable period, withstanding deepening of the adjacent foreshore. Change in vegetation can therefore be 'sudden' once the tree is lost, although stress may have been occurring over a much longer period.

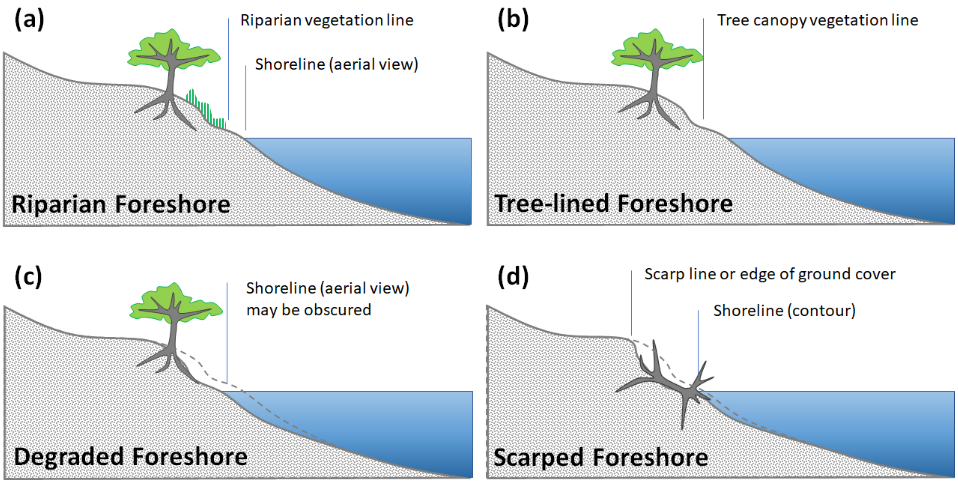

Figure 4-18: Typical Eroding Foreshore Sequence

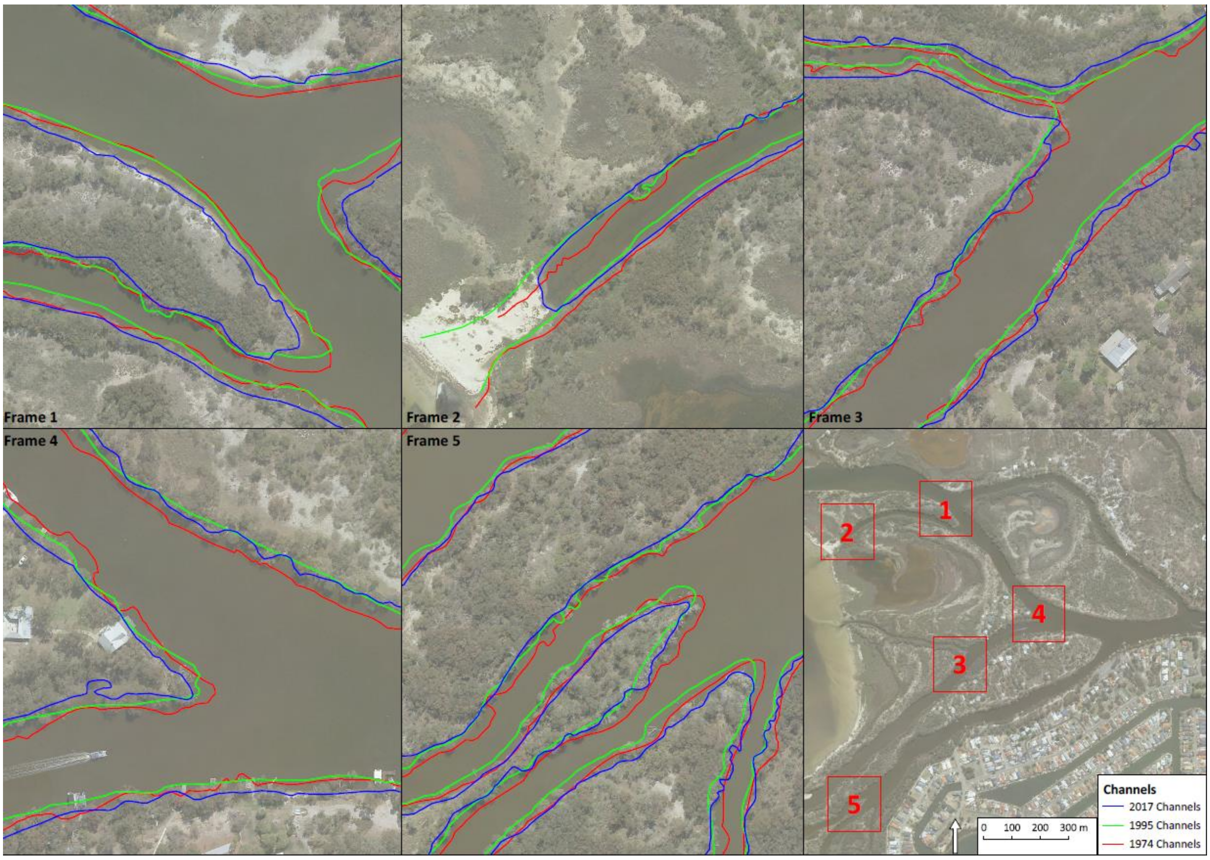

Figure 4-19: Channel Changes Within the Murray River Delta

Shorelines mapped from aerial imagery from 1974, 1995 and 2017 illustrates that the Islands foreshores have been historically dynamic. Overall, there has been general expansion of the channels, with occasional, typically local reversals. A significant change was apparent for the smaller channels 'cutting through' Meeyip Island, with the northern channel contracting after its entrance was plugged by sediment (Figure 4-19 Frame 2), and the southern channel consequently expanding (i.e. local scale channel avulsion).

Although all channels have generally widened over time, particularly following opening of Dawesville Channel, a wider scale avulsion appears to be occurring across the Islands. The northern channels have generally expanded less than those to the south, suggesting that a greater portion of flow (tidal and riverine) is passing through the southern channels.

The lower Serpentine River is comprised of a series of basins, connected by channels. Observed change within this area is small, mainly characterised by sill development near the entrance or exit of channels, which indicates tidal flows are active. Potential response to sea level rise has been evaluated using geometry of the basins and channels. As the percentage increase of channel cross-section is larger than the percentage increase of basin area with sea level rise, it is expected that the lower Serpentine River will have comparatively low sensitivity to sea level rise.

Figure 4-20: Channel Classification

Erosion hazard along channel margins for the lower Murray and Serpentine Rivers has been defined as three separate classes (Figure 4-20), acknowledging the differences in foreshore dynamics between the ocean, estuary, and river channels. Distinction has been made based on observed active processes, including 'switching' of channels, experiencing flow within the Islands, and local influences of foreshore vegetation. In the absence of detailed measurements of channel change, allowances for erosion hazard have been based upon likelihood for different mechanisms for erosion being active, distinguished for three sections, with transition between estuary and wetland buffers outlined in DC 2.3 (WAPC 2002) and SPP 2.9: Water Resources (WAPC 2006):

- Channels within the Islands area have been defined with an erosion hazard of 50m by 2120, accounting for higher tidal flows and potential for channel switching.
- An erosion hazard allowance of 30m by 2120 has been defined where there is a single main channel for the Murray River (adjacent to Yunderup) and within the lower Serpentine River.
- Within the secondary channels and small lakes adjacent to the Murray River, an erosion hazard of 15m by 2120 has been defined. These waterbodies typically receive only a small quantity of flow, usually under extreme water level or flood overflow conditions.

Variation of the erosion allowance over time has been scaled with sea level rise (Table 4-3).

Table 4-3: Erosion Allowances for River Channels

Date	2020	2030	2050	2070	2120
Sea Level Rise	0.00m	0.07m	0.15m	0.50m	0.90m
% Allowance	10%	17%	25%	60%	100%
Murray Delta	5.0m	8.5m	12.5m	30m	50m
Primary Channels	3.0m	5.1m	7.5m	18m	30m
Secondary Channels	1.5m	2.1m	3.8m	9m	15m

4.7. MAN-MADE STRUCTURES

Existing foreshore protection structures within Yunderup provide land retention, including canal estate walling, a bund around the man-made lake south of Yunderup and a containment bund at the southern entrance to the Murray River. These features have been assumed to be maintained to provide the existing standard of protection. For canal walling, additional upkeep is likely required with higher water levels, but existing wall heights are sufficient for walling to provide protection against erosion, illustrated by the extent of land above the present-day severe flood level (Figure 3-7). The bund around the man-made lake presently has a crest height of +1.1 to +1.5mAHD (Figure 4-21), which will require enhancement prior to 2070 to prevent collapse through frequent overtopping.

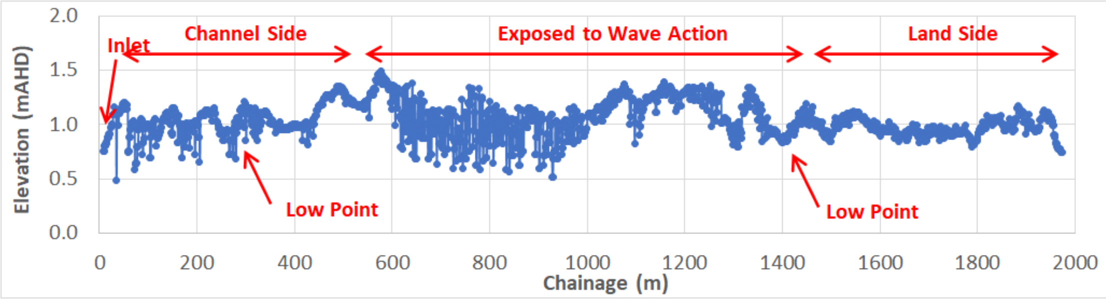

Figure 4-21: Variation of bund crest levels for Yunderup Lake

4.8. EXTREME EROSION (WETLAND INFILL) SCENARIO

Potential for wetland infill to cause extreme erosion hazard has been identified. Mapping of the potential extent of erosion under a 'full infill' scenario for a sea level rise of 0.9m by 2120 has been undertaken (Figure 4-22). This shows significant potential for erosion along the east side of Peel Inlet, of 1-2km width. Wetland infill may also occur along the south and southwest foreshore areas, with 0.4-0.8km potential erosion. A smaller potential for wetland infill was identified toward the southern end of Harvey Estuary. The extent of potential erosion due to wetland infill approximately corresponds to the boundaries of modern foreshore landforms, which developed during the present sea level era.

:

Figure 4-22: Wetland Infill Scenario for 2120

5. Conclusions

Analysis of the Shire of Murray foreshore has been undertaken, to support development of a Coastal Hazard Risk Management and Adaptation Plan. Evaluation has included characterisation of estuarine morphology, determination of historic foreshore dynamics and analysis of tide gauge records. This observational basis has been supplemented by hindcast modelling of wave conditions within the estuary, to determine potential erosion response to severe storms.

Inundation characteristics were determined from the Peel Inlet tide gauge, including extreme distribution fitting for water levels of 2 to 100-year ARI, corresponding to +0.78m to +1.09mAHD. The potential for more severe inundation associated with the passage of a tropical cyclone was evaluated by modelling coastal conditions, with the transfer into the estuary modulated by the spectral characteristics of the storm surge. Simulation of a design storm based upon TC Alby, with intensity increased by 10% and an approximate 'worst-case' track gave a flooding level of +1.44mAHD. This approximates an event of recurrence 500-year ARI.

Erosion modelling was based upon modelling of a synthetic storm, developed from the May 2003 storm, which is the most severe storm on record. Wind speeds and water levels were scaled up to 100-year ARI conditions, to provide an approximation for a storm event with recurrence of approximately 100 years. Modelled erosion due to the synthetic storm was in the range of 8-22m, with larger response occurring on lower-lying foreshore areas.

Assessment of aerial imagery from 1977-2017 identified that historic foreshore changes have been large in the vicinity of the Murray River mouth and generally small (<0.2m/yr) in other locations. Movement has generally been characteristic of foreshore rollover, where narrow spits and berms collapse landward (i.e. although there are large changes in area, they represent small changes in volume). Estimated rates of change, when projected landward, are in the order of 0.8-1.6m/yr around the Murray River mouth.

Future response to sea level rise has been modelled, based upon a critical assumption that the mechanism of foreshore rollover continues to be active, with moderate infill of the wetland located to landward. Rollover can potentially cause erosion in the range of 10-160m, with greater erosion expected where the foreshore is lower. The process of wetland infilling, which has not been incorporated into the modelling, has the potential to increase substantially under projected sea level rise.

Appendix A – Peel Harvey Estuary Context

Appendix B – Meteorology and Oceanography

Appendix C – Vegetation Line Change Summary

Appendix D – Murray Delta Imagery Sequences

Appendix E – Profiles Used to Evaluate of Response to SLR

Appendix F – Peel-Harvey Bathymetric Change

Appendix G – Variability of Benthic Coverage

Appendix H – Wave Hindcast Modelling Report

Appendix I – Extreme Surge Flooding Assessment

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Appendix A – Peel Harvey Estuary Context

GEOLOGY & SURFACE SEDIMENTS

Geology of the Swan Coastal Plain, which includes the Mandurah Region, is divided by the Darling Scarp between the Yilgarn Block to the east (Precambrian granites) and the Perth Basin to the west, with mostly Cretaceous limestone (Gozzard 2011). The shelf margin is characterised by calcareous material, including limestone reefs from relict shorelines, extensive limestone pavement across the inner shelf and a veneer of mobile sediments transitioning to landward as a series of substantial dunes (Searle & Semeniuk 1985; Collins 1988). Three distinct ages are apparent in the superficial sediments of the Swan Coastal Plain, with a sequence of weathered coastal dune systems, including the Bassendean, Spearwood and Quindalup sands, listed in order of decreasing age and proximity to the coast (McArthur & Bettenay 1974; McArthur & Bartle 1980). Peel-Harvey Estuary is situated between the Spearwood and Bassendean dune systems.

Surface geology adjacent to the east side of Peel Inlet and Harvey estuary is characterised as coastal, lagoonal and alluvial (Figure A-1):

- Coastal landforms occur along the northern margin of Harvey Estuary, to Point Grey. This is parallel to the series of limestone ridges and waterbodies occurring in the Yalgorup region, including Lake Clifton and Leschenault Estuary.
- Lagoonal landforms are present along the southern and eastern margins of Peel Inlet, formed by active reworking by estuary waves and tides.
- Alluvial landforms, formed through floodplain processes are dominant for much of the Shire of Murray, including both active modern channels and older floodplain deposits.

Evaluation of sediments throughout the Peel-Harvey estuarine system has previously been conducted using a network of boreholes (Robertson 1972; Logan *et al*. 1976; Treloar 1978; Brown *et al*. 1980; Semeniuk & Semeniuk 1990). Interpretation indicated that:

- Underlying sediments are low permeability muds and silts.
- An intermediate layer of silts, sands and organic material is expressed on much of the estuary bed. This material is subject to wave scour and redistribution, with limited capacity for further deposition.
- An upper layer of sand, characteristic of marine origin, fringes much of the two basins. This material is swept by wave action, forming relatively broad inter-tidal terraces along the margins of Harvey Estuary.
- Zones of fluvial deposition are located at the bay-head deltas for the Murray-Serpentine system and Harvey River.
- An extensive area of marine sand and shell fragments is present in the vicinity of Mandurah Channel, suggesting a significant supply of marine sediment over geomorphic time scales (thousands of years).

Depositional behaviour inferred from boreholes is largely supported by modern observations, although there are clear differences in the rates of deposition. Aerial photography since 1973 has shown active deposition at the mouth of the Murray River, with lesser accretion in the Harvey birdsfoot delta, particularly since diversion and damming works on the Harvey River. Gradual accumulation within Mandurah Channel and growth of Fairbridge Bank has been measured through hydrographic survey, with more gradual accumulation in Sticks Channel.

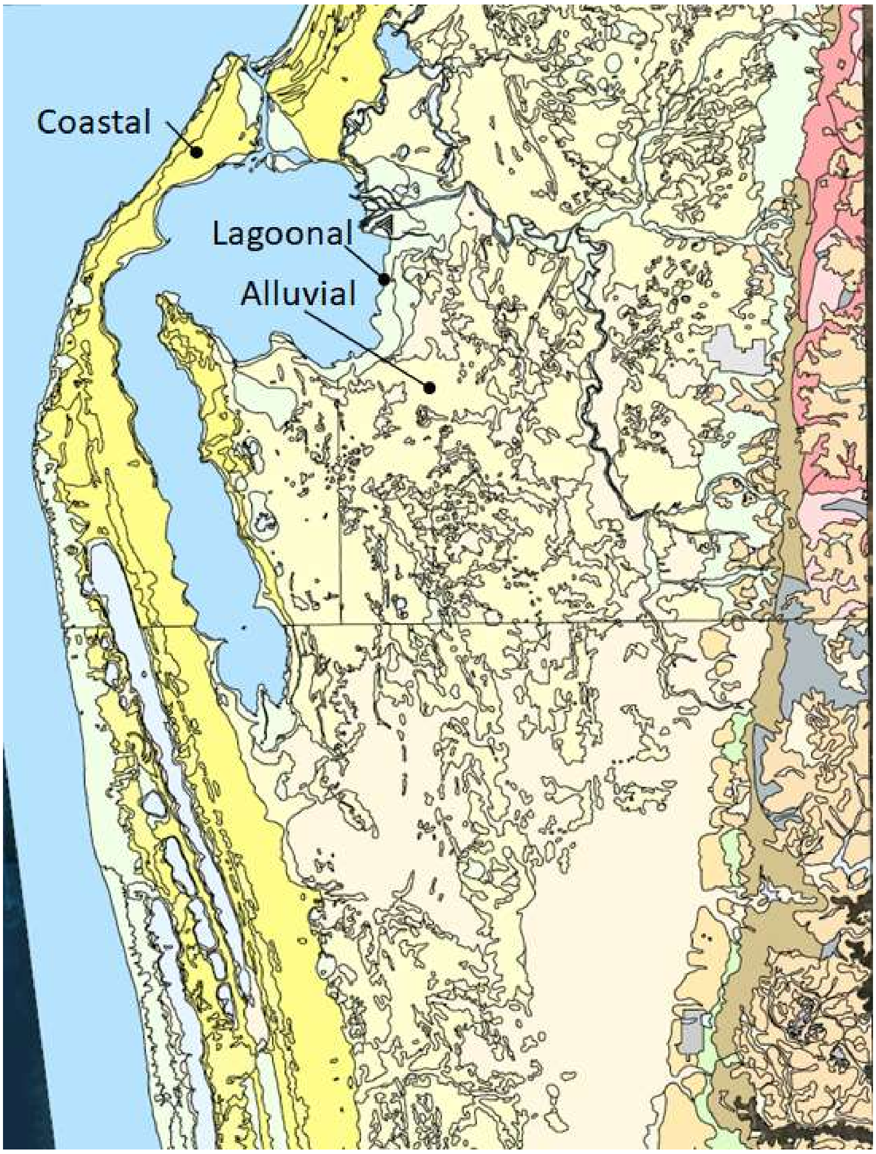


Figure A-1: Extract from 1:50,000 Surface Geology (GSWA)

There has been limited previous description of bed sediment mobility within the estuary, although most of the boating channels requiring minor maintenance dredging (APASA 2010; BMT Oceanica 2015). The entrance to South Yunderup Canals is an exception to this, with significantly increased accretion following a loss of benthic vegetation after Dawesville Channel was opened (Damara WA 2008). Aerial photography indicates that events causing benthic vegetation to be stripped also occurred prior to construction of the Channel, and in recent years well after the Channel (see Appendix E).

ESTUARINE DRIVERS, CONTROLS AND FORESHORE DYNAMICS

Peel-Harvey estuarine foreshore is generally comprised of sedimentary material, subject to forcing from wave and current hydrodynamics of the estuary water body. As with other geomorphic structures, this sediment takes on a form that responds and interacts with the hydrodynamic forcing and is influenced by the composition and supply of the sedimentary material (Wright & Thom 1977). However, estuarine systems, particularly those with shallow basins, have several characteristics influencing their behaviour (Figure A-3):

- Hydrodynamics of the estuary are low energy, allowing contributions from waves, tides and wind-generated currents to variously influence estuary morphology. Variation of these drivers, such as caused by weather events or seasonality, may cause behaviour to switch, particularly when acting in different directions.
- Hydrodynamic influence on the bed may vary over short spatial scales, due to differences in fetch length, or flow structure changes with water depth.
- The relatively small spatial scale gives variation in foreshore aspect, affecting alongshore sediment mobility due to waves or currents.
- Riparian and benthic vegetation may locally modify bed stress or stability.
- Limited tidal range inside the estuary may enhance the significance of flood conditions, whether driven by runoff or coastal flooding, i.e. a small flood event can cause water levels outside the range occurring during ambient tidal conditions.
- The modern (in a geomorphic sense) and depositional nature of estuaries (Dalrymple *et al*. 1992) supports spatial variability in the composition of material within the estuary. Differences in material mobility may influence behaviour.

Consequently, in an estuarine setting, variability of drivers typically interacts with a wider range of controls (geometry, vegetation or material) than in a coastal setting. For this reason, foreshore dynamics may effectively respond over several different temporal and spatial scales.

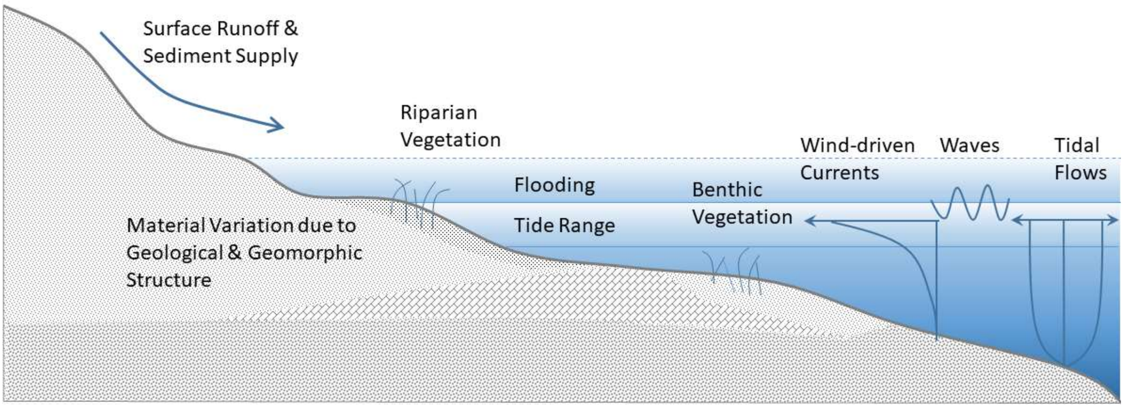


Figure A-2: Schematic of Foreshore Influences

ESTUARINE STRUCTURE & GEOMORPHOLOGY

Peel-Harvey Estuarine System is a large waterbody, draining a catchment of 11,930 km^2. It includes input from the Harvey, Murray and Serpentine River systems, along with local catchment drainage. The estuarine system is a geologically modern feature on the greater Swan coastal floodplain and is likely to have evolved from a floodplain structure towards its current form following Post-glacial inundation over the late Holocene (Robertson 1972; Logan *et al.* 1976; Treloar 1978; Brown *et al*. 1980). Although parts of its structure may be considerably older, the present structure is likely to have developed over the last 2,000 years, when sea levels have remained approximately constant, possibly declining 1-2 m (Wyrwoll *et al*. 1995).

The modern estuary has two distinct but connected estuarine basins, with a relatively narrow channel extending from Peel Inlet to the Indian Ocean. In 1994, Dawesville Channel was opened, providing an artificial connection from Harvey Estuary to the ocean. This excavation has artificially caused foreshore morphodynamics, beyond the general pattern of accretion normally expected in a modern estuarine system (Dyer 1973; Perillo 1995a, 1995b; Ryan *et al.* 2003). Further up-stream the shallow Peel Inlet has an irregularly shaped area of approximately 70km^2, and the slightly deeper Harvey Estuary an elongated structure with an area of approximately 50 km^2 (Figure A-3). The Murray and Serpentine Rivers debouch into the northeast of Peel Inlet, and the Harvey River flows into the southern end of Harvey Estuary, although much of the catchment flow is abstracted through Harvey Diversion Drain. Both basins are substantially sheltered from the direct influence of ocean waves, notably the prevailing swell.

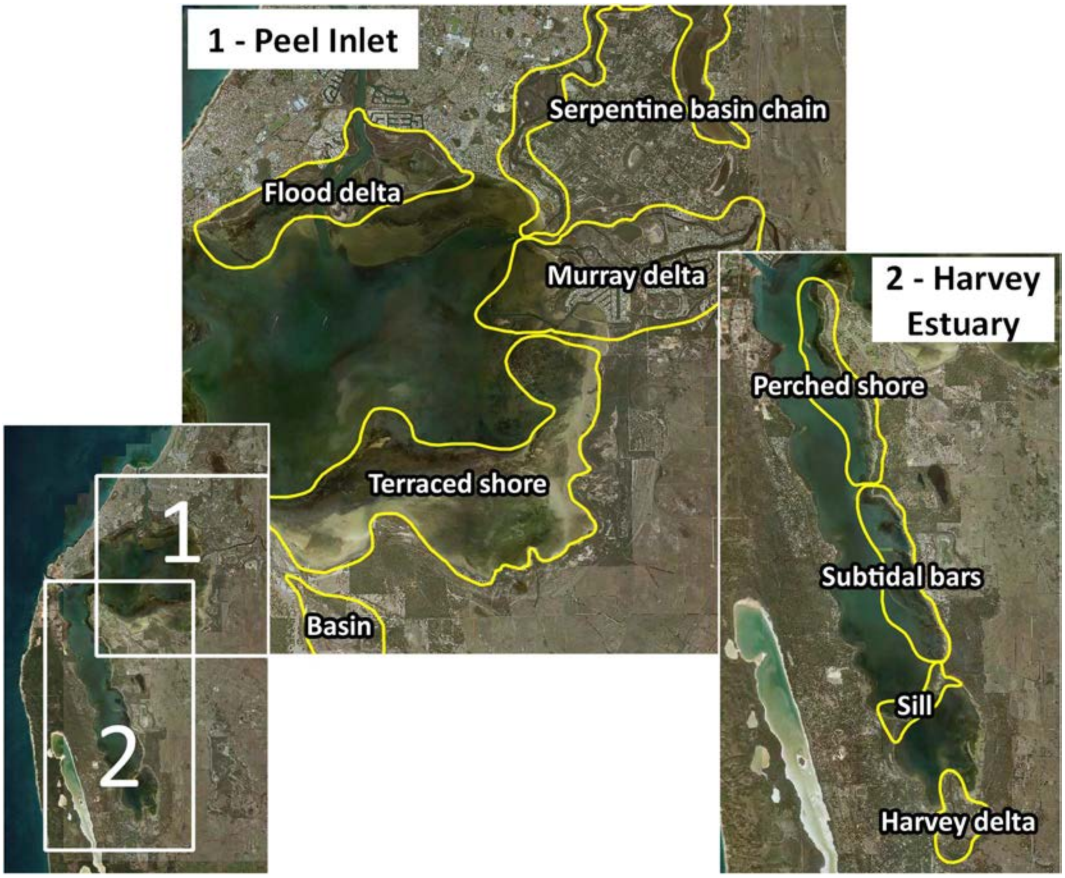


Figure A-3: Major Foreshore Features

Importantly, the low energy dynamics of sheltered estuarine beaches such as the Peel-Harvey system differ from those on the open coast; as has been reported from a wide variety of estuarine environments around the world (Davidson-Arnott & Fisher 1992; Nordstrom & Roman 1992; Makaske & Augustinus 1998; Jackson *et al*. 2002; Eliot *et al*. 2006; Travers *et al*. 2010). Key factors include:

- Absence of prevailing swell.
- Fetch limits for wind-wave generation, and
- Frequent presence of sub-tidal terraces.

These factors should be considered in any appraisal of estuarine shoreline change in the estuaries of Southwestern Australia. Their significance in the Peel-Harvey system is described below.

Peel Inlet

Peel Inlet is a nodular shaped basin, approximately 8-10 km across from any direction, and generally 1-2 m deep throughout. Extensive sub-tidal terraces are present along the southern, eastern and northern shores of the inlet, including large areas of samphire marshes (McComb *et al*. 1995). The Murray and Serpentine rivers debouch along the northeast shore of the inlet, with the Murray forming a complex prograding delta. Much of the land surrounding Peel Inlet is very low relief, reflecting its floodplain origins, and the geologically recent development of the inlet during a period of nearly stable sea levels.

Until opening of the Dawesville Channel, Peel Inlet was connected to the Indian Ocean only through Mandurah Channel, a narrow waterway which substantially restricted the transmission of ocean tides into the estuary basins. Mobility of channel sediments was evident throughout Mandurah Channel, with shoals occurring at the ocean entrance and wetlands with shallow inter-braided channels occurring at the entrance to Peel Inlet. The structure of the estuary, with its large basin and narrow entrance channel is characteristic of a wave-dominated estuary (Ryan *et al*. 2003). This classification is further supported by a ternary classification based on waves, tides and run-off (Harris *et al*. 2002) although it is recognised that the existing structure is substantially influenced by geology, with a limestone ridge forming the western boundary of the estuary (Section 2.2) and sheltering the estuarine basins.

Absence of background swell means that there is limited energy to define a 'prevailing' configuration and the shores are instead forced by wind-waves. Due to fetch limitation, there is an effective wave limit, such that there is little difference between the waves generated by moderately strong or extreme winds. For the purpose of driving sediment transport, this determines that above a characteristic threshold, the persistence of wind is of greater significance than the speed.

For those foreshore areas with subtidal terraces, which are common in the Peel-Harvey system, the terrace provides separation between sediment transport mechanisms along the outer and inner margins of the flats. Transport on the shoreward margin is limited by depth limitation and friction except under high water level conditions. This discrepancy inhibits the 'recovery' phase typically observed on open coast beaches after storm erosion, and is part of the mechanisms sustaining the terrace structure. As a consequence, estuarine beaches may exhibit relict features from severe events for many years, if not decades.

Prior to opening of Dawesville Channel, historically observed dynamics along the Peel Inlet shore mainly occurred in the vicinity of the Murray-Serpentine delta, and Mandurah Channel. In general, the delta area experienced ongoing accretion as fluvial sediments were deposited in the basin. Mandurah Channel experienced a mixture of accretion and erosion, but the pattern is obscured by human intervention, including dredging, construction of shore structures and boat wakes. Subsequent to opening Dawesville Channel, much of Peel Inlet shore showed erosive characteristics including scarping and the loss of fringing saltmarsh areas (Calvert 2002). These were anticipated results of the increased water level ranging and tidal flows caused by the channel excavation. Aerial photographs of the inlet also show zones of benthic vegetation loss, but it is noted that such events also occurred intermittently prior to Dawesville Channel (Damara WA 2008).

It is important to recognise that the historical stability of the estuarine shorelines may understate the active dynamics. The extensive sub-tidal terraces act to dissipate wave energy, and hence the majority of sediment transport is likely to occur along the edge and surface of the sub-tidal terrace, except during extreme water level events (Nordstrom & Roman 1992). Evolution of the sub-tidal terrace therefore may occur without a corresponding shoreline change until an extreme event occurs, and consequently can result in a relatively sudden shoreline movement.

The expected pattern of evolution is determined by the fetch-limited nature of the estuary basin, which may provide variation of the wave climate over relatively short distances. This determines dependence of shore stability upon the distribution of wind directions and enables the formation of extensive cross-shore features such as bars and spits, which are capable of episodic change during storm events (Niederoda & Tanner 1970; Prats 2003). The formation or collapse of ephemeral features can allow localised erosion or deposition over relatively short periods of time, and consequently, allowance for coastal setbacks should consider any reliance upon such ephemeral features. Erosion potential is enhanced where there is variability of alongshore transport, such as caused by a change in shore aspect, a difference in riparian vegetation or soils. Drainage systems including streams and river channels may also provide erosion potential due to seasonal variability of flow.

Harvey Estuary

Harvey Estuary is an elongated cigar-shaped basin with crenulated shores, roughly 20 km long, and 2-3 km wide, and typically about 3 m deep towards the centre of the estuary. A shallow sill defines a small basin at the southern end, which has provided sufficient shelter for an unusual birdsfoot delta to form where the Harvey River enters the estuary (Figure A-4). The sides of the estuary are characteristic of coastal barrier dune systems from previous eras, and provide high relief compared to the floodplain east of Peel Inlet. Low relief land is restricted to a narrow fringe along the shore, and salients where the crenulated shores project further into the estuary.

Figure A-4: Birdsfoot delta in Harvey Estuary

Processes Influencing Peel-Harvey Morphology

The relative influence of different driving processes varies substantially across the estuary, including local-scale influences of landform and bedform structures on hydrodynamics. Features indicative of difference types of forcing and land forming processes include:

- A flood delta present at the southern end of Mandurah Channel, indicates high tidal flows through the channel, with flow speeds reducing as they enter Peel Inlet. This depositional area includes the series of low-lying wetlands and intertidal flats of the Creery wetlands.
- The lower Serpentine River is a very gently graded river system comprised of a series of basins, with interconnected flood channels. These basins provide hydraulic detention, which reduces the capacity for riverine floods to convey sediment to the estuary. Basins to the east of the present mouth potentially suggest a previous flow path, which may act as a breakout pathway under extreme events. Historic modification of the Serpentine catchment included excavation of trenches between basins to drain wetlands and increase the agricultural area.
- A 'bay head delta' occurs at the mouth of the Murray River. This landform is characteristic of high sediment supply from upstream and indicates potential for relatively high flows.
- The east and southeast shores of Peel Inlet have extremely wide subtidal terraces, particularly south of Yunderup, Austin Bay and Robert Bay. These are typical of low energy estuarine shores.

- Foreshore terraces with transverse bars occur on the east side of Harvey estuary, indicating low wave energy conditions, frequently occurring from a southerly direction.
- A 'birdsfoot delta' occurs at the mouth of Harvey River. Such landforms are characteristic of sediment supply from upstream and very low energy conditions within the estuary basin.

These features largely suggest the estuarine basins provide separation between runoff processes active in the river channels and the tidal flows active in Mandurah Channel, Grey Channel between the two basins, and Dawesville Channel. Transition between flow dominated behaviour and wave dominated behaviour occurs near channel entrances and is likely to vary spatially over time.

In addition to broad-scale structural features associated with the rivers and channels, there are smaller-scale convex foreshore features at locations around both estuarine basins (e.g. Sandy Point). Some of these features are potentially underpinned by natural rock formations, but for most, active foreshores include mobile sedimentary features, with retention enhanced by either vegetation or constructed edge treatments. Modelling of Harvey Estuary hydrodynamics has suggested that local-scale convexities may induce gyres in estuary circulation, reinforcing the structure through sediment transport (Hearn & Lukatelich 1990).

RIPARIAN VEGETATION

Sheltered conditions within an estuarine setting provide increased opportunity for the sustained presence of riparian vegetation, ranging from sedges and saltbush through to salt tolerant trees, such as melaleuca. Vegetation typically provides a stabilizing role on estuary foreshores, whether through binding of sediment to the root mass, enhancement of dune-building processes, or wave sheltering from fallen logs, and therefore the presence of riparian vegetation is influential in foreshore dynamics.

The capacity for different species to establish and subsequently thrive is a function of ecological and geomorphic conditions. Influencing factors include surface water and groundwater chemistry; inundation frequency; soil type; nutrient supply; traffic; undercutting pressure; or sediment smothering (Trudgeon 1988). Different species, sometimes at various stages of maturity, are affected by different factors. Consequently, the effects of inundation and sediment dynamics often result in characteristic cross-shore zonation of vegetation species (Figure A-5). Changing conditions may cause pressure on this zonation to migrate, subject to resilience of the vegetation, which may result in phases of dieback and recolonization.

Mechanisms affecting riparian vegetation include:

- Plant life cycles, including developing maturity and response to seasonal pressures;
- Substantial variation of environmental conditions, such flooding or drought cycles, or anthropogenic factors such as nutrient loads or major engineering works;

- Foreshore dynamics, including seasonal or longer-term movements of foreshore sediments, which may build or erode spits, beaches or estuarine berms (these are sometimes described as foreshore 'dunes');
- Micro-climate variation, such as pond-channel structure within a wetland, or nutrient load associated with stormwater management and debris. There is often feedback between vegetation species development and microclimate, as more established vegetation is typically capable of stabilizing larger features such as dunes or banks.

These mechanisms are often inter-related, limiting identification of cause and effect and therefore obscuring appropriate management responses in situations where it is considered appropriate.

Within Peel-Harvey Estuarine System, characteristic forms of riparian vegetation include marshlands, wetlands and estuarine woodlands, which may occur singly, or in a sequence related to species eco-geomorphological capacity (Figure A-5):

- Estuarine marshlands, including samphire and *halosarcia* communities are extensive near the southern end of Mandurah Channel (Creery Wetland), Robert Bay, Murray-Serpentine and Harvey river mouths, (McComb *et al*. 1995). These are very flat, intertidal areas.
- Fringing estuarine wetlands, typically populated by sedge species such as *juncus krausii* occur adjacent to marshlands, but also intermittently along segments of Peel Inlet and Harvey Estuary shores (Calvert 2002).
- Estuarine woodlands, with *melaleuca* common (Calvert 2002).

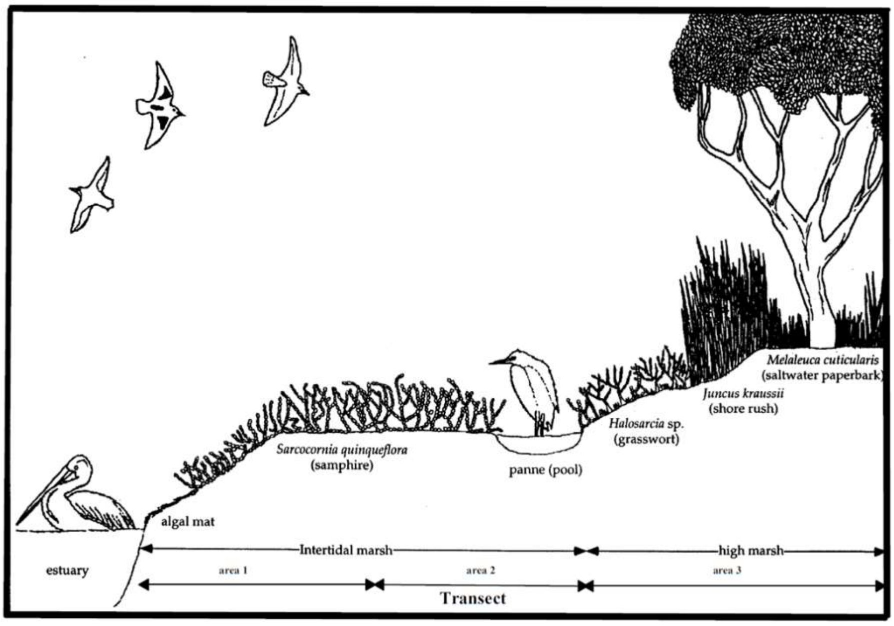


Figure A-5: Characteristic Riparian Zonation for Peel-Harvey Wetlands

(From McComb *et al*. 1995)

Development of the estuary has resulted in a complex geomorphic arrangement, including basin-channel structures and ridge-swale sequences that have developed under varying conditions, resulting in a mixture of active and relict riparian basins (Semeniuk & Semeniuk 1990). This arrangement enables substantial ecological change to occur in the foreshore zone, with switching between ‘dry’ and ‘inundated’ conditions able to occur with relatively subtle changes in hydrology or sea level. Riparian vegetation has been observed to respond to such changing conditions with migration of riparian zones (McComb *et al*. 1995). Species death may occur if adverse conditions are sustained for a critical period – this may vary from days through years, depending on robustness.

Opening of Dawesville Channel caused a substantial change to both inundation frequencies and seasonal salinity variation. Of particular importance, there was no longer a coincidence between winter high water levels and brackish conditions (Young 1986), with a result of saline stress and dieback for less tolerant species (Gibson 2001; Calvert 2002; Carter *et al*. 2006).

ESTUARY MODIFICATIONS

Peel-Harvey Estuarine System has been substantially modified since European settlement in Western Australia. Initial modifications largely involved land clearing and drainage to support agricultural use of the catchment. This was followed by substantial modification of the ocean entrance and Mandurah Channel, to improve the reliability of small craft navigation and improve estuary-ocean water exchange (DMH 1985).

Foreshore infrastructure has been progressively installed as residential and recreational pressure adjacent to the estuary has increased. This has included walling to stabilize foreshore parks and road reserves, and boat ramps to support small craft use of the estuary. Construction of canal estates commenced in the 1970s at Yunderup, with subsequent proliferation of facilities along Mandurah Channel from the 1980s. Additional canal estates were developed following opening of Dawesville Channel in 1994, and Mandurah Ocean Marina was opened in 2001.

Between the 1900s and 1970s, the hydrology of Harvey and Serpentine Rivers was modified, for reasons of land drainage, flood management and water supply. Major works included construction of a southward-draining network from Kwinana and de-snagging along the Serpentine, damming of the Harvey River and construction of Harvey Diversion Drain. In addition, agricultural drains were established for land along the eastern side of Harvey Estuary.

Changes to the hydrology and land-use altered estuarine water chemistry, resulting in progressive eutrophication of the waterway (Hodgkin *et al*. 1980). Holistic assessment of Peel-Harvey catchment was undertaken, ultimately leading to a set of management actions (DCE 1984b, 1985; Gorham *et al*. 1988). The action with the most profound consequences for Peel-Harvey foreshore dynamics was construction of Dawesville Channel, opened in 1994, which substantially increased tidal exchange into the estuary to enhance water quality.

Dawesville Channel

As of 1985, more than half the phosphorus discharged into the Peel-Harvey estuary system came through Harvey River into the south of Harvey Estuary, where there was very little exchange with ocean waters due to the isolation of these waters from Mandurah Channel. High levels of phosphorus input with limited oceanic exchange resulted in the reported *Nodularia* blooms (DCE 1984a). Initially observed in the Harvey Estuary by DEC in 1978, *Nodularia* was subsequently carried into Peel Inlet after which blooms were reported in both water bodies (DCE 1984a).

Options to manage the increasingly eutrophic state of the Estuary were evaluated, with Peel Inlet and Harvey Estuary Management Strategy (CALM 1985) developed to enhance Estuary water quality through short and long term measures. The strategy included an engineering intervention to excavate a channel between Harvey Estuary and the Indian Ocean. The proposed Dawesville Channel was intended to enhance tidal flushing and create a more marine environment, inhibiting growth of *Nodularia*. This measure was coupled with continued harvesting of nuisance weed and modified agricultural practices, to reduce nutrient input to the Estuary.

Predictions associated with the Dawesville Channel (Paul & Hutton 1985, Tong 1985, Gorham *et al*. 1988, Ryan 1993) include:

- The estuarine coastline between the Dawesville Channel and Mandurah Channel would not be eroded.
- Siltation in Mandurah Channel would not increase detrimentally.
- Training walls and entrance cross-section could be designed in tidal equilibrium, such that the channel would flush out sediment entering the channel.
- Tidal range inside the Estuary would increase from 15-20% of oceanic levels to 45-50% following construction of the Channel. This approximately corresponds to an increase of average daily tidal range from 0.1m to 0.3m.
- The altered tidal regime was predicted to create a greater number of areas conducive to saltwater mosquito breeding (saline wetlands/marshes).
- Estuary flushing time was predicted to decrease from 90 to 30 days in Peel Inlet and from 150 to 50 days in Harvey Estuary.
- Water exchange per tidal cycle during typical summer conditions was predicted to increase from $5.5x10^6$ m^3 to $6.3x10^6$ m^3 through Mandurah Channel, and from 3.3 $x10^6$ m^3 to 6.4 $x10^6$ m^3 through Grey Channel between the two estuary basins. Water exchange through Dawesville Channel was predicted to be 16.5 $x10^6$ m^3.
- Clearer water was expected with enhanced mixing due to increased tidal movement and greater flushing of organic matter.
- An ecological transition in species was predicted, from those that could withstand the variation from fresh to hypersaline water, to predominantly marine species. This was considered likely to impact commercial fisheries, reducing resident species numbers but creating a higher diversity in marine species.
- Increased quality of the overall estuary environment was expected to lead to increased recreational use of the Estuary by the public.

In 2003, a report was released demonstrating the progress and compliance with Environmental Conditions (EPA 2003). This report listed predicted changes and corresponding observations following Dawesville Channel construction. Predictions include:

Factor	**Predicted change following Dawesville Channel Construction**	**Observed change following Dawesville Channel Construction**
Tidal	Daily tidal range increase from 17% to 45-50% of ocean tide in the Peel, and from 15% to 60-70% of ocean tide in the Harvey. Decreased duration of tidal inundation/exposure. Increased frequency of tidal inundation/exposure.	Increase to 48% of ocean tide in the Peel, and to 55% of ocean tide in the Harvey. As predicted As predicted
Flooding	Transition to being driven predominantly by river flow to an influence from daily or storm surge tides affecting the eastern estuary edge. Transition from average water level decrease of 0.4m in 10 days to average water level decrease of 0.4m in 3 days.	As predicted As predicted
Hydraulic Characteristics	Decrease in average residence time from 30 days to 10 days in the Peel, and from 50 days to 17 days in the Harvey. Increase in water exchange per tidal cycle from 5.5x10^6 m^3 to 6.3x10^6 m^3 in the Mandurah Channel, and from 3.5 x10^6 m^3 to 6.4 x10^6 m^3 in the Grey Channel. Water exchange through the Dawesville Channel expected to be 16.5 x10^6 m^3. Period of stratified conditions to reduce by approx. 2 months, with stratification to be more intense.	As predicted As predicted As predicted
Sediment Characteristics	Non-apatite phosphorus stores in estuarine sediment expected to gradually deplete, with subsequent reduced periods of anoxia and less release of phosphorus from sediments to the water column	Assessment incomplete in 2003
Water Quality	Transition from salinity extremes towards marine salinity prevailing for most of the year, with associated strong stratification. Hypersalinity to end. Reduced frequency and duration of deoxygenation periods, reduced turbidity (reduction in *Nodularia blooms)* and more rapid return to low nutrient levels, associated with estuarine flushing.	As predicted, except for some occurrence of hypersaline conditions (less extreme than previously). As predicted, except for summer turbidity in the Harvey due to winds resuspending sediment.

Modified from EPA (2003)

Impacts of Dawesville Channel that are important for foreshore dynamics include:

- A step change in the character of water level variability within the Estuary. This extended the foreshore's hydraulic zone, over which surface waves provide bed stress and may mobilise sediment.
- Substantial modification of tidal currents. and
- Alteration of ecological conditions, affecting riparian and benthic vegetation.

Distinguishing the impact of Dawesville Channel upon the estuarine system has been partly obscured by climate variability, including decadal-scale rainfall decline, and anthropogenic development of the estuary (Elliott *et al*. 2016).

Other Anthropogenic Factors

In addition to Dawesville Channel, land use change has occurred along the Shire of Murray, affecting the foreshore. The most substantial change adjacent to the shore is development of Yunderup Canals and the Islands, at the mouth of the Murray River, which includes a dredged navigation channel (Figure A-6.

Figure A-6: Land use change near Yunderup demonstrating land development and waterway modification since 1974.

Semi-rural development at Birchmont has been established with a foreshore reserve of approximately 65m width (Figure A-7).

Figure A-7: Land use change near Birchmont demonstrating semi-rural development and pasture change

Other anthropogenic activities include construction of agricultural drains and small boat ramps at Birchmont and Herron Point. Some foreshore response to the drains is apparent, with development of sediment fans at the drain mouths in Austin Bay and Robert Bay. However, these features have remained relatively stable since the 1970s.

GEOMORPHIC UNITS

The foreshore has been divided into geomorphic units, approximately corresponding to length scales of 1-2km, characterising sections of the foreshore that behave in related ways or are affected by similar stresses (Figure A-8). Divisions were based on apparent points of substantial change, including foreshore morphology and separation between embayments. This corresponds to the 'Segment' scale used for classification of City of Mandurah and Swan River foreshores.

Embayment structure and morphology was used to split the foreshore into segments, mapped at a scale of 1:30,000. Segments were defined by locating sediment splits:

- Where a substantial change to landform processes is apparent, specifically separation between deltaic and foreshore landforms.
- Where a significant barrier to alongshore sediment transport was identified.
- If the shore changed aspect by more than 45°.
- Where a perceptible change in active stresses is apparent (e.g. at tidal channels).

At this scale, the finite volume of mobile sediment determines that foreshore change is developed through a coherent combination of erosion and accretion (i.e. change is related but may not be in the same direction). For example, embayment structure may support changes to shore alignment or variation of total sediment volume without corresponding effect on adjacent segments, although these are typically not wholly disconnected, as they experience similar environmental forcing, and are connected by sediment bypassing between segments.

The segments provide a basis for spatial 'smoothing' of erosion estimates, which have been determined at individual profiles along the length of the Murray foreshore. Morphology was evaluated using the Department of Water LIDAR, collected in 2008/09. (Figure A-9). Transects were extracted from the LIDAR from approximately -1m AHD to +3mAHD landward, resulting in profiles of varying length.

Inconsistent return from the LIDAR intermittently results in a 'rough' profile. This is a mixture of data issues and complex low level topography, as illustrated by the ridges and basins present across the Islands in the elevation band of 0.5-1.5mAHD (Figure A-10). Features in this band are presently subject to low rates of overtopping, which will increase with projected sea level rise, providing a significant mechanism for coastal change.

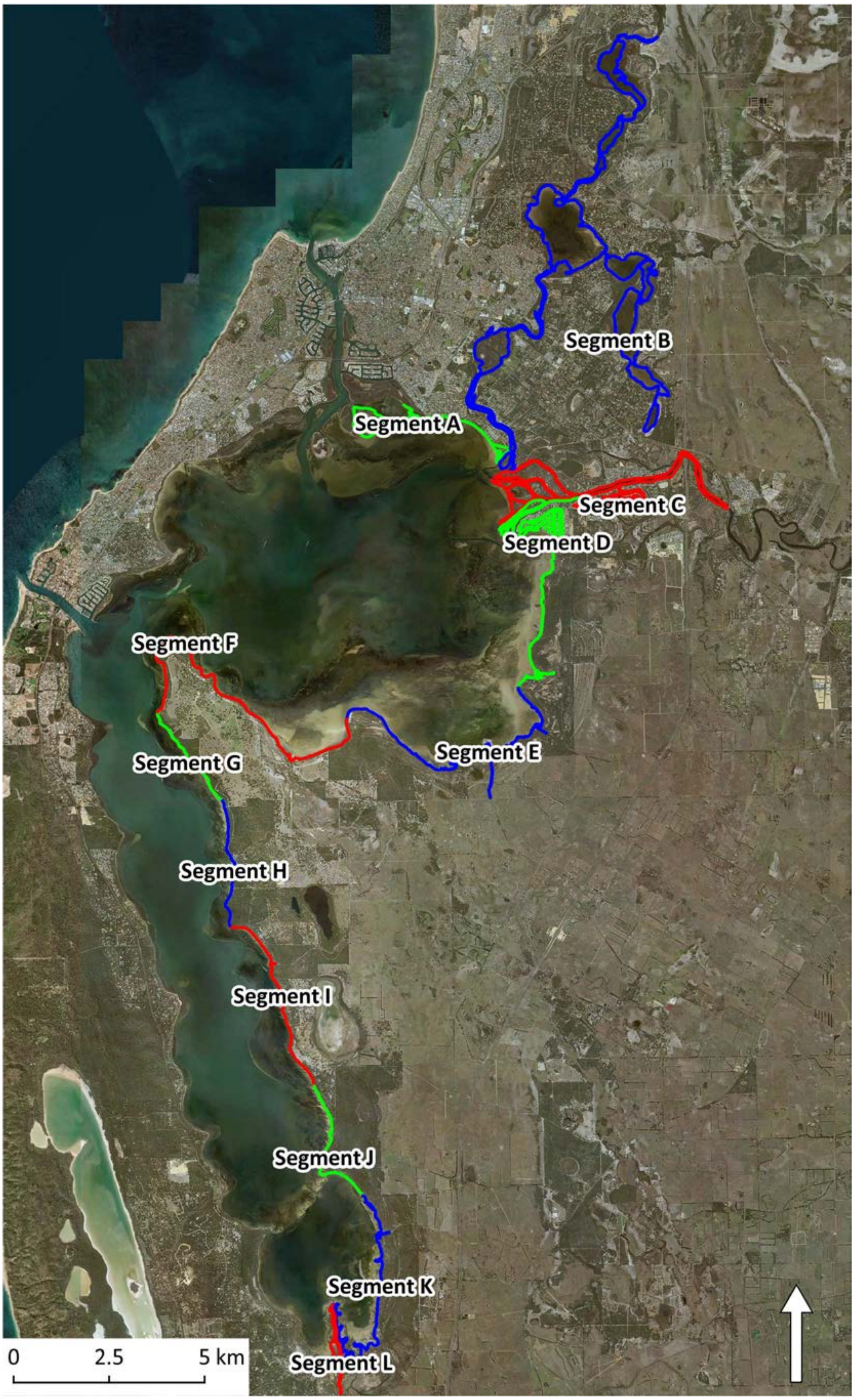


Figure A-8: Shire of Murray Foreshore Segments

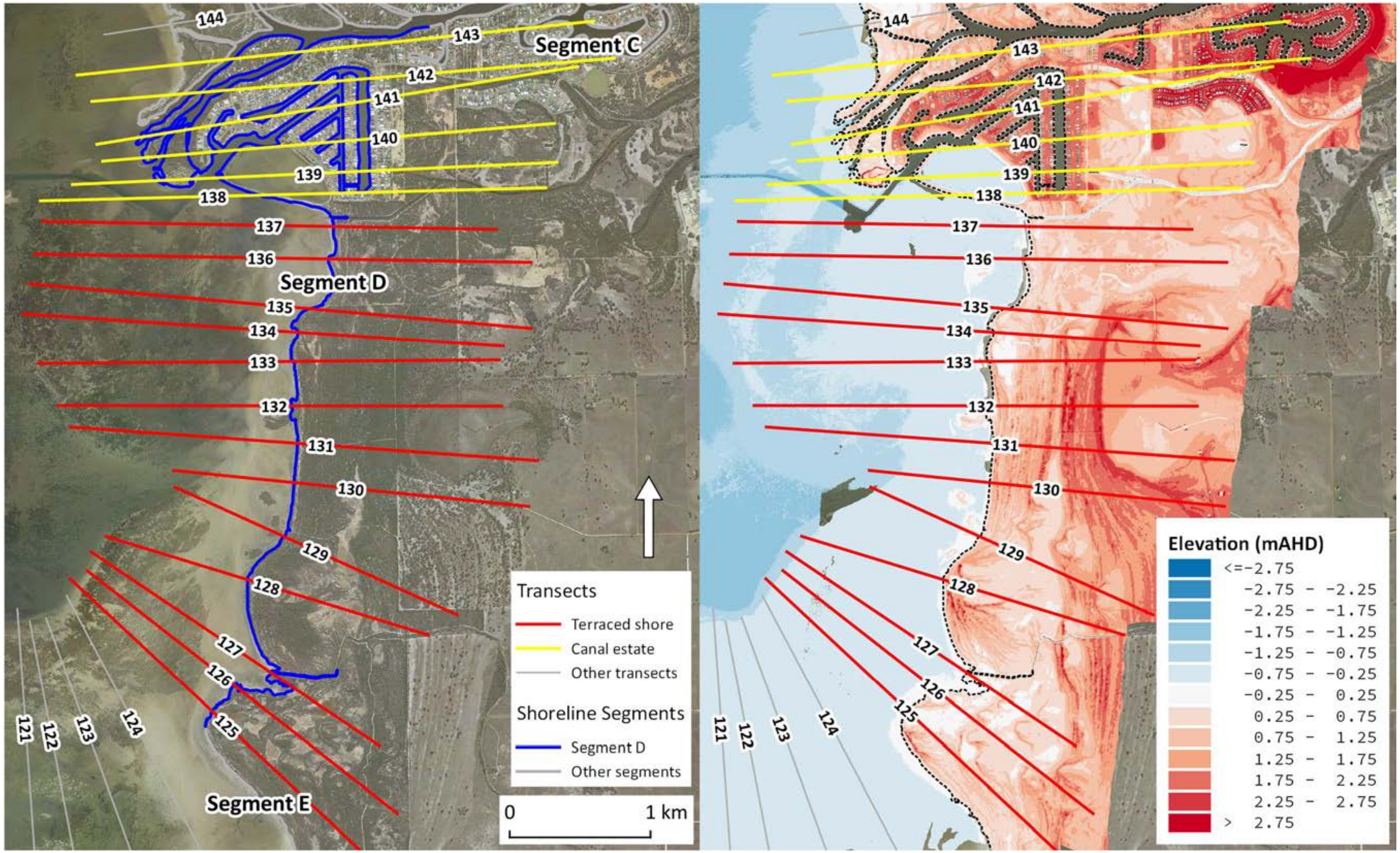


Figure A-9: Location of Segment D and Profiles 125 – 143 with shoreline variability

Figure A-10: Complexity of Low-Level Topography

Appendix B – Meteorology and Oceanography

Meteorologic and oceanographic conditions determine the hydrodynamics (water levels, waves and currents) of Peel-Harvey Estuarine system, and therefore are drivers of foreshore dynamics. Mandurah region has been historically well instrumented, using a mix of permanent and temporary installations. Information used for this assessment includes wind records measured by the Bureau of Meteorology and water levels measured by the Department of Transport (Figure B-1). Other available information includes river flow information measured by the Department of Water and Environmental Regulation.

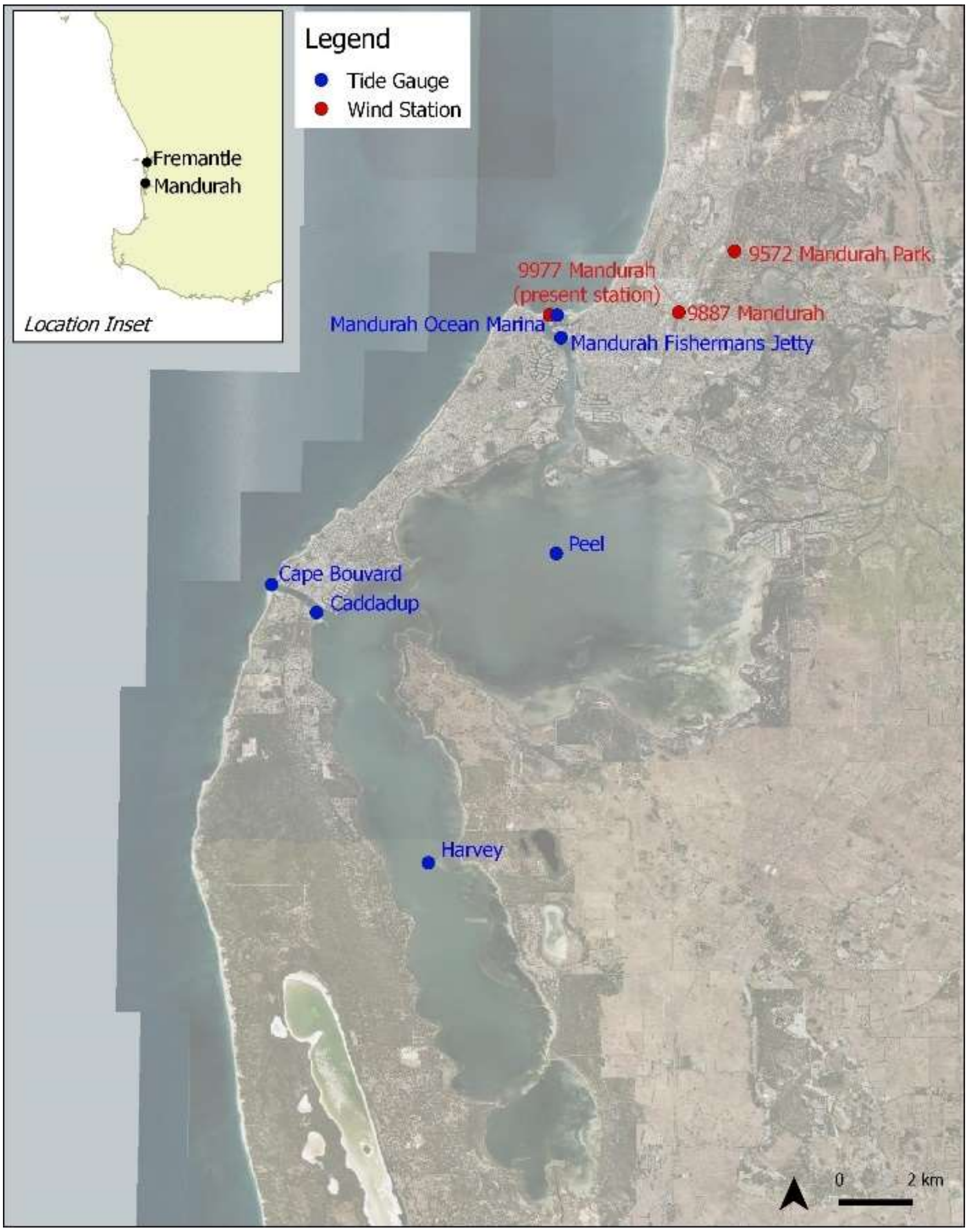


Figure B-1: Meteorological and Oceanographic Measurement Locations

Winds

Wind is significant in the Peel-Harvey Estuarine System due to its role in generation of waves and currents, with both wind speed and direction having influence. Wind observations in the Peel-Harvey region are historically available from three Bureau of Meteorology weather stations, with one Automatic Weather Station presently operating (Table B-1).

Table B-1: Summary of Mandurah BOM Weather Stations

Station	Name	Location	Operation	Elevation	Frequency of Observations
WS 9572	Mandurah Park	32.5031°S 115.7664°E	Jan-1965 to Dec-1985	15m	9am & 3pm only
WS 9887	Mandurah	32.5211°S 115.7500°E	Nov-1987 to Oct-2001	21m	3-hourly
WS 9977	Mandurah	32.5219°S 115.7119°E	Oct-2001 to present	3m	3-hourly

Comparison of wind records from the three stations at Mandurah showed:

- geographic and topographic effects of measurements from different locations.
- differences in frequency of observations.
- differences in velocity and direction scales

These have contributed to differences evident in a wind speed time series (Figure B-2), and speed and direction frequency plots (Figure B-3) for the three stations.

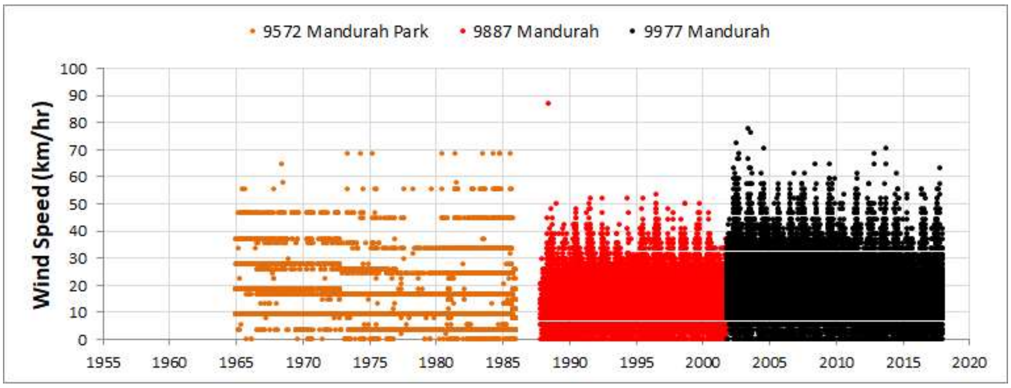


Figure B-2: Mandurah Wind Speed Time Series (All Stations)

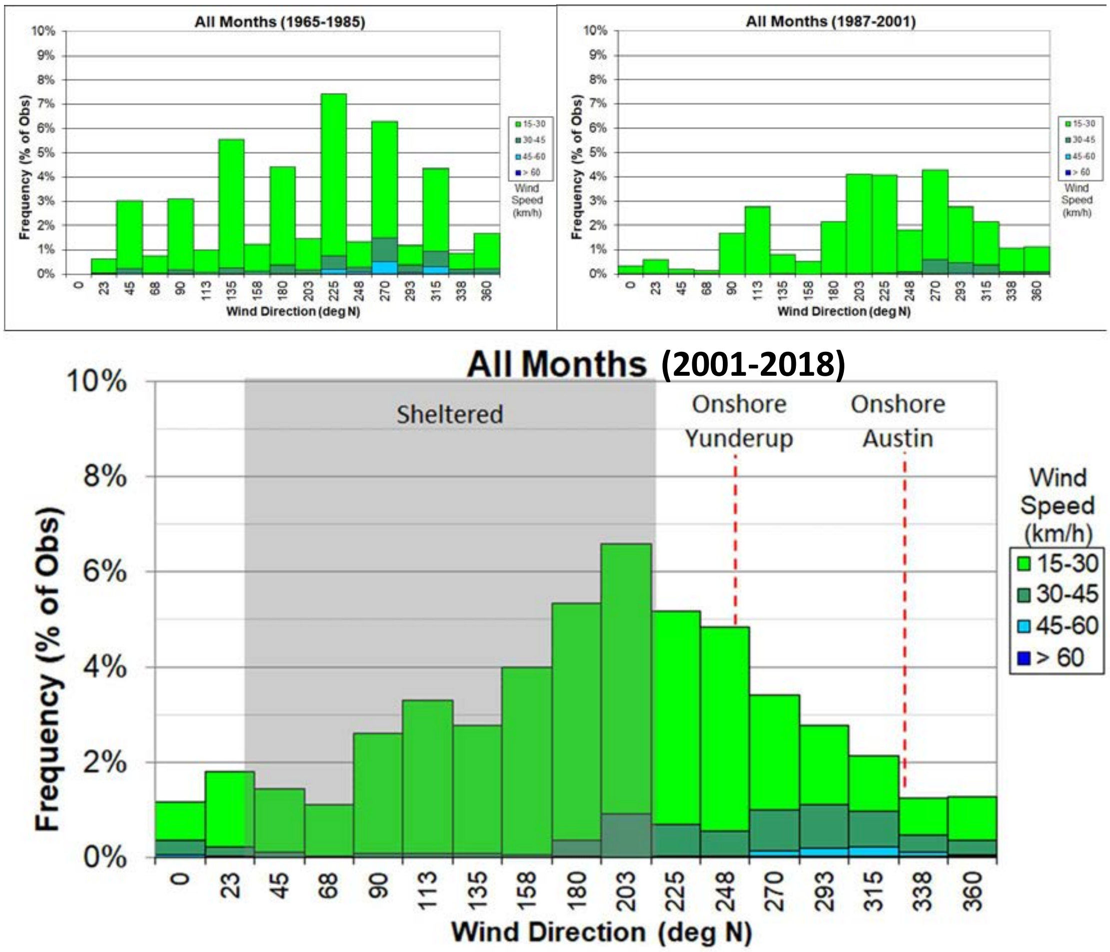


Figure B-3: Mandurah Speed and Direction Frequency Plots (All Stations)

Observations from the present station (WS 9977) located at Mandurah Ocean Marina, immediately adjacent to the shore provides a consistent set of coastal observations since 2001. This station is considered to provide a reasonable representation of winds occurring in the study area, with some minor discrepancies possible due to differences in overland sheltering and changes in exposure of winds (i.e. across the Peel Inlet and Harvey Estuary).

Monthly wind speed and direction frequency plots from the present station illustrate the seasonal shift in wind patterns (Figure B-4). Southerly sea breezes are prevalent from October through to April, with easterlies mainly occurring in February and March. Between May and September, westerlies are dominant, with strong winds generally from the west to northwest. From May to July, northeast winds have a significant secondary occurrence.

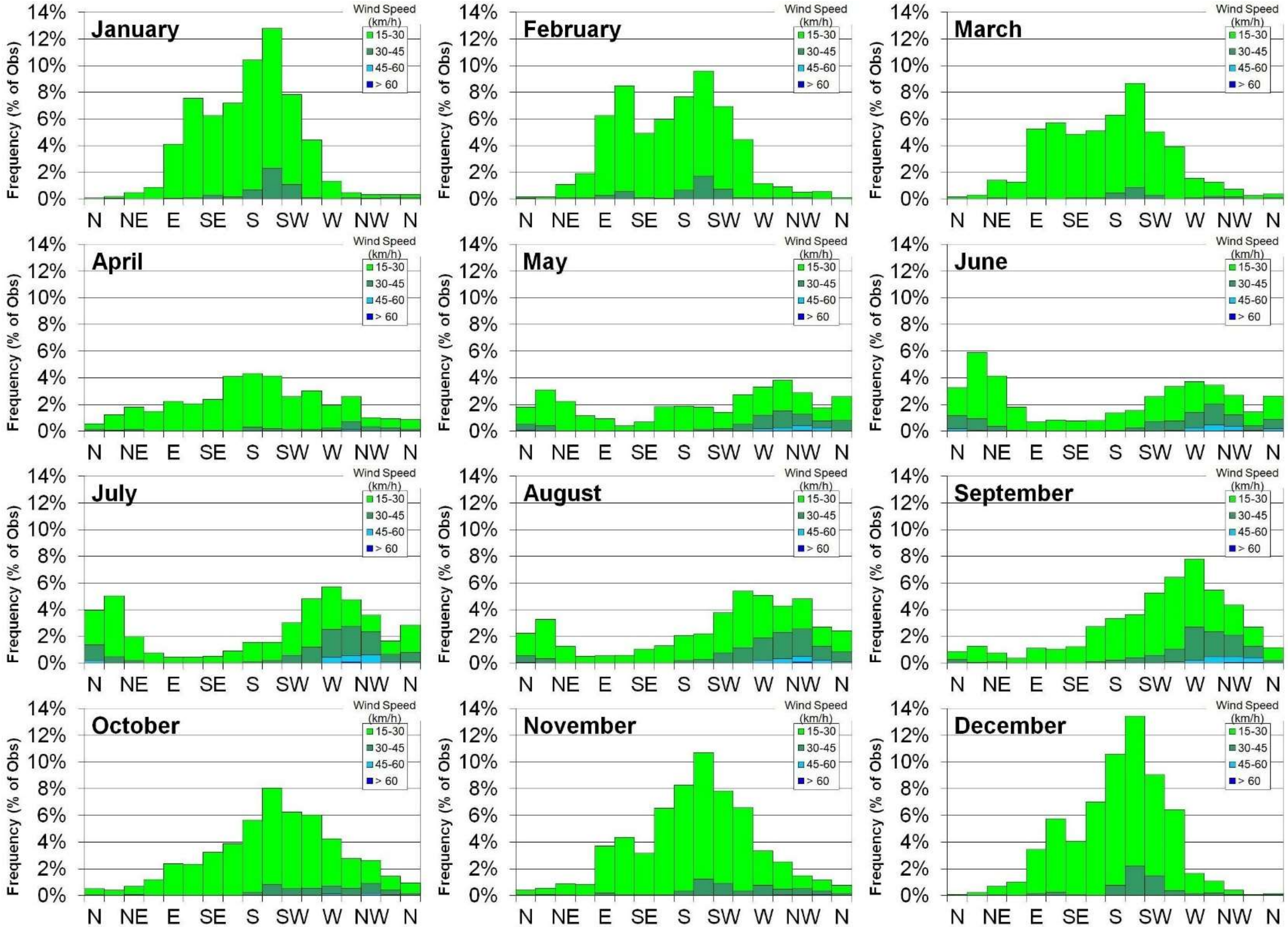


Figure B-4: Monthly Speed and Directional Frequency (Station 9977 – 2001 to 2018)

A speed and directional frequency plot for wind speeds above 45km/hr shows that strong winds are generally limited to from the northwest quadrant (Figure B-5). Low incidence of strong winds from the southwest quadrant may partly be due to sheltering adjacent to the weather station. The Shire of Murray foreshores experience onshore winds from the west through northwest directions, although modal winds arrive at an angle to the shore, suggesting a tendency for alongshore transport.

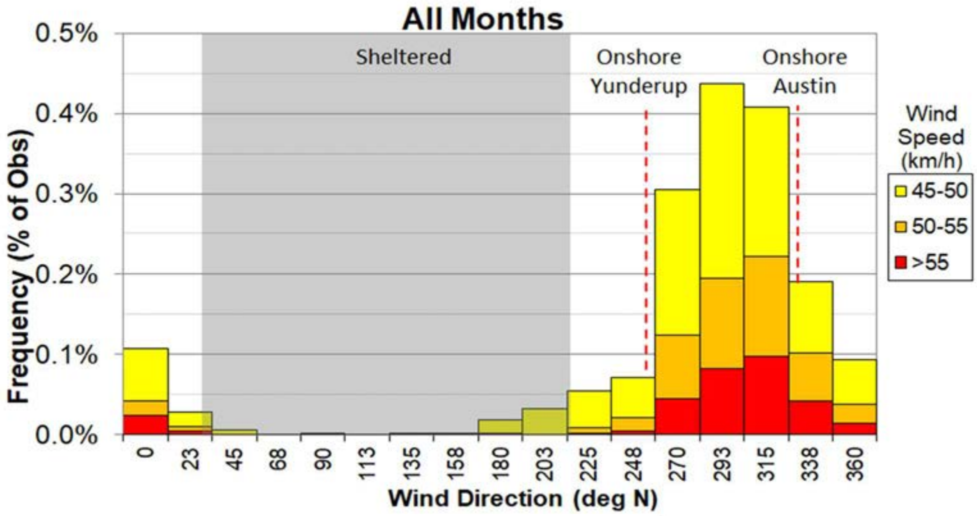


Figure B-5: Speed and Directional Frequency of Strong Winds (BOM Station 9977– 2001 to 2018)

Prevailing / frequent (Figure B-3) and dominant / strong (Figure B-5) onshore winds have the opposite directional distribution on Yunderup and Birchmont foreshores. This suggests capacity for alongshore reversal. For Austin and Robert Bay, modal prevailing and dominant winds are both west of onshore, however there is a weaker association of wind direction to waves because of the very wide shallow terrace.

Variation of wind speed with direction has been examined through evaluation of the Mandurah 2001-2018 wind record, to generate a directional extreme wind distribution (Figure B-6). Analysis steps involved:

1. Separating the wind record into 45^o bands, overlapping by 22.5^o.
2. Estimating the wind speed relative to the middle of the directional band using the function $U' = U \cos(\phi-\phi')$ where U is measured wind from direction ϕ and U' is the component of wind in direction ϕ'.
3. Identify maxima that occur with a minimum of 2 days separation between wind events.
4. Using a rank-based plotting probability, undertake extreme value curve fitting within each directional band, using the method of Petrauskas & Aagaard (1971).

This analysis demonstrates the significant difference in extreme wind speeds from the east-southeast compared with the west-northwest.

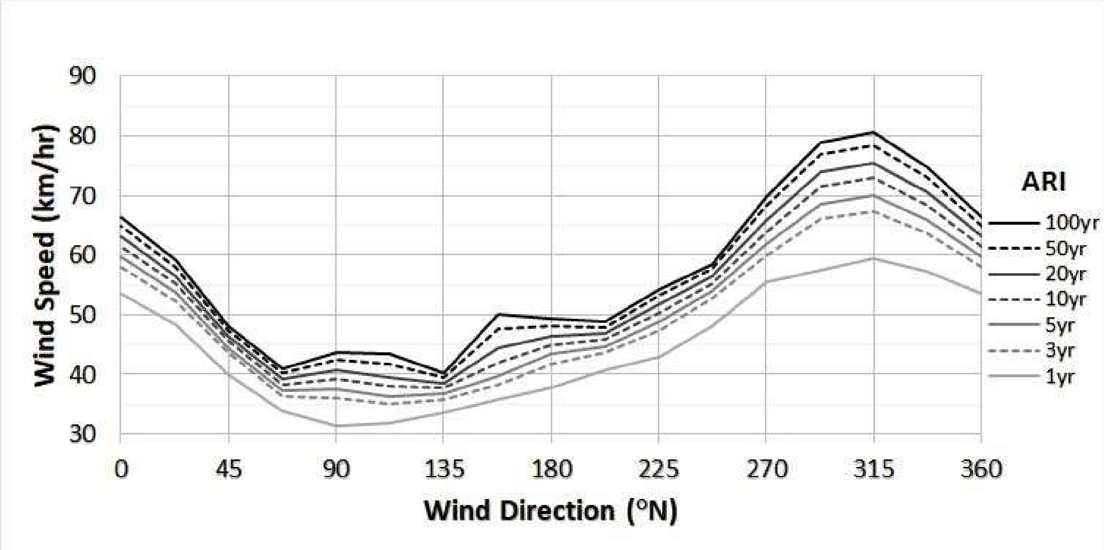


Figure B-6: Directional Extreme Wind Analysis

Annual cumulative summations of the 9am wind speed cardinal components (E-W and N-S) have been used to examine whether there are any apparent patterns of change or standout years. By summing wind vector measured at the same time for each day over a year, a 'wind drift' is calculated. This provides a directional tendency of the wind over the time considered: i.e. a positive net annual easterly wind drift value, for a specific year, indicates that for that year there was a tendency towards stronger easterly winds than during average conditions (Figure B-7). Periods where different weather stations have been used are marked by the dashed vertical lines. The observations are generally partitioned by these breaks, with mild differences between each of the sites.

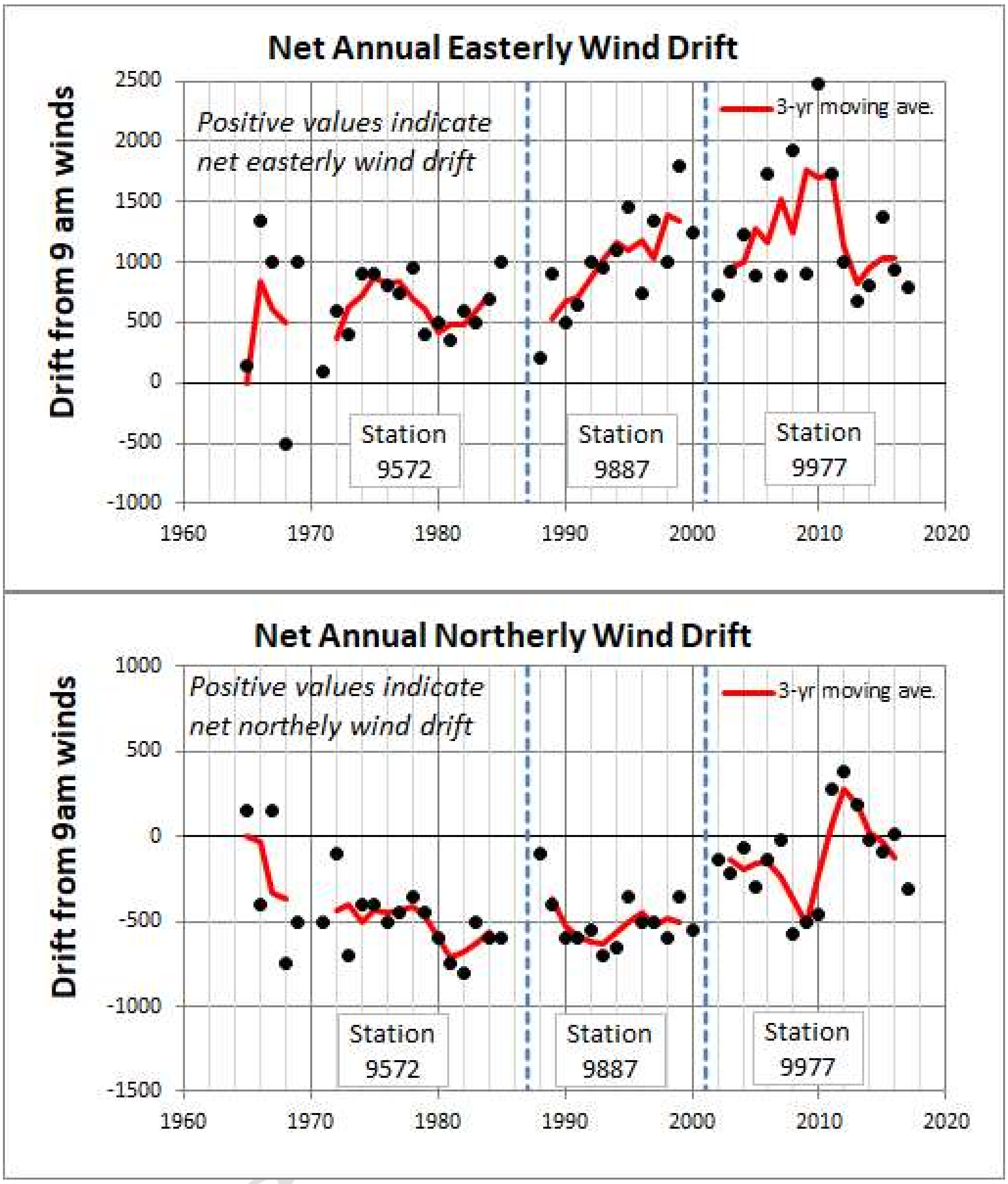


Figure B-7: Mandurah Annual Net 9am Wind Drift

These plots show considerable inter-annual variability, with peaks in the 3-year moving average for the E-W and N-S components in 2009-2011 and 2011 respectively. Standout years in the present record (WS 9977) for each cardinal direction (N,S,E,W) are shown in Figure B-8. A "Strong Year" is defined by the magnitude of the *Wind Drift* relative to the average; hence, a "Strong East Year" is characterized by the easterly cumulative wind run (Red) being consistently above the easterly average (top black line). Conversely, a "Strong West Year" would have a cumulative wind run consistently below the average.

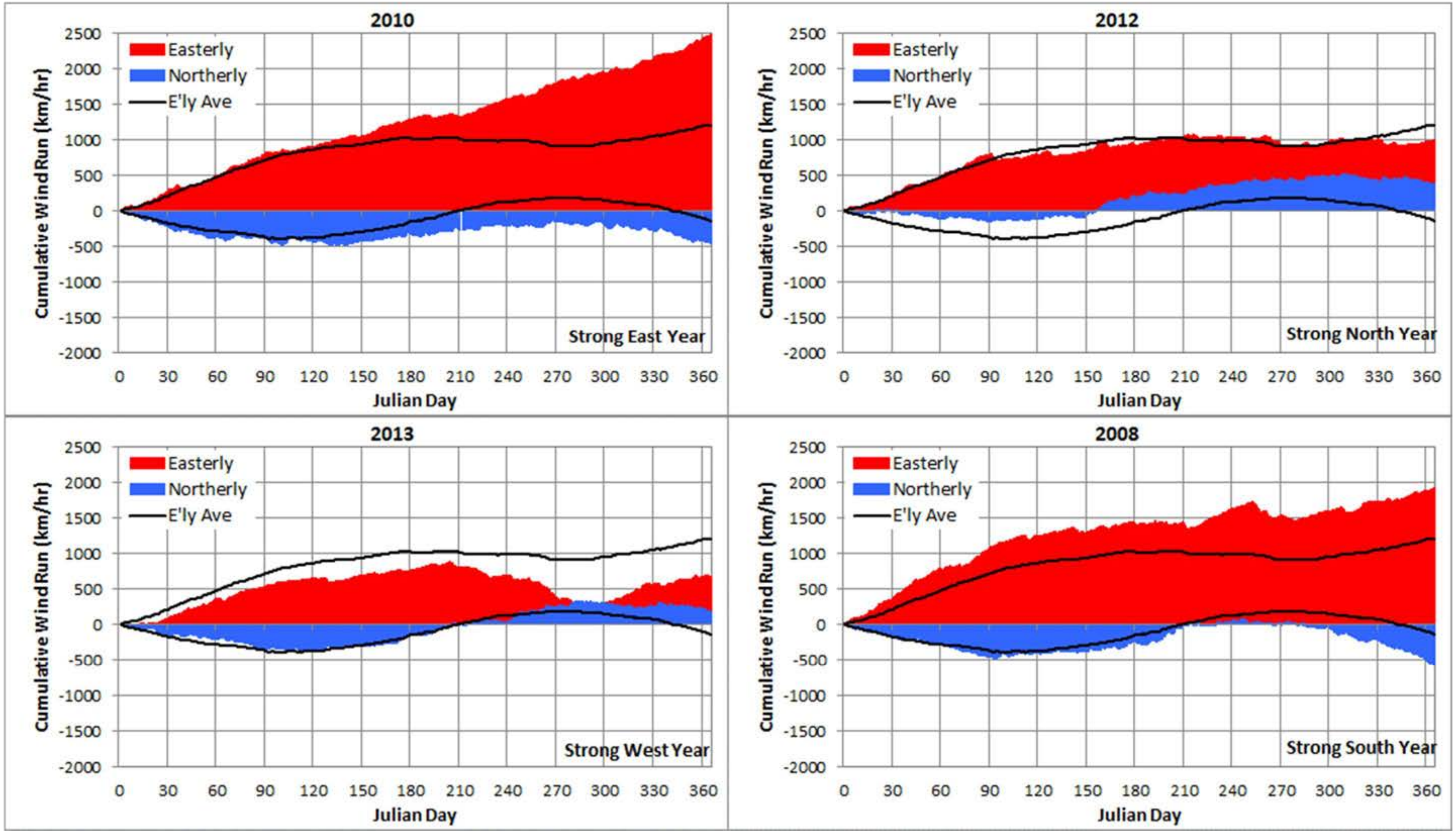


Figure B-8: Strong and Weak Annual 9am Wind Cumulative Summations

Water Levels

Water level observations from five tidal stations throughout the Mandurah region have previously been shown to have high coherence, with a reduction in tidal range from the coast to the estuary basins (Damara WA 2009). There was a significant change in character of water levels in the Peel-Harvey basins due to opening of Dawesville Channel in 1994 (Eliot & McCormack 2018). Key features affecting the water level in the study area include:

- A micro-tidal, mainly diurnal climate with solstitial tidal peaks in June and December. Tidal planes have been derived for three tide gauges in Peel-Harvey Estuary (Table B-2).

Table B-2: Tidal Planes for Peel-Harvey Tide Gauges

Derived from Harmonic Analysis of 1995-2016 records

		Mandurah	Peel	Harvey
Highest Astronomical Tide	HAT	1.14mCD	1.02mCD	1.07mCD
Mean Higher High Water	MHHW	0.78mCD	0.70mCD	0.73mCD
Mean Lower High Water	MLHW	0.71mCD	0.68mCD	0.70mCD
Mean Sea Level	MSL	0.55mCD	0.55mCD	0.55mCD
Australian Height Datum	AHD	0.54mCD	0.54mCD	0.54mCD
Mean Higher Low Water	MHLW	0.39mCD	0.42mCD	0.40mCD
Mean Lower Low Water	MLLW	0.32mCD	0.39mCD	0.37mCD
Lowest Astronomical Tide	LAT	-0.04mCD	0.08mCD	0.03mCD

- Significant meteorological surges, associated with low barometric pressure and westerly storm events, with depressed water levels during sustained easterly winds or high barometric pressure (Hamon 1966). This influences the joint occurrence of winds and water levels.
- Minor, occasional surges associated with the passage of continental shelf waves (i.e. not directly associated with local meteorological conditions), including remote generation from tropical and sub-tropical zones by tropical cyclones (Eliot & Pattiaratchi 2010).
- Seasonal mean sea level range of approximately 0.3m, peaking in June, apparently related to pressure belt latitudinal movement and variation of Leeuwin Current structure and intensity (Pattiaratchi & Buchan 1991).
- Inter-annual mean sea level variability, correlated with the El Niño-Southern Oscillation (ENSO) phenomenon, also correlated with variability of Leeuwin Current structure and intensity (Feng *et al.* 2004). High mean sea levels occur during the la Niña phase.
- An 18.6-year cycle of daily tide range, with the annual tidal range varying by approximately 20% (~0.2m). The lunar nodal cycle last peaked around 2006, with the next peak due in 2025 (Eliot 2010).
- Local wind set-up associated with strong winds across basins. The influence of wind set up was evident during the passage of TC Alby in April 1978 when strong north-

northwest winds across the Harvey Estuary resulted in an increase in water levels from north to south of almost 0.6m (Damara WA 2009).

Hourly water levels observations from the Peel tide gauge, along with the 30 day running mean, are shown in Figure B-9. The largest event observed occurred on 16 May 2003, when maximum water levels of 1.55m CD to 1.61m CD were recorded during the passage of a significant winter storm. There were several high water level events (exceeding 1.20m CD) during a peak in mean sea level associated with a strong la Niña event over 2011-2013.

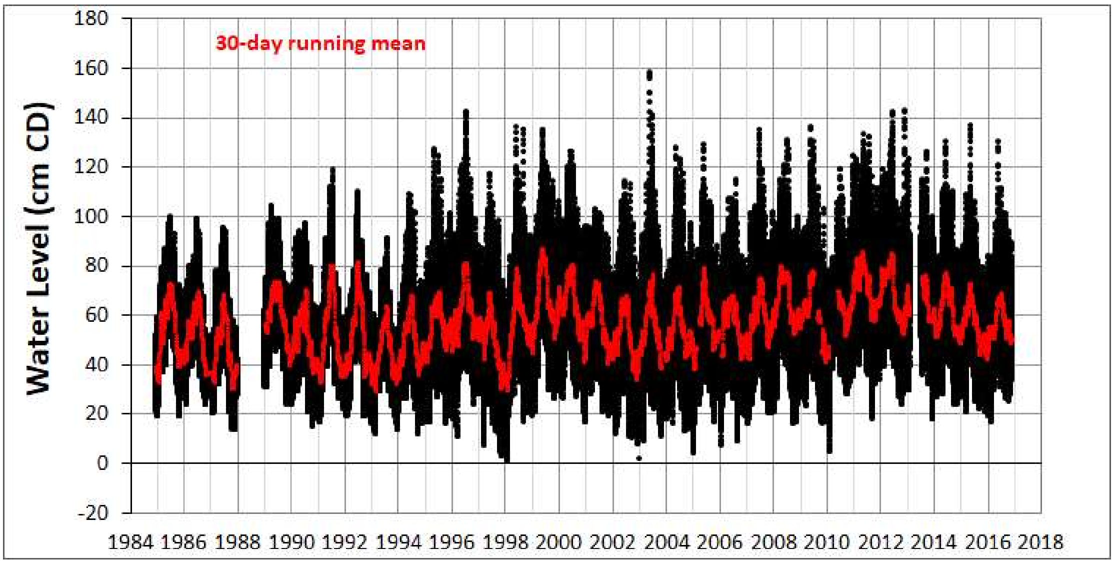


Figure B-9: Peel Inlet Water Levels (1984-2016)

Although storm events may occur all year, extreme water levels are generally restricted to between May-July, when seasonal peaks for mean sea level, surge and tide are in phase (Table B-3).

Table B-3: Summary of Seasonal Changes in Water Level Processes

<table>
<tr><th></th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>Tide</td><td>Peak</td><td></td><td>Low</td><td></td><td colspan="3">Peak</td><td></td><td>Low</td><td></td><td colspan="2">Peak</td></tr>
<tr><td>Surge</td><td colspan="3">Low*</td><td></td><td colspan="4">Peak</td><td colspan="2"></td><td colspan="2">Low*</td></tr>
<tr><td>MSL</td><td>Low</td><td colspan="3"></td><td colspan="3">Peak</td><td colspan="3"></td><td colspan="2">Low</td></tr>
</table>

**Occasional tropical cyclone shelf waves during summer months (December-March)*

The frequency and magnitude of high water level events are particularly influenced by sources of inter-annual variability, in combination with variation between individual storms (Eliot 2012). Identified sources of variability include:

- Up to 0.3m of variability in the mean sea level signal between high and low years, largely corresponding to ENSO phenomenon; and

- Up to 0.15m of variability in the *oceanic* tidal signal between high and low years attributed to the 18.6-year lunar nodical cycle. A smaller influence occurs within the estuary. The latest peak in the cycle occurred in 2006.

The likelihood of high water level events increases during periods of elevated mean sea levels (la Niña) and highs in the lunar nodical tidal cycle and particularly when the two are in phase.

The nature of the water level change due to opening of Dawesville Channel is illustrated by the distinct change observed during 1994 (Figure B-10). The water level signature clearly became more ‘spiky’ after opening of the channel, with greater variation over short time scales.

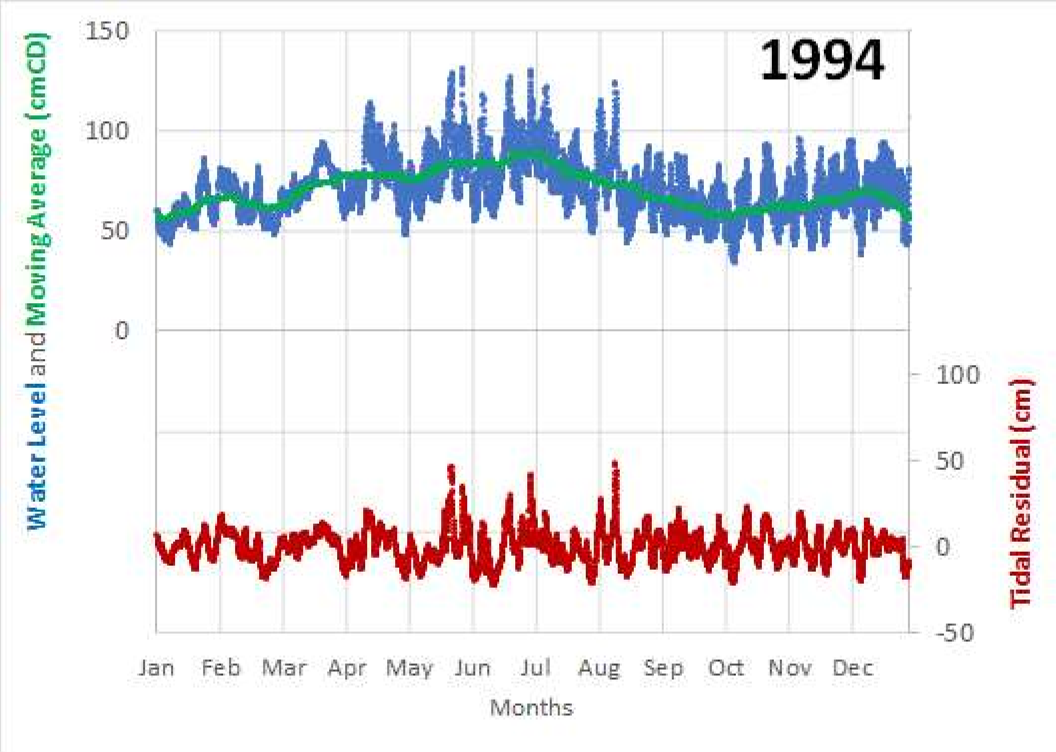


Figure B-10: Observed Water Level and Tidal Residual in Peel Inlet 1994

Harmonic analysis of the water level record has been used to further explore the changes, with separation into mean sea level, tidal and tidal residual components (Figure B-11, Figure B-12). Two large changes are demonstrated by the tidal signal, including (i) a datum shift; and (ii) large-scale increase in the tidal signal.

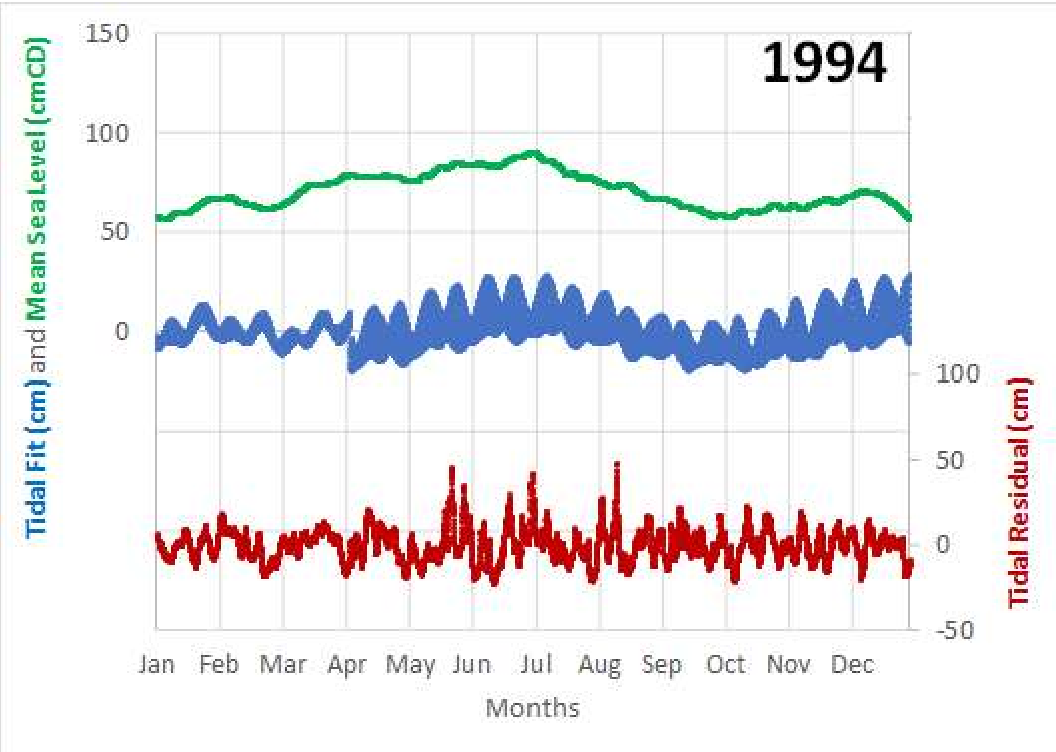


Figure B-11: Change to Water Level Processes after Dawesville Channel Opening

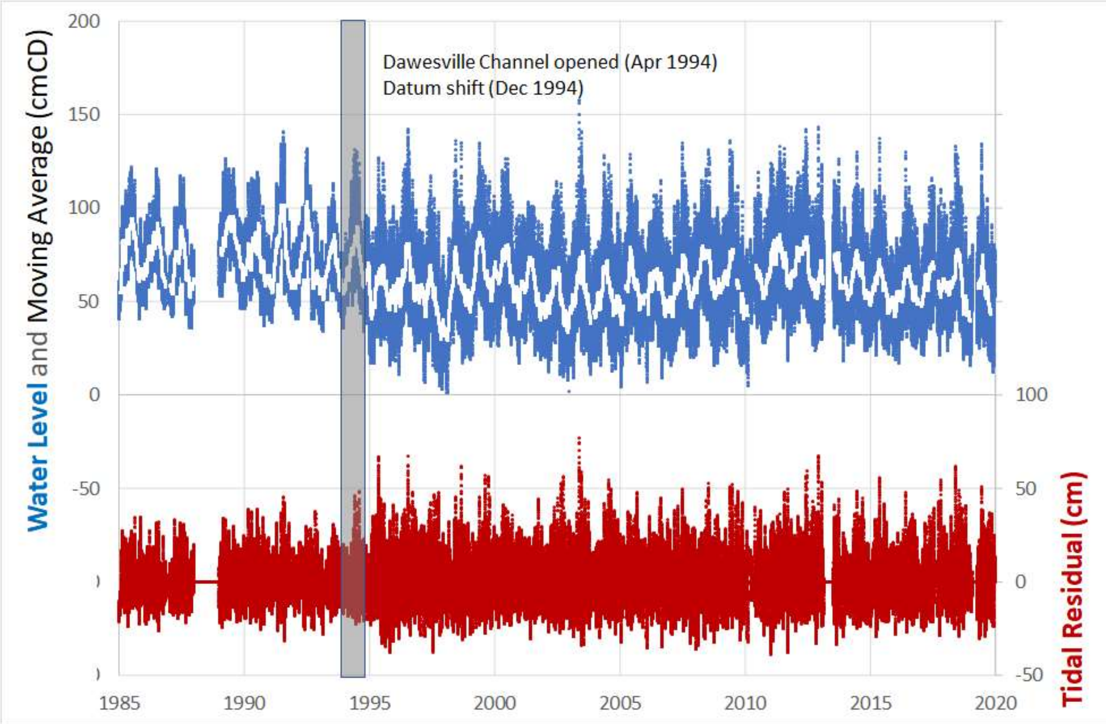


Figure B-12: Water Level Record and Tidal Residuals from Peel Tide Gauge

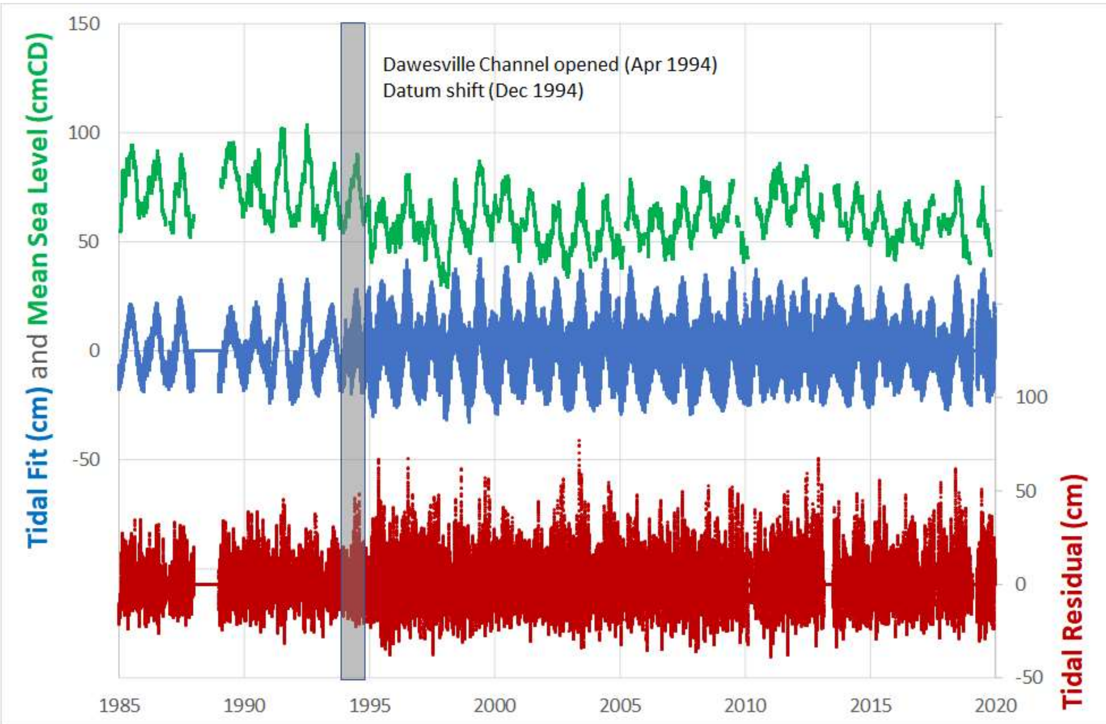


Figure B-13: Water Level Decomposition from Peel Tide Gauge

Winds and Water Levels

Relative timing of strong winds and high water levels influences spatial variation of nearshore processes in Peel-Harvey Estuarine System, including foreshore erosion-recovery patterns and wave overtopping. Specifically, foreshores with a westerly aspect are likely to experience more severe conditions due to potential for coincident high wave and water level conditions associated with westerly storms. These are the major cause of extreme wind speeds (Steedman & Associates 1982; Lemm *et al*. 1999) and cause positive storm surge through onshore wind and wave set-up and lower central pressure.

The joint probability of high wave and water levels for all directions has been assessed using a cross-plot of strong winds at and water levels from Mandurah for the available overlapping data period of 2001-2019 (Figure B-14). Maximum water level envelopes have been derived for wind speeds above 30km/hr and 50km/hr, representing reasonable upper limits.

This assessment indicates exposure of Peel-Harvey foreshores to waves is:

- Greatest along south-west to north facing foreshores, with all wind speeds above 50km/hr observed from 180°N clockwise through to 22.5°N (Figure 6 1). The most extreme wind and water level combination occurred during a severe winter storm on 16 May 2003, when a maximum water level of 1.55m AHD coinciding with a 52km/hr wind from 259°N. For these foreshores, beaches are likely to be dominated by waves.
- Lowest along east to southeast facing foreshores. For these foreshores, beaches will display a mixture of responses to wave and tide processes, with beach berm formation during high water levels potentially playing an important role in beach recovery.

This simple assessment helps explain the relationship between foreshore aspect and wave exposure within the Peel-Harvey Estuarine System. It also informs selection of flood risk scenarios and required foreshore walling design criteria.

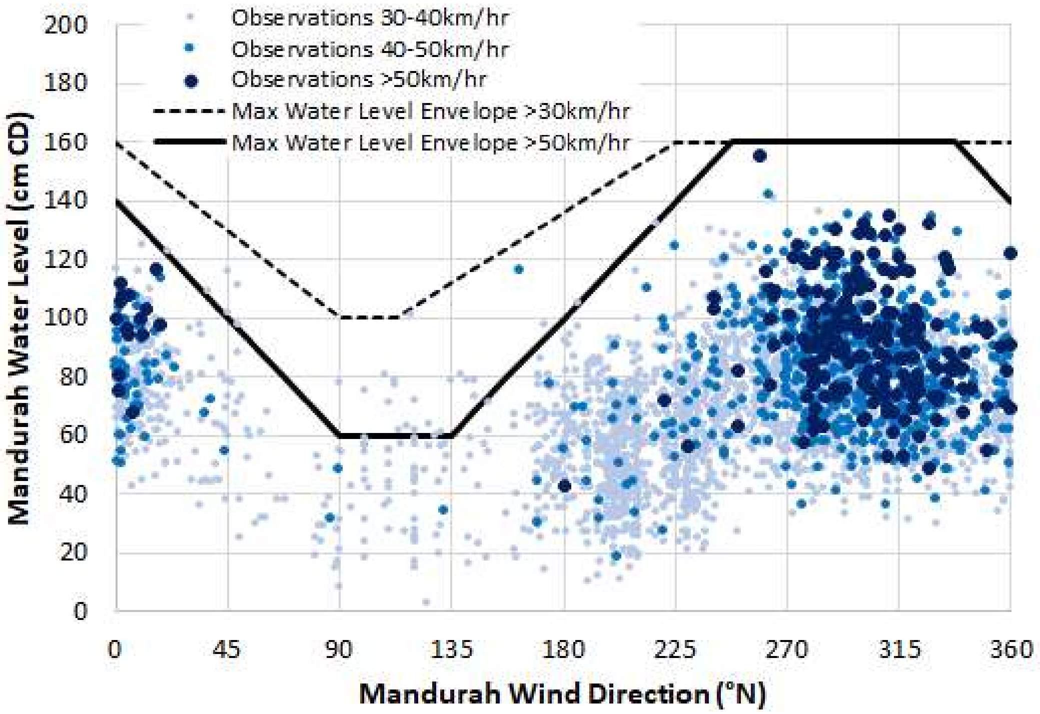


Figure B-14: Joint Occurrence of Winds and Water Levels

Spectral Admittance

Detailed evaluation of the changes in water level associated with opening of Dawesville Channel has demonstrated that both tides and surges inside the Peel-Harvey Estuarine System were increased (Eliot & McCormack 2019). The change to residuals was demonstrated to be spectrally related (Figure B-15), with negligible increase to long-period water level fluctuations (e.g. 30 days) and substantial enhancement of shorter period fluctuations (e.g. 6-12 hours).

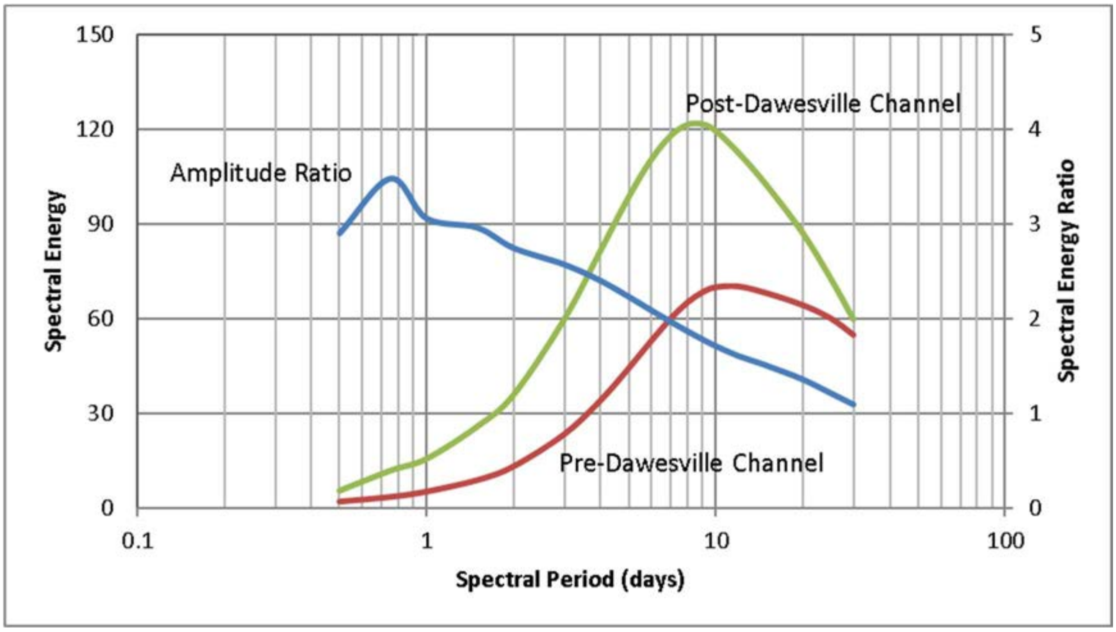


Figure B-15: Spectral Change of Tidal Residuals in Peel Inlet after Dawesville Channel

The pattern of spectral enhancement was also illustrated by the changes in tides (Figure B-16). However, this process is less well defined, as harmonic analysis may effectively transfer energy between modes of a similar frequency – such that the change needs to be considered as a combined function of multiple near-period constituents.

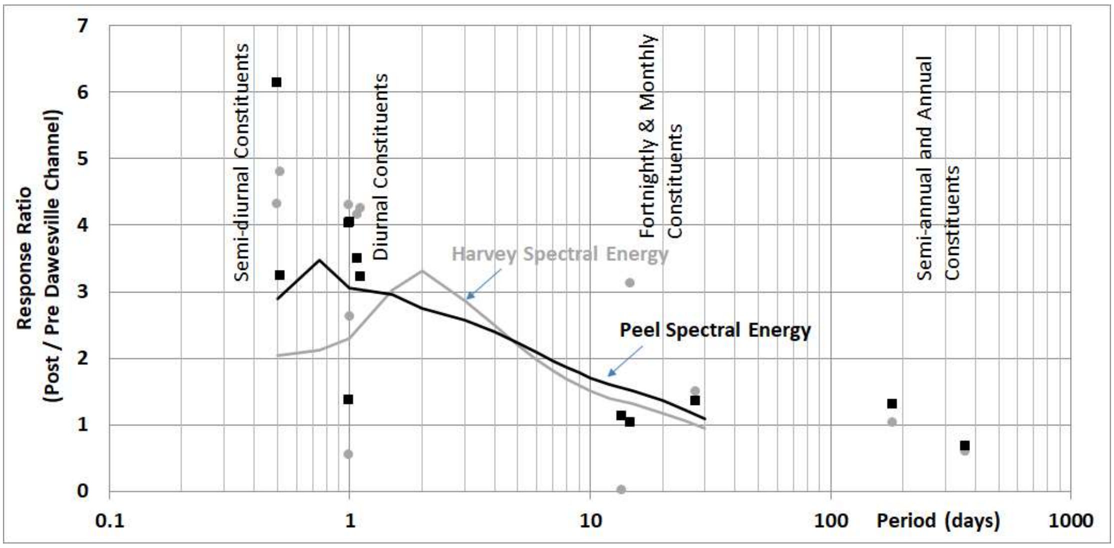


Figure B-16: Spectral Change of Tides and Residuals after Dawesville Channel

The conclusion that the estuary acts similarly to a spectral filter was consequently considered as a basis for transfer from ocean conditions to flood levels within the estuary. Harmonic analysis of the Mandurah tide gauge record from 2015 was compared with that of Peel Inlet, to assess transfer through into the estuary. This analysis was conducted for tidal harmonics, to enable identification of finer time scales. Ratios of tidal constituents demonstrated the effects of near-period constituents, plus enhancement of small-scale overtides, caused by distortion of the tidal signal entering shallow water.
An approximately log-linear response function was developed, which has been used for determination of the extreme coastal flooding condition (Report Section 3**Error! Reference source not found.**).

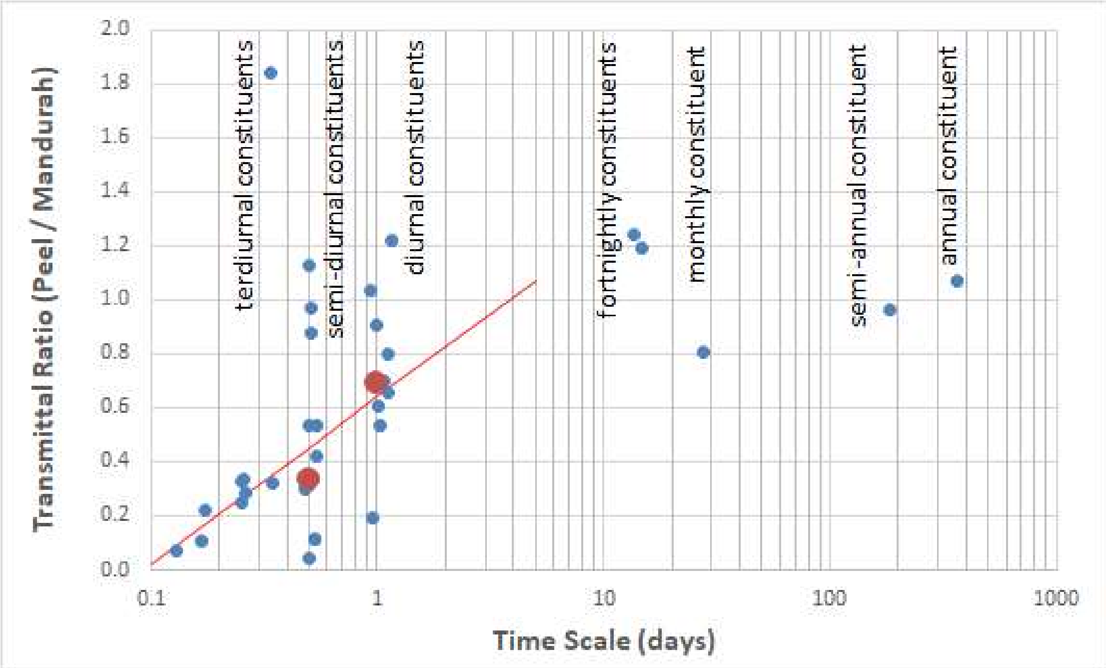


Figure B-17: Ocean-Estuary Admittance of Tidal Constituents 2015: Mandurah to Peel Inlet

Wave Conditions

There are no long-term measurements of waves within Peel-Harvey Estuary, with conditions expected to be highly affected by the position within the estuary due to wind fetch limitation (Travers *et al*. 2010). Consequently, numerical modelling has been used to explore potential wave conditions within the estuary (refer to Appendix H).

The SWAN (Surface Wave and Nearshore) model has been used to hindcast wave conditions within the estuary. Hindcasting was undertaken using a matrix of 10-minute average wind speeds and directions, covering the range measured from the Mandurah anemometer (Figure B-3). Modelling was unvalidated, as no suitable wave measurements were identified. However, this is a conventional application of SWAN, where use of typical parameters is likely to produce a fair representation, suitable for spatially comparative analysis. The model bathymetry and indicative mesh is based on the 20m gridded surface derived from 2016 LIDAR (Figure B-18).

Outputs corresponding to each wind speed and direction 'bin' have been used to hindcast wave conditions at each of ~900 points at approximately 100m intervals around the estuary margin. This has been used to create an equivalent wave height-direction-frequency matrix for each point (Figure B-19). Conversion from wind conditions observed from 2001-2018 to estimated wave conditions allows development of a hindcast time series for each point around the estuary (Figure B-20). It is noted that this approach neglects the time for waves to reach steady state under sustained wind conditions, however this is typically rapid for the relatively short fetches across the estuary (generally less than 30 minutes).

Some known limitations of the wave hindcasting approach are caused by local topographic influences on the wind observations and the requirement for waves to be described at some distance from the shore, such that they are not constrained by water depth. For the hindcast undertaken, expected biases include:

- Wave conditions from the south and east are expected to be slightly underestimated due to damping in the wind data set from the local topography at Mandurah Ocean Marina, where the Bureau of Meteorology anemometer is located. For the Peel-Harvey Estuarine System, some topographic sheltering is provided by the large ridge running along the western side of Harvey Estuary. These effects are acknowledged but have not been accounted for in the wave hindcast.
- Wave hindcast outputs have been provided at an approximate depth of 1.0m during mean sea level conditions, which can be up to 1km offshore along the western foreshore and is almost 2km in Austen Bay. The width of the estuarine margin may provide substantial damping to incident wave conditions, therefore affecting conclusions from the hindcast.

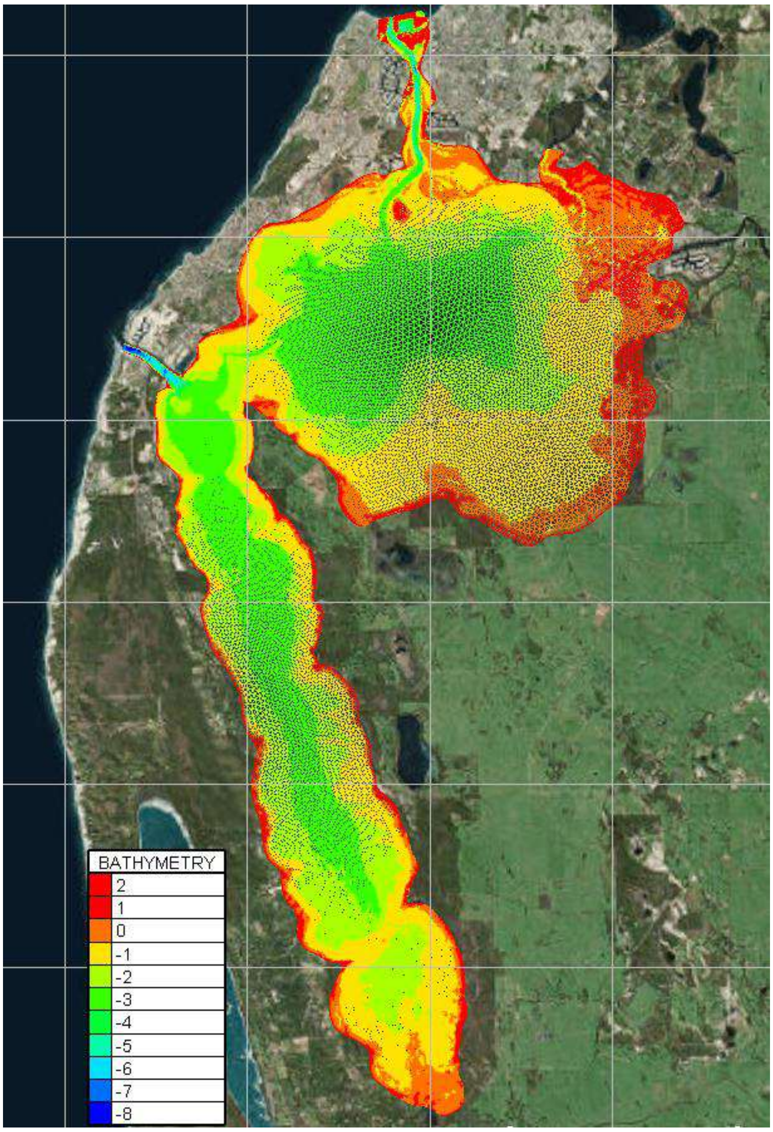


Figure B-18: Wave Hindcast Model Bathymetry

Wind Speed (m/s)		Wind Direction (deg)																
		0.0	22.5	45.0	67.5	90.0	112.5	135.0	157.5	180.0	202.5	225.0	247.5	270.0	292.5	315.0	337.5	360.0
Wind Frequency	100yr	19.5	17.6	14.6	12.3	11.4	11.7	12.2	13.0	13.8	14.8	15.7	17.6	20.2	21.0	21.7	20.9	19.5
	30yr	18.7	16.8	13.9	11.8	10.9	11.2	11.7	12.5	13.2	14.2	15.0	16.8	19.3	20.1	20.7	19.7	18.7
	10yr	17.8	16.0	13.3	11.2	10.4	10.6	11.1	11.9	12.5	13.5	14.3	16.0	18.4	19.1	19.7	19.0	17.8
	3yr	16.7	15.1	12.5	10.6	9.8	10.0	10.5	11.2	11.8	12.7	13.5	15.1	17.3	18.0	18.6	17.9	16.7
	1yr	15.6	14.0	11.6	9.8	9.1	9.3	9.7	10.4	11.0	11.8	12.5	14.0	16.1	16.7	17.2	16.6	15.6
	0.003	14.2	12.8	10.6	8.9	8.3	8.4	8.9	9.4	10.0	10.8	11.4	12.7	14.6	15.2	15.7	15.1	14.2
	0.01	12.5	11.3	9.3	7.9	7.3	7.5	7.8	8.3	8.8	9.5	10.0	11.2	12.9	13.4	13.9	13.3	12.5
	0.03	10.4	9.4	7.8	6.6	6.1	6.2	6.5	6.9	7.3	7.9	8.4	9.4	10.8	11.2	11.5	11.1	10.4
	0.1		6.9	5.7	4.8	4.4	4.5	4.8	5.1	5.4	5.8	6.1	6.8	7.9	8.2	8.4		

Wave Height (m)		Wind Direction (deg)																
		0.0	22.5	45.0	67.5	90.0	112.5	135.0	157.5	180.0	202.5	225.0	247.5	270.0	292.5	315.0	337.5	360.0
Wind Frequency	100yr	0.19	0.18	0.18	0.17	0.17	0.18	0.18	0.18	0.19	0.19	0.19	0.18	0.18	0.20	0.21	0.21	0.19
	30yr	0.19	0.17	0.17	0.16	0.16	0.17	0.17	0.18	0.18	0.19	0.18	0.18	0.17	0.19	0.20	0.19	0.19
	10yr	0.19	0.17	0.16	0.16	0.15	0.16	0.17	0.17	0.17	0.18	0.17	0.17	0.17	0.17	0.19	0.19	0.19
	3yr	0.16	0.16	0.16	0.15	0.15	0.16	0.16	0.16	0.17	0.17	0.17	0.16	0.16	0.17	0.17	0.18	0.16
	1yr	0.14	0.15	0.15	0.14	0.14	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.15	0.16	0.18	0.10	0.14
	0.003	0.13	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.15	0.16	0.15	0.15	0.15	0.07	0.08	0.13
	0.01	0.11	0.13	0.13	0.14	0.14	0.14	0.15	0.15	0.14	0.13	0.15	0.15	0.15	0.15	0.07	0.03	0.11
	0.03	0.10	0.12	0.13	0.12	0.10	0.11	0.13	0.14	0.14	0.13	0.12	0.15	0.15	0.13	0.02	0.02	0.10
	0.1		0.07	0.11	0.01	0.02	0.03	0.05	0.07	0.10	0.12	0.11	0.09	0.07	0.04	0.02		

Wave Period (s)		Wind Direction (deg)																
		0.0	22.5	45.0	67.5	90.0	112.5	135.0	157.5	180.0	202.5	225.0	247.5	270.0	292.5	315.0	337.5	360.0
Wind Frequency	100yr	1.20	1.28	1.30	1.26	1.25	1.30	1.33	1.35	1.34	1.31	1.29	1.26	1.20	1.10	1.07	1.10	1.20
	30yr	1.19	1.27	1.28	1.24	1.24	1.28	1.31	1.34	1.33	1.29	1.27	1.25	1.19	1.08	1.06	1.09	1.19
	10yr	1.13	1.26	1.25	1.22	1.21	1.25	1.29	1.32	1.31	1.27	1.26	1.23	1.18	1.08	1.03	1.08	1.13
	3yr	1.13	1.24	1.23	1.19	1.19	1.22	1.27	1.30	1.29	1.25	1.24	1.22	1.17	1.07	1.02	1.01	1.13
	1yr	1.14	1.21	1.20	1.15	1.16	1.19	1.25	1.28	1.27	1.22	1.22	1.20	1.15	1.04	0.98	1.04	1.14
	0.003	1.14	1.18	1.16	1.11	1.11	1.17	1.21	1.25	1.24	1.20	1.19	1.18	1.14	1.04	0.97	0.99	1.14
	0.01	1.11	1.14	1.12	1.05	1.11	1.08	1.12	1.17	1.20	1.18	1.13	1.14	1.11	1.02	0.93	1.15	1.11
	0.03	1.02	1.10	1.07	1.05	0.95	0.95	0.98	1.04	1.10	1.14	1.11	1.06	1.04	0.96	1.10	1.25	1.02
	0.1		0.91	1.05	0.87	0.84	0.83	0.82	0.86	0.91	0.96	0.98	1.02	1.03	1.04	1.08		

Wave Dir (deg)		Wind Direction (deg)																
		0.0	22.5	45.0	67.5	90.0	112.5	135.0	157.5	180.0	202.5	225.0	247.5	270.0	292.5	315.0	337.5	360.0
Wind Frequency	100yr	39	67	78	89	106	123	138	152	162	181	195	211	230	275	320	1	39
	30yr	39	68	78	89	106	123	139	152	162	181	196	211	228	270	315	8	39
	10yr	38	68	77	88	106	123	139	152	162	180	196	211	227	258	316	9	38
	3yr	51	68	76	87	105	124	139	152	162	180	197	211	226	255	289	5	51
	1yr	58	68	75	86	105	124	140	152	162	178	198	211	226	252	298	49	58
	0.003	60	67	74	83	105	122	142	152	163	178	198	212	225	244	241	56	60
	0.01	62	67	73	81	99	139	145	155	165	176	197	213	226	236	227	81	62
	0.03	64	66	71	77	142	143	148	160	169	175	186	209	224	225	201	93	64
	0.1		72	68	138	141	146	150	166	175	179	179	181	192	184	180		

Figure B-19: Wave Matrix for Yunderup (Location 407)

Box defines points that would be used for hindcast under wind of 10.5m/s from 165°

Wave modelling was conducted for steady wind conditions corresponding to each of the wind speed and direction combinations in the upper table. Model outputs of significant wave height, period and wave direction are plotted in each of the subsequent tables. The relationship between wind and wave estimates allows estimation of waves. For example, wind conditions of 10.5 m/s from a direction of 165° are within the box marked inside the upper table. The corresponding box in the lower three tables indicates the interpolation space for significant wave height, wave period and wave direction, respectively.

For each location around the estuary margin, the wave matrices have been used as look-up tables, combined with the 17 years of wind observations to provide wave hindcast time series (Figure B-20). Water level variation was included in the hindcast, through consideration of the modelled MSL +/-0.3m cases. Wave conditions within the estuary are generally low energy, with average wave heights of 0.2-0.3m and annual maxima of 0.4-0.6m. These conditions are suitable for development of riparian vegetation (Shafer *et al*. 2003), with disturbance such as undercutting expected when waves are above ~0.5m.

Time series illustrate seasonal differences in hindcast wave conditions:

- The greatest seasonal variation of wave height occurs where there are the largest northwesterly fetches (e.g. Austin Cove). Smaller seasonality is apparent where fetches are generally shorter, or there is a narrow directional over which waves could be generated (e.g. Birchmont).
- Seasonality of wave conditions is similar for each year, suggesting limited inter-annual variability. This is unsurprising, as fetch limitation within the estuary means that there is typically only a small increase in wave height even for large differences in wind speeds.

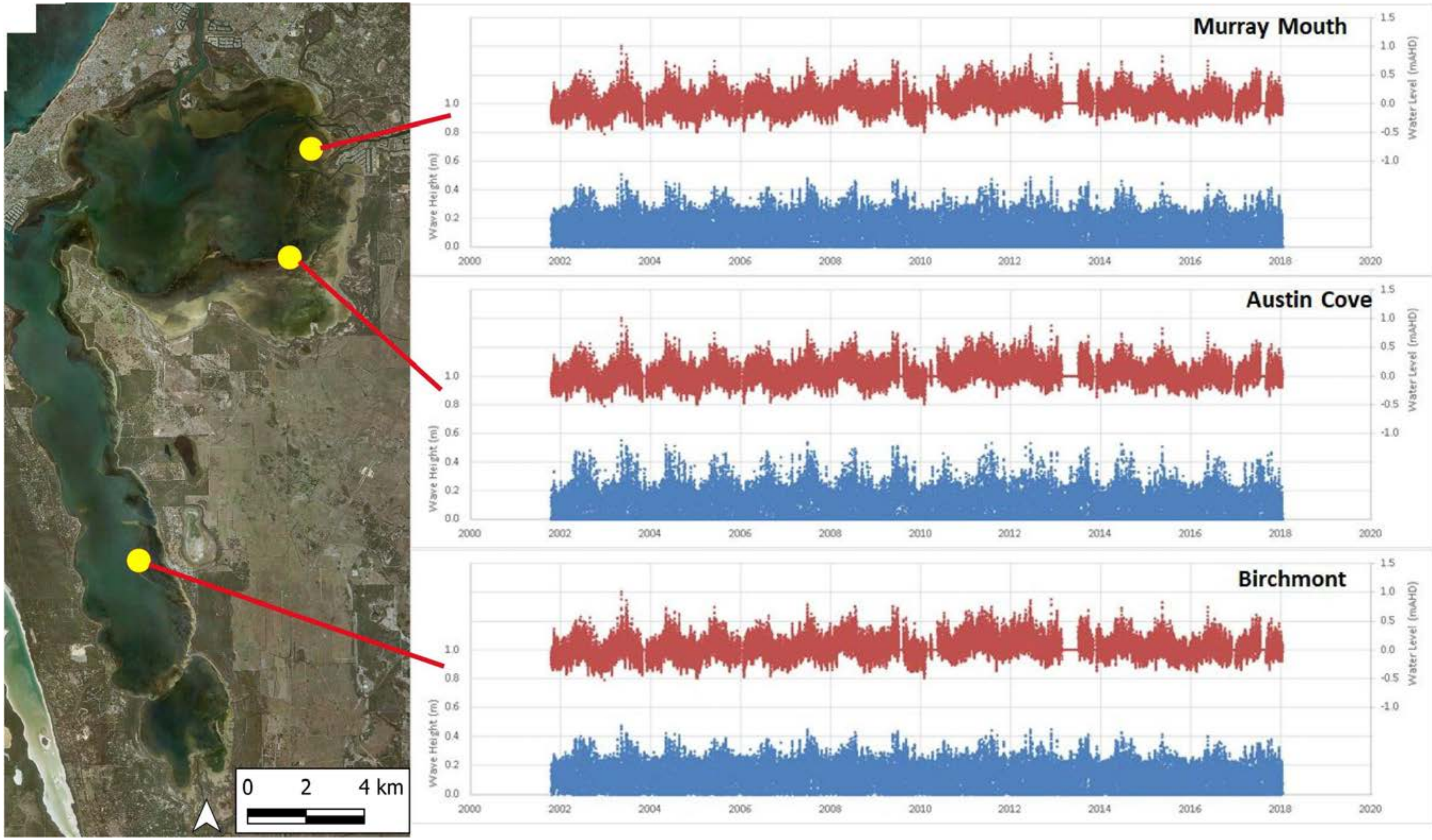
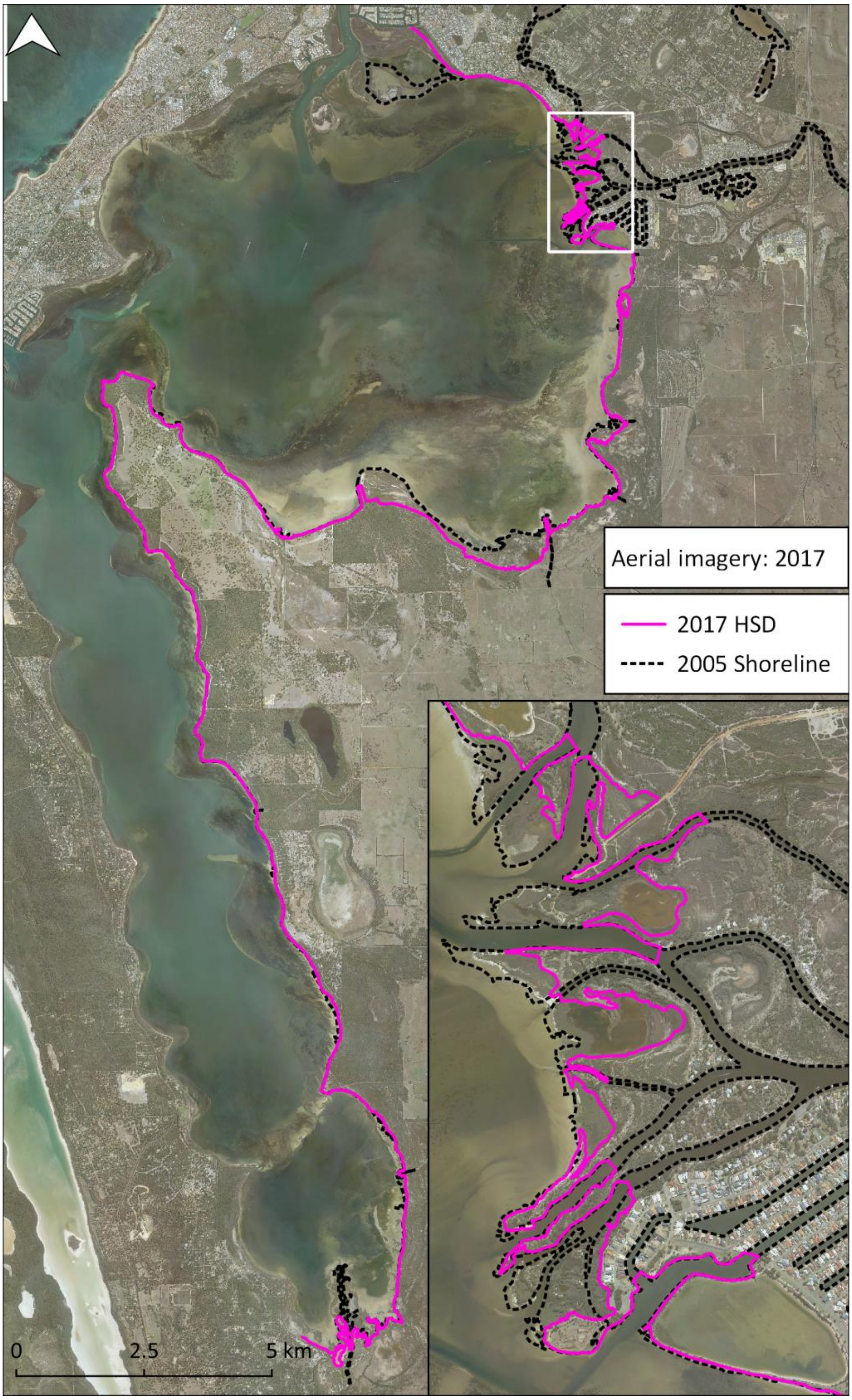


Figure B-20: Hindcast Time Series for Three Sites & Corresponding Wind Components

Appendix C – Vegetation Line Change Summary



Areas of identified vegetation line change (2005-2017)

A0 to A1 - Minor Change

1994 to 2005

1994 Imagery

1994 - Yellow Line

2005 - Green Line

Little change, some seasonal variation to sand spit at eastern end of Creery Island, although little movement of vegetation line.

Little change around Peel Parade near A1.

Variations in submerged features.

1994 to 2005

2005 Imagery

1994 - Yellow Line

2005 - Green Line

2005 to 2011

2011 Imagery

2005 - Green Line

2011 - Blue Line

Little change, more submerged features due to higher average water levels in 2011.

2005 to 2017

Little change, some retreat of vegetation on Creery Island towards 2017.

2017 Imagery

2005 - Green Line

2017 - Red Line

A1 to A2 - Minor Change

1994 to 2005

1994 Imagery

1994 - Yellow Line

2005 - Green Line

2005 Imagery

1994 - Yellow Line

2005 - Green Line

Some minor movement of shoreline. Variations in submerged features; historic dredge scars evident in 1994 imagery.

2005 to 2011

2011 Imagery

2005 - Green Line

2011 - Blue Line

Little change, submerged features due to higher average water levels in 2011.

2005 to 2017

Minor change, seawalls installed along much of this foreshore between 2011 and 2017. These seawalls have pushed shoreline south by between 4.0m and 8.5m in some locations, removing the high tide sandy beach.

2017 Imagery
2005 - Green Line
2017 - Red Line

A2 to A3 - Minor Change North End, Seawall Refurbished, Major Change at Point north of Serpentine River Entrance

1994 to 2005

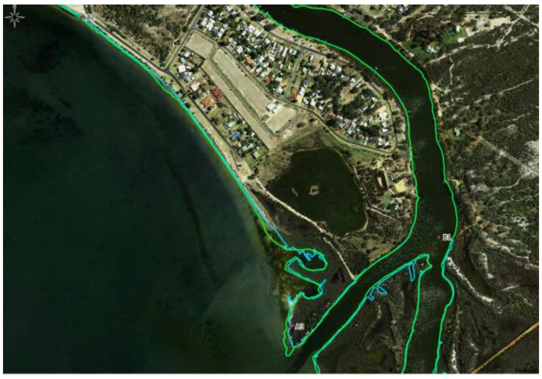
1994 Imagery
1994 - Yellow Line
2005 - Green Line

Minor recession of shoreline in northern part of segment.

Reshaping of point feature on northern side of Serpentine River entrance, with 18m of erosion at tip of point, and 45m of erosion adjacent to this. The sand appears to have shifted to a new vegetated area on this point, with an increase in width of 27m due to accretion - **major change**.

2005 Imagery
1994 - Yellow Line
2005 - Green Line

2005 to 2011



2011 Imagery
2005 - Green Line
2011 - Blue Line

Shoreline recession up to 10m along the northern part of this foreshore section skewed by high water levels of 2011.

Rock armouring installed along northern section of foreshore between 2005 and 2011, presumedly to protect adjacent asphalt road. This seawall discontinues at parkland with inland lake.

Further erosion of point feature at northern side of Serpentine River Entrance. Point tip has receded 28m, northern edge of point has receded between 19m and 13m, small spit of length 26m has accreted in the middle of this point feature, in a NW direction - **major change**.

2005 to 2017

2017 Imagery
2005 - Green Line
2017 - Red Line

Upgraded seawall installed along northern part of this segment between 2011 and 2017. This seawall has reclaimed eroded foreshore since 2011, but shoreline is still between 2m and 8m landward of 2005 position.

Note refurbished seawall is from A2 point, in a southerly direction to 1/3 of the way along John Street.

Erosion at parkland with lake up to 17m landward of its 2005 position in its most affected part, however it has accreted from the 2011 high water level position.

At the point north of the Serpentine River entrance, erosion of 50m from the 2005 position has been experienced. This is 24m of erosion between 2011 and 2017 - **major erosion**.
The spit that was forming on the NW side of this point in 2011 imagery has migrated further north, and has stabilised with the growth of vegetation. It is 36m from the 2005 shoreline position at its longest point - **major change**.

A3 to C1 (not including the inner banks of the Serpentine River) - Major Change

1994 to 2005

1994 Imagery
1994 - Yellow Line
2005 - Green Line

2005 Imagery
1994 - Yellow Line
2005 - Green Line

Erosion of the NW and SE points on the SW end of Jennala Island. Between 1994 and 2005, the NW point's vegetation line has eroded approximately 70m, while the SE point's vegetation line has eroded approximately 30m. The centre section of the SW end of Jennala Island has eroded by between 16m and 20m - **major erosion**.

The point that the vehicle barge docking area at the end of Tonkin Drive is located on, has eroded by between 5m and 7m during this time period.

Erosion has impacted Cooleenup Island's western end between 1999 and 2005, with its southern point eroding by 6m, northern point eroding 8m and variable erosion along the shoreline.

2005 to 2011

2011 Imagery
2005 - Green Line
2011 - Blue Line

The rate of erosion at the SW end of Jennala Island has decreased; 3m of erosion at its N part, 11m in its middle section and 13m erosion at the W corner.

The point which has the barge dock at the end of Tonkin Dr, has eroded a further 2m to 4m, with scalloping of foreshore experienced.

	The W end of Cooleenup Island has eroded; its point has receded by 13m and its protruding features have receded by 3m to 17m - **major erosion**.

2005 to 2017

2017 Imagery

2005 - Green Line

2017 - Red Line

The rate of erosion at the SW end of Jennala Island has remained steady from 2005 to 2011 to 2017. Erosion from 2005 to 2017 amounts to 7m of erosion at its N part, 15m in its middle section and 27m erosion at the W corner. This can be considered as **major erosion**.

Between 2005 and 2017, approximately 5m of erosion has been experienced around the point which has the barge dock at the end of Tonkin Dr.

Further erosion at the W end of Cooleenup Island. The point has receded 44m between 2005 and 2017, the majority of this erosion (32m) occurring between 2011 and 2017 - **major erosion**. A new spit has formed between 2011 and 2017 on the northern side of the Point, it is 11m in length. The western shoreline of Cooleenup Island has eroded at a rate of 25 and 2m from 2005 to 2017, with 8m of this erosion experienced between 2011 and 2017 - **major change**.

C1 to D1 (not including the inner banks of the Murray River) - Major Change

1994 to 2005

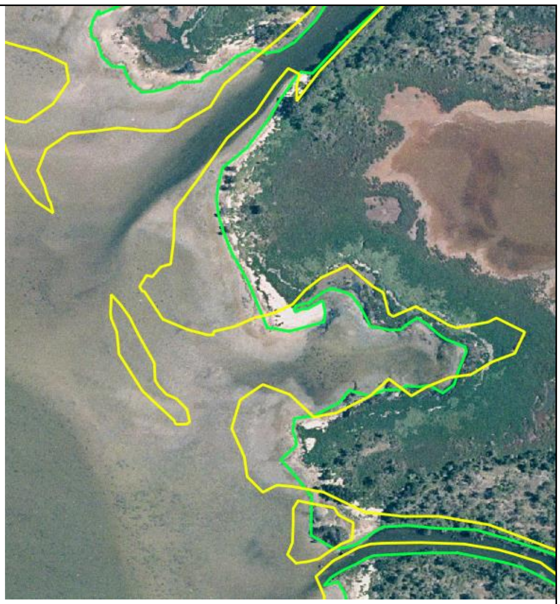
1994 Imagery
1994 - Yellow Line
2005 - Green Line

2005 Imagery
1994 - Yellow Line
2005 - Green Line

Major change with **major erosion** experienced along the western sides of all of the Murray River delta islands, being Meeyip, Ballee, Worallgarook and Little Yunderup Islands.

Major change per island:

Meeyip Island (western side, 2005 Imagery): **Major erosion** at the northern end, with an area of 150m long and 35-50 m wide eroded. 176m long section from the centre to the southern end has eroded, with an entire “T-head” spit removed from 76m landward erosion.



Ballee Island (western side, 2005 Imagery): **major erosion** including the loss of a small sand island at the northern end. The vegetation line has receded 50m at the northern end and 33m at the southern end. Some repositioning of the natural channel of Worallgarook Branch with reforming of a small vegetated feature at the SW corner of Ballee Island.

Worallgarook Island (western end, 2005 imagery):
Major erosion on the NW corner, reshaping of the centre of this foreshore, with an area 85m long and over 15m wide eroded. The centre section has accreted some 19m, and the south western point end has reshaped with the shrinkage of a small island by 40m in length.

	 **Little Yunderup Island** (south-western end, 2005 Imagery): **Major erosion** to much of this small island, (note the poor resolution of the 1994 imagery reduces confidence in the position of the 1994 vegetation line). There may have been over 60m eroded from the SW end of this island between 1994 and 2005.
2005 to 2011  **2011 Imagery** 2005 - Green Line 2011 - Blue Line	**Major erosion** at the NW tip of **Meeyip Island** between 2005 and 2011, this point receded by 90m and experienced a 17m reduction in width along the north half of its SW facing beach. The remaining half of the SW facing beach, experienced **major change** with the formation of a sand bar and a thing long lagoon feature running parallel to the beach. The southern corner of the island experienced accretion from 2011 to 2017, essentially closing the 15m wide entrance to the natural channel of Meeyip Branch. This was a reversal of the erosion trend in this area from 2005 to 2011.

	Ballee Island eroded by up to 15m on its NW and SW areas, with a small accretion zone in its centre - **major change**. **Worallgarook Island** eroded by up to 15m on its NW half, and reshaped with minor accretion in the middle of its westerly facing centre beach. The SW point had areas that eroded between 24m and 14m - **major change**. **Little Yunderup Island**'s NW facing side eroded some 9m, with this eroded sand presumedly accreting between this small island and the larger Yunderup Island, fusing the two islands together.
2005 to 2017  **2017 Imagery** 2005 - Green Line 2017 - Red Line	The **major erosion** trend continued at the NW tip of **Meeyip Island** between 2011 and 2017, this point receded by a further 30m (totalling 120m of recession 2005 to 2017). An area of 200m length by average width of 15m eroded from 2011 to 2017 (total width of shoreline lost 2005 to 2017 is 25m to 40m along this beach. The southern corner of the island also eroded, with a range of 11m to 23m. Erosion on **Ballee Island** continued on the northern and southern corners sections, with the accreted beach in the centre moving slightly, and the intertidal marsh in the centre of the island's eastern side building up in elevation - **major change**. **Worallgarook Island** appears to have had accretion along the intertidal marshes of its western side. Some erosion has towards the southern end of this beach, and protruding features that were previously located on the SW point in 2005 and 2001 have eroded away. A small sand spit of width 18m, has accreted on Worallgarook Island's side of the Yunderup Branch natural channel - **major change**.

Little Yunderup Island's NW facing side eroded some 9m from 2011 to 2017, bring the total eroded width up to 18m (2005 to 2017). The sand bank fusion between the smaller and larger Yunderup Islands (forming 2005 to 2011) accreted further from 2011 to 2017.

D1 to D2 (not including the inner banks of the Murray River) - Major Change

1994 to 2005

1994 Imagery
1994 - Yellow Line
2005 - Green Line

2005 Imagery
1994 - Yellow Line
2005 - Green Line

Erosion of the SW end of **Goongoolup Island** occurred, with the vegetation line receding at least 26m between 1994 and 2005. On the mainland of South Yunderup, the SW section receded by 20m - **major change**.

Within the artificial canal system, the non-armoured shoreline (no seawall) near the South Yunderup boat ramp and at Marma Way/Moyup Way has eroded slightly during this timeframe. Aside from an additional canal arm being constructed parallel to Batavia Quays, the canal system has not eroded due to its artificial hard walling.

Some erosion has been experienced around the reclaimed bund/pond area that is located opposite the South Yunderup Boat Ramp. The perimeter of this bund is not armoured with a seawall; its SW corner eroded by 20m between 1994 and 2005 - **major change.** The remainder of the southerly facing bund wall experienced minor erosion during this timeframe - **minor change**.

2005 to 2011

2011 Imagery
2005 - Green Line
2011 - Blue Line

Elevated water levels in 2011 combined with erosional pressures between 2005 and 2011 to cause an overall recession of the SW end of **Goongoolup Island**. Between 13m and 6m of vegetated shoreline was removed. Two spits also formed, one on each side of this island. Each of the spits extend past the 2005 shoreline position by approximately 18m - **major change**.

On the mainland of South Yunderup, SW section receded by 13m, with recession decreasing around to the southern section to 7m of vegetated shoreline removed. Reshaping of the spit system at the Murray River delta occurred. At the entrance to the Canal System, the shoreline has evolved to form an additional spit some 220m SE of South Yunderup Boat Ramp - **major change.**

Erosion within the artificial canal system, near the South Yunderup boat ramp and at Marma Way/ has been experienced, with around 10m eroded from both sides of the Batavia Quays canal entrance corners and the adjacent vegetated canal banks(along Moyup Way (these canal banks are not armoured) - **major change**.

On the opposite side of the main entrance canal, the non-armoured canal banks have

	eroded by 6m to 2m. Around the perimeter of the pond bund all the way to its intersection with the historic shoreline, similar rates of erosion have been experienced, while up to 10m of shoreline has been removed from the bund wall's SW corner - **localised major change**.
2005 to 2017  **2017 Imagery** 2005 - Green Line 2017 - Red Line	The 2017 imagery shows that erosion at the SW end of **Goongoolup Island** has continued - **major change**. The breakthrough penetration of the beach into a small lagoon between 2011 and 2017 has then morphed into shoreline erosion exceeding 20m in this immediate area. The spits on either side of the island have also accreted by approximately 10m during this timeframe (overall both new spits accreted by approximately 30m from 2005 to 2017). On the mainland section of South Yunderup, the 2005 to 20011 trend of foreshore erosion has continued, , but at a slightly lesser rate. A tidal lagoon has formed on the SW corner of this area, with accretion closing off the existing spit. On the eastern side, just south of South Yunderup boat ramp, another intertidal lagoon and mud flat has been formed through accretion of sediment - **major change**.

	Erosion has continued along the non-armoured parts of the main navigation channel into South Yunderup Canals - **minor change**. The shoreline around the bunded pond has stabilised since 2011, due to the lower water levels up to 2017 - **minor change**.

D2 to E1 - Minor Change

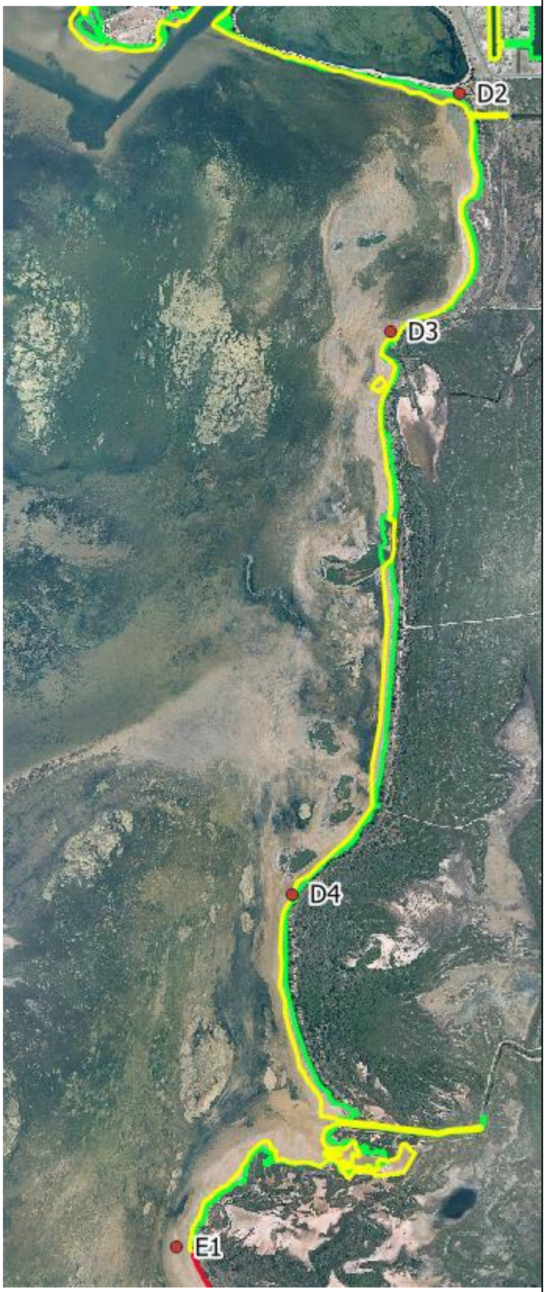
1994 to 2005

1994 Imagery

1994 - Yellow Line

2005 - Green Line

Minor change along this stretch of foreshore between 1994 and 2005.



2005 Imagery

1994 - Yellow Line

2005 - Green Line

<table>
<tr><th>2005 to 2011</th><th>2005 to 2017</th></tr>
<tr><td>

2011 Imagery
2005 - Green Line
2011 - Blue Line

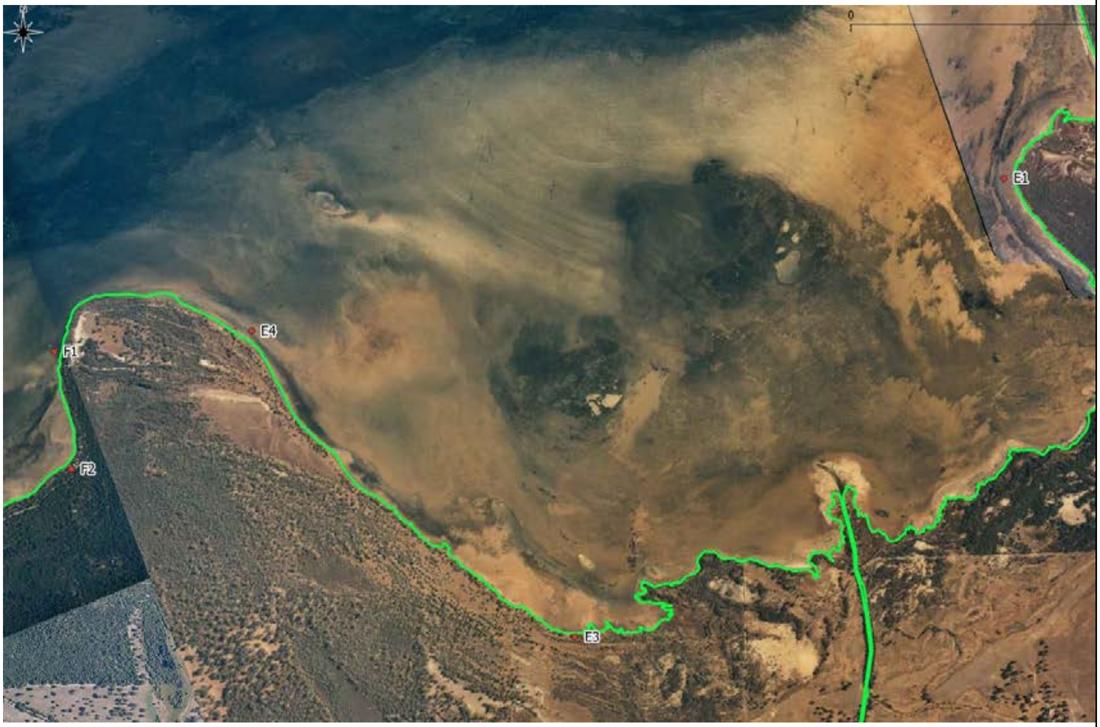
Minor change along this stretch of foreshore between 2005 and 2011.</td>
<td>

2017 Imagery
2005 - Green Line
2017 - Red Line

Minor change along this stretch of foreshore between 2005 and 2017. Elevated water levels in 2011 caused little vegetation retreat.</td></tr>
</table>

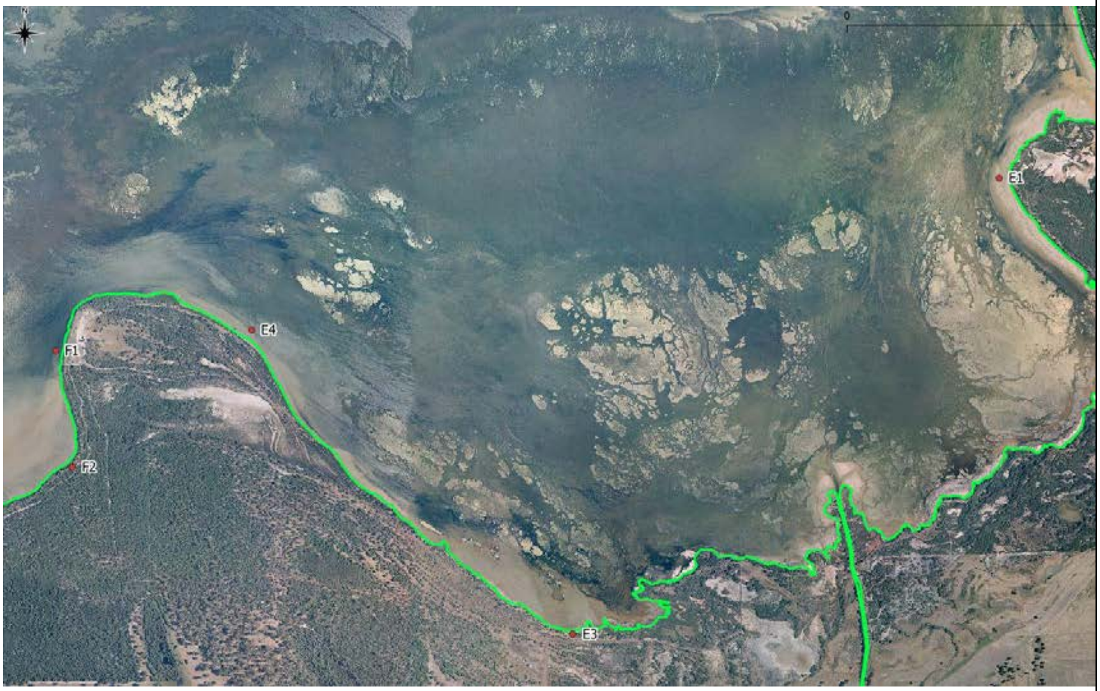
E1 to F1 - Minor Change

1994 to 2005



1994 Imagery

2005 - Green Line



2005 Imagery

2005 - Green Line

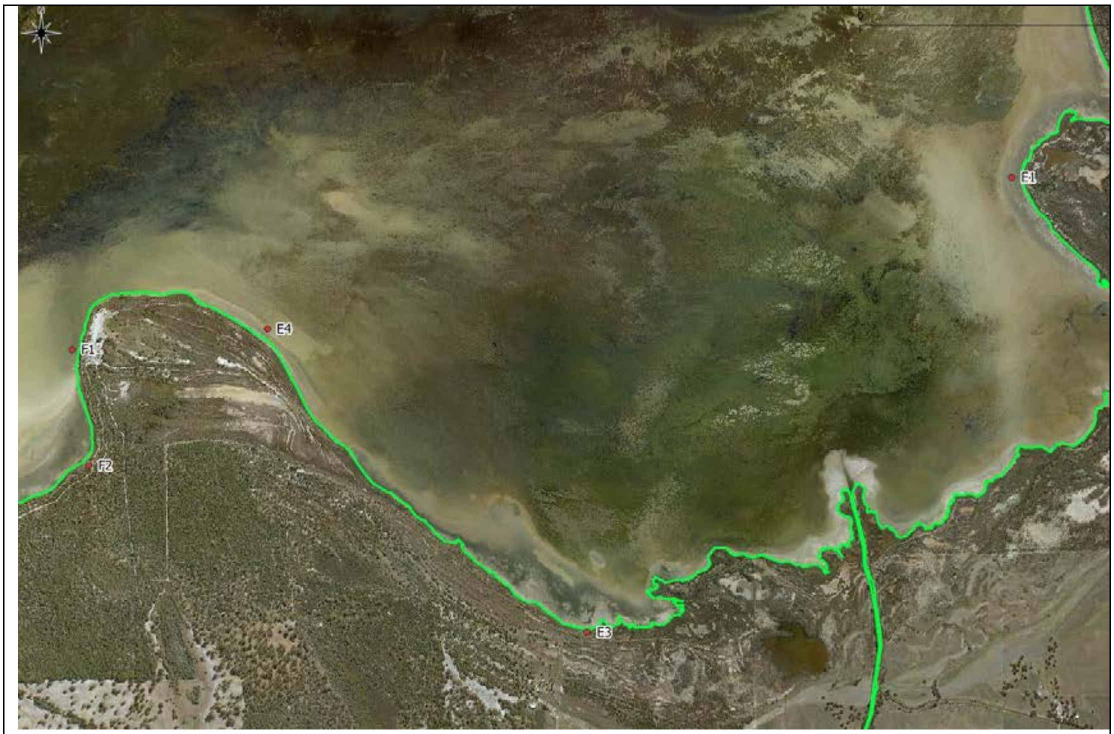
Minor change along this stretch of foreshore between 1994 and 2005.

2005 to 2011

2011 Imagery
2005 - Green Line

Minor change along this stretch of foreshore between 2005 and 2011.

2005 to 2017



2017 Imagery

2005 - Green Line

Minor change along this stretch of foreshore between 2005 and 2017. Elevated water levels in 2011 caused little vegetation retreat.

F1 to G1 - Minor Change

1994 to 2005

1994 Imagery
2005 - Green Line

2005 Imagery
2005 - Green Line

Minor change along this stretch of foreshore between 1994 and 2005.

2005 to 2011

2011 Imagery

2005 - Green Line

Minor change along this stretch of foreshore between 2005 and 2011.

2005 to 2017

2017 Imagery

2005 - Green Line

Minor change along this stretch of foreshore between 2005 and 2017. Elevated water levels in 2011 caused little vegetation retreat.

G1 to H1 - Minor Change

<table>
<tr><td>1994 to 2005

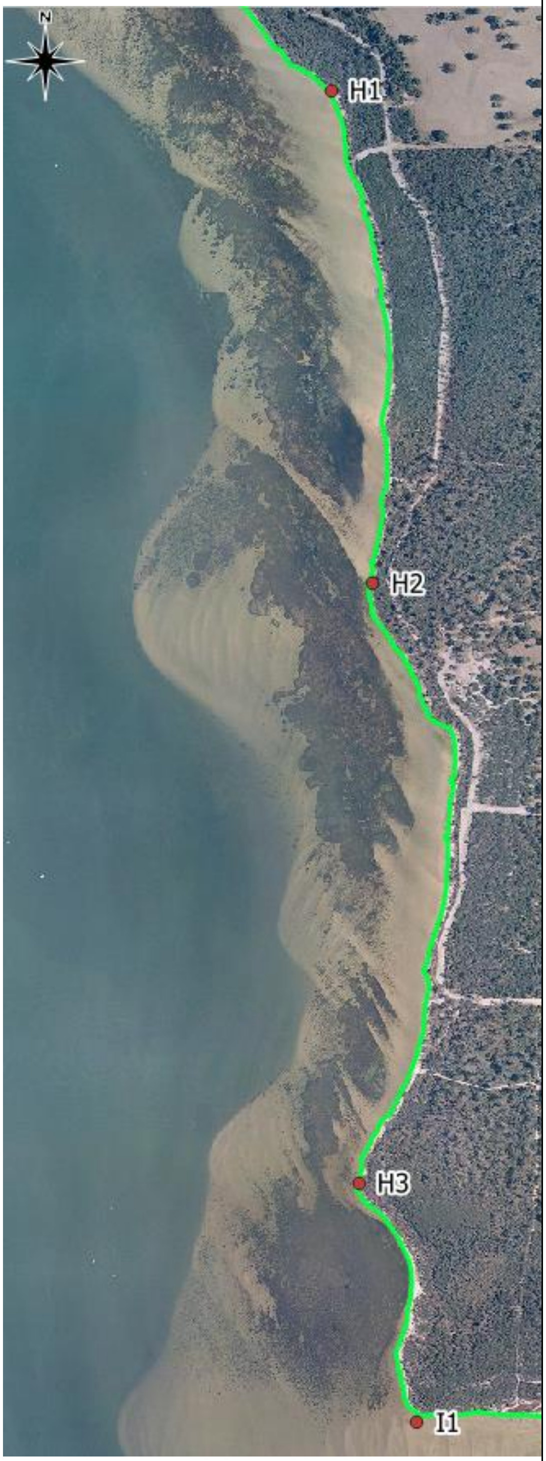

1994 Imagery
2005 - Green Line</td><td>1994 to 2005

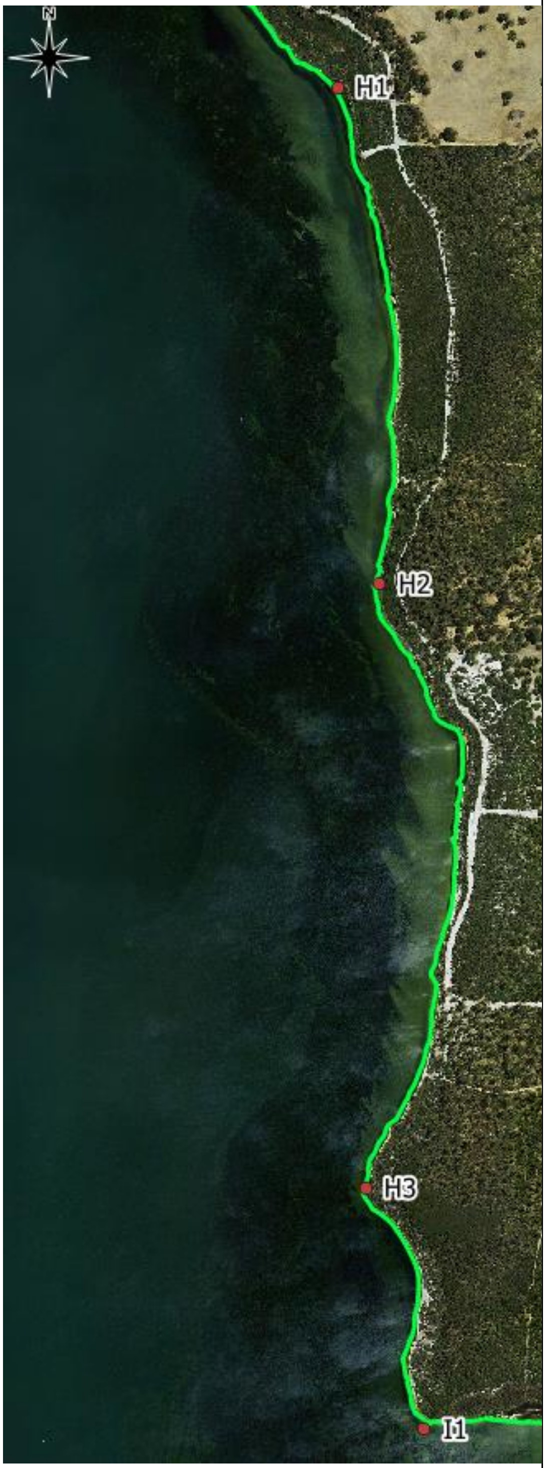
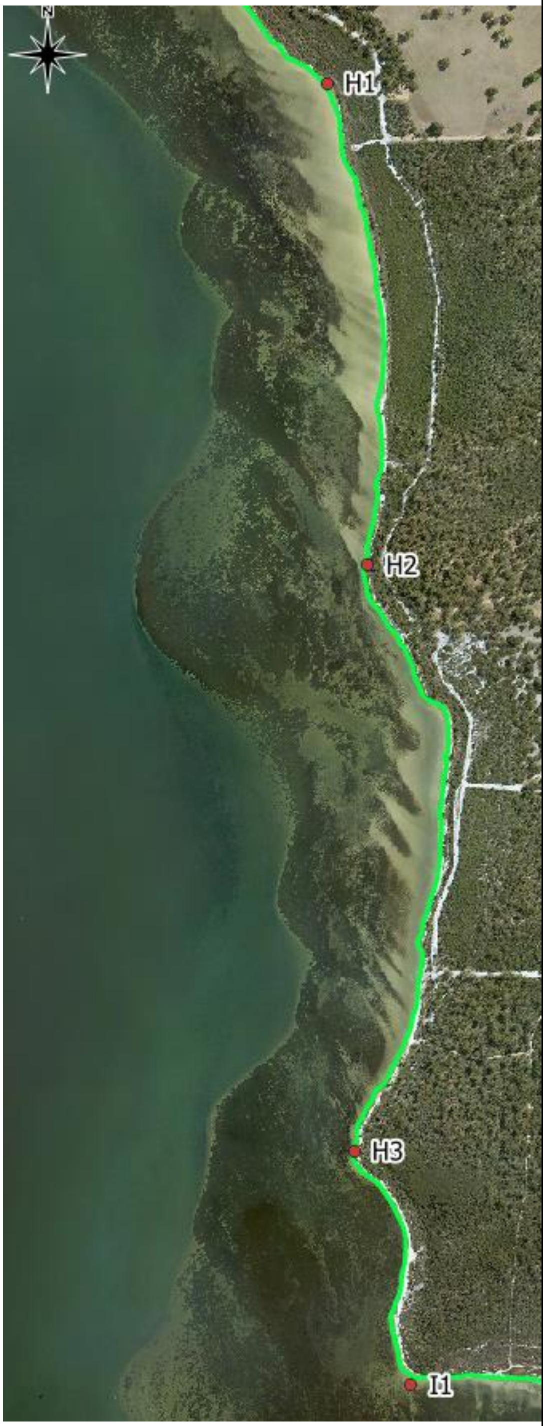

2005 Imagery
2005 - Green Line

Minor change along this stretch of foreshore between 1994 and 2005.</td></tr>
</table>

2005 to 2011	2005 to 2017
 **2011 Imagery** 2005 - Green Line **Minor change** along this stretch of foreshore between 2005 and 2011.	 **2017 Imagery** 2005 - Green Line **Minor change** along this stretch of foreshore between 2005 and 2017. Elevated water levels in 2011 caused little permanent vegetation line retreat.

H1 to I1 - Minor Change

1994 to 2005	**1994 to 2005**
 	
1994 Imagery 2005 - Green Line	**2005 Imagery** 2005 - Green Line **Minor change** along this stretch of foreshore between 1994 and 2005.

2005 to 2011	2005 to 2017
 **2011 Imagery** 2005 - Green Line **Minor change** along this stretch of foreshore between 2005 and 2011.	 **2017 Imagery** 2005 - Green Line **Minor change** along this stretch of foreshore between 2005 and 2017. Elevated water levels in 2011 caused little permanent vegetation line retreat.

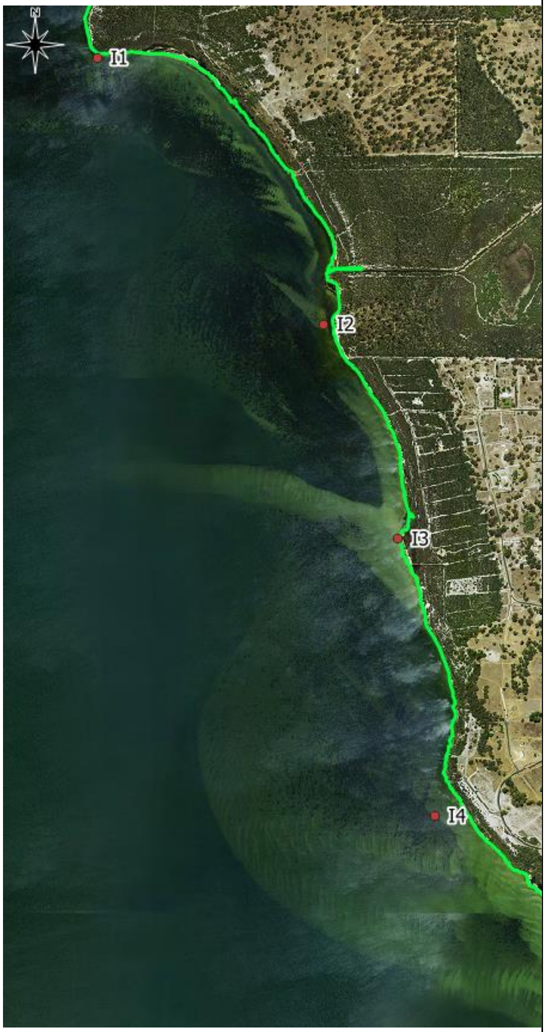
I1 to J1 - Minor Change

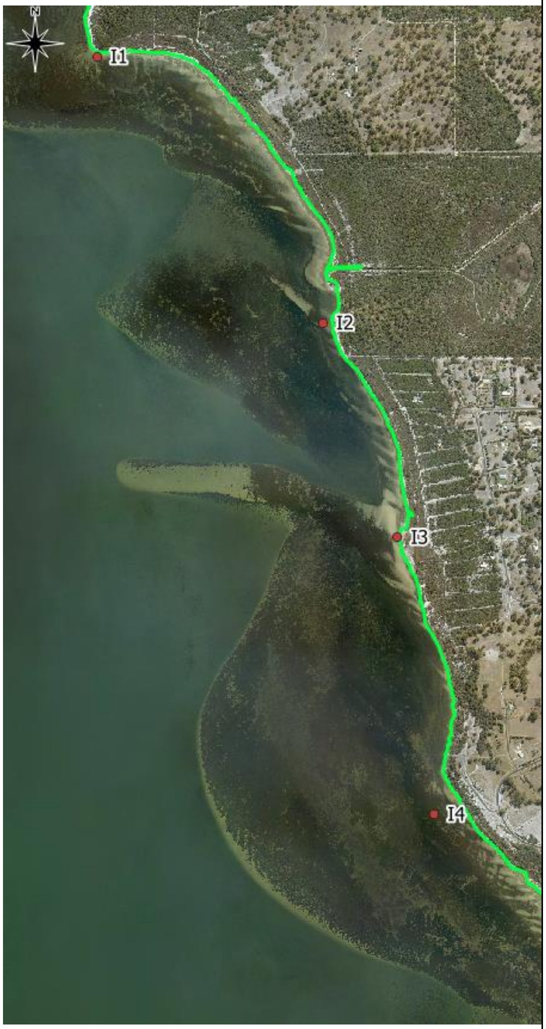
<table>
<tr><td>1994 to 2005

1994 Imagery
2005 - Green Line</td><td>1994 to 2005

2005 Imagery
2005 - Green Line

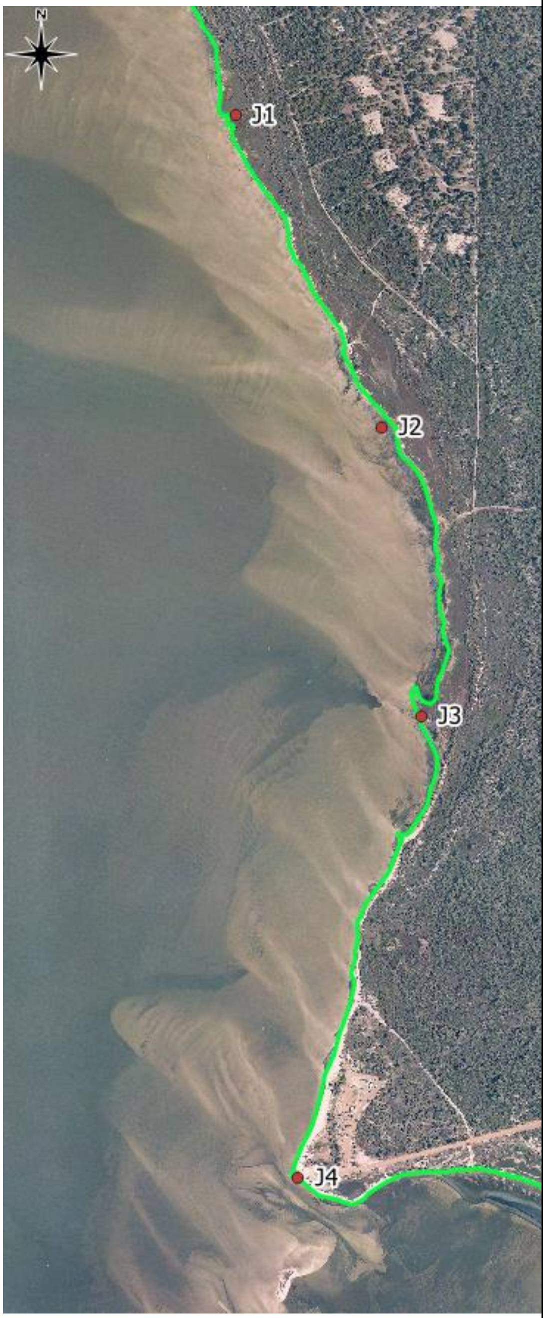
Minor change along this stretch of foreshore between 1994 and 2005.</td></tr>
</table>

<table>
<tr><td>2005 to 2011

2011 Imagery
2005 - Green Line

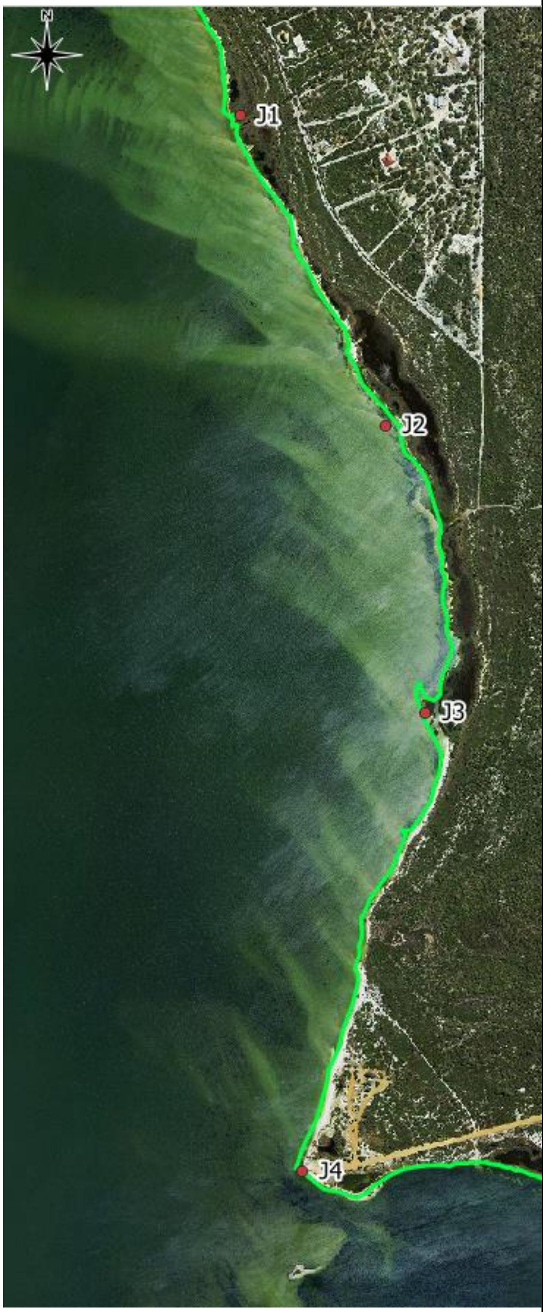
Minor change along this stretch of foreshore between 2005 and 2011.</td><td>2005 to 2017

2017 Imagery
2005 - Green Line

Minor change along this stretch of foreshore between 2005 and 2017. Elevated water levels in 2011 caused little permanent vegetation line retreat.</td></tr>
</table>

J1 to J4 - Minor Change

1994 to 2005	**1994 to 2005**
	
2005 - Green Line **1994 Imagery*** (* 1994 Imagery digitisation error around J4)	**2005 Imagery** 2005 - Green Line **Minor change** along this stretch of foreshore between 1994 and 2005.

2005 to 2011

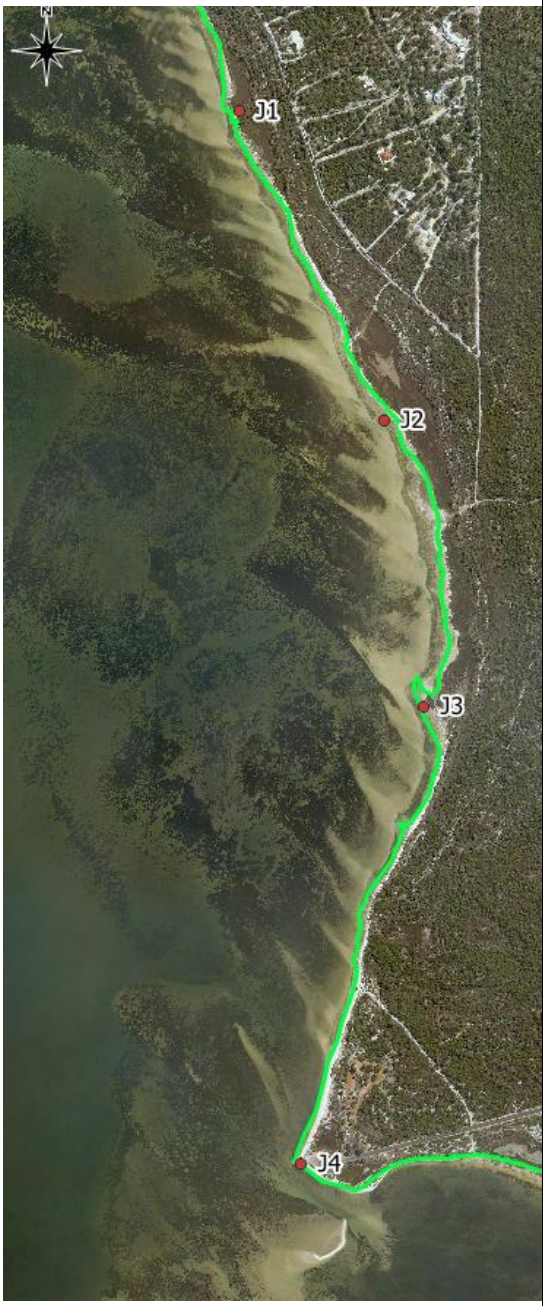


2011 Imagery

2005 - Green Line

Minor change along this stretch of foreshore between 2005 and 2011.

2005 to 2017



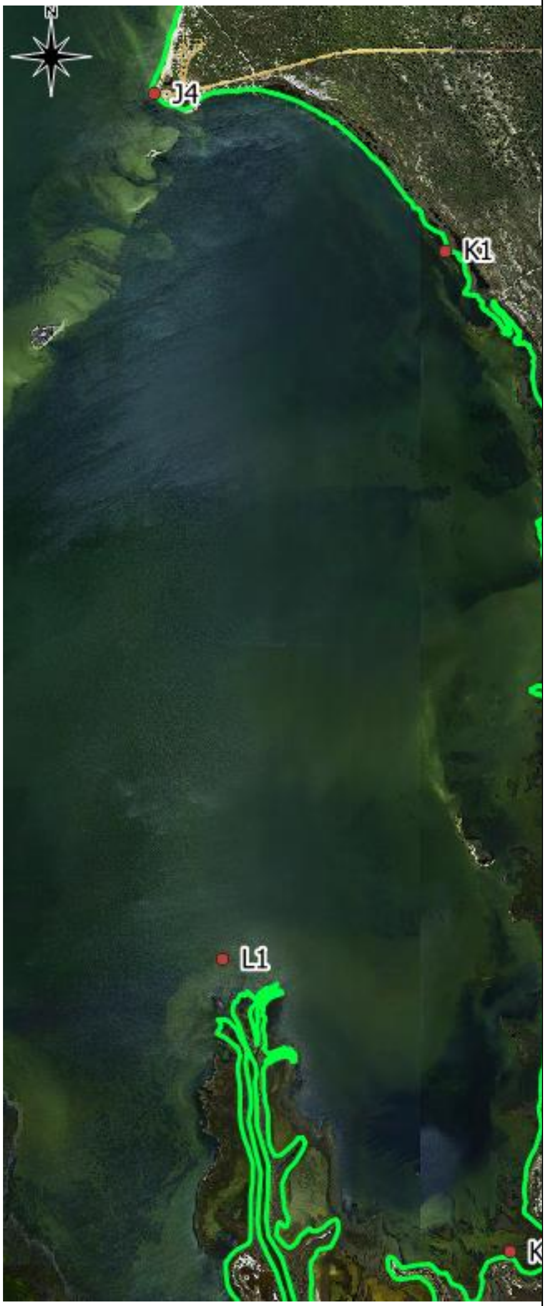
2017 Imagery

2005 - Green Line

Minor change along this stretch of foreshore between 2005 and 2017. Elevated water levels in 2011 caused little permanent vegetation line retreat.

J4 to K3 - Minor Change

1994 to 2005	1994 to 2005
 **1994 Imagery*** 2005 - Green Line (* 1994 Imagery digitisation error around J4)	 **2005 Imagery** 2005 - Green Line **Minor change** along this stretch of foreshore between 1994 and 2005.

2005 to 2011	2005 to 2017
	
2011 Imagery 2005 - Green Line **Minor change** along this stretch of foreshore between 2005 and 2011.	**2017 Imagery** 2005 - Green Line

Minor change along this stretch of foreshore between 2005 and 2017. Elevated water levels in 2011 caused little permanent vegetation line retreat.

K3 to L2 - Minor Change

<table>
<tr><td>

1994 to 2005

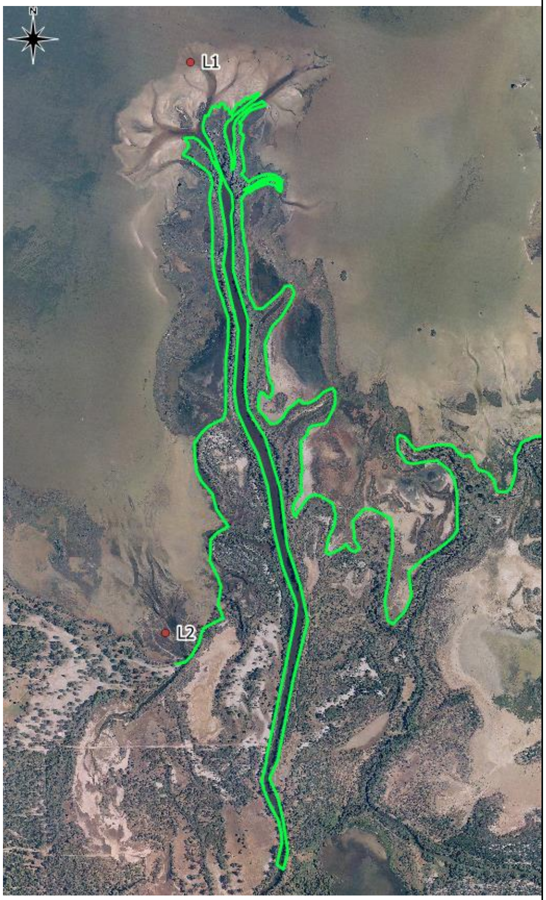
1994 Imagery*

2005 - Green Line

(* 1994 Imagery digitisation error around J4)

</td><td>

1994 to 2005

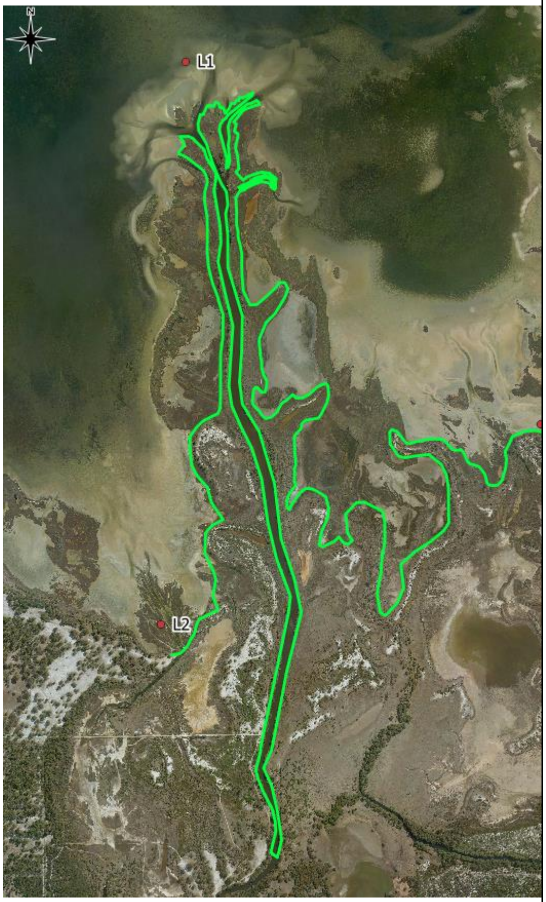


2005 Imagery

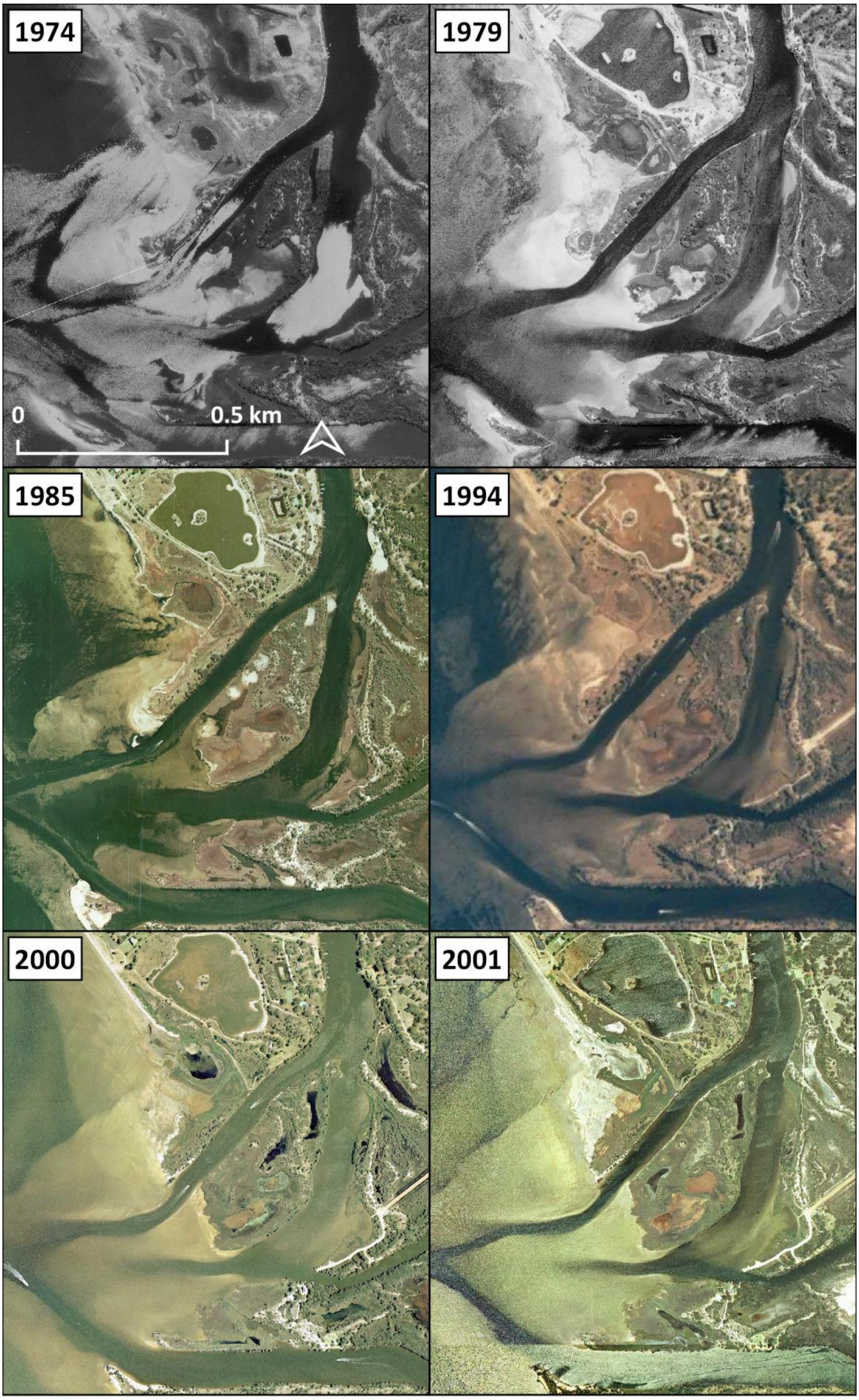
2005 - Green Line

Minor change along this stretch of foreshore between 1994 and 2005.

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

2005 to 2011	2005 to 2017
 **2011 Imagery** 2005 - Green Line **Minor change** along this stretch of foreshore between 2005 and 2011.	 **2017 Imagery** 2005 - Green Line **Minor change** along this stretch of foreshore between 2005 and 2017. Elevated water levels in 2011 caused little permanent vegetation line retreat.

Appendix D – Murray Delta Imagery Sequences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1994
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2001
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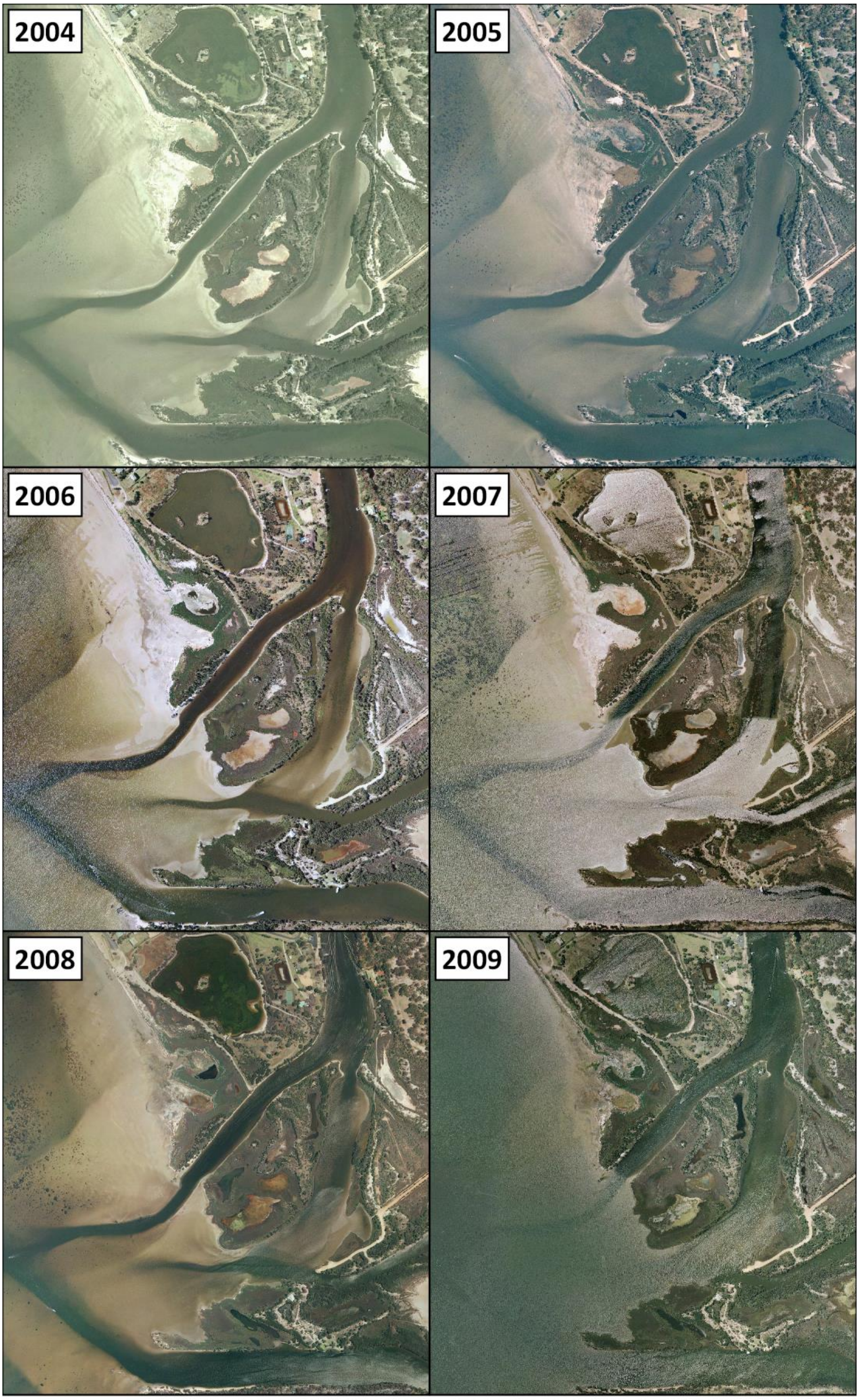
0.5 km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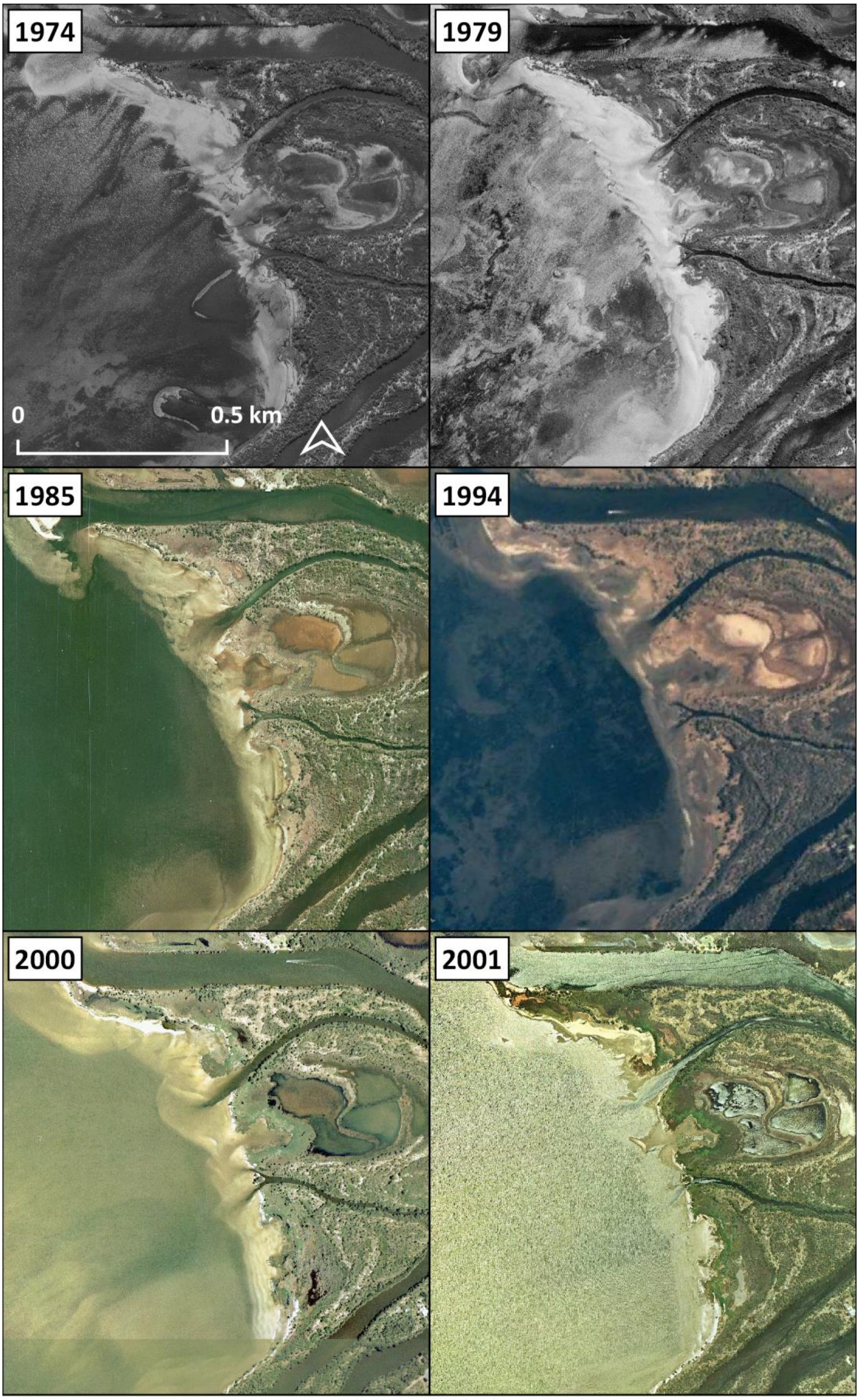
2017


1974
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0.5 km
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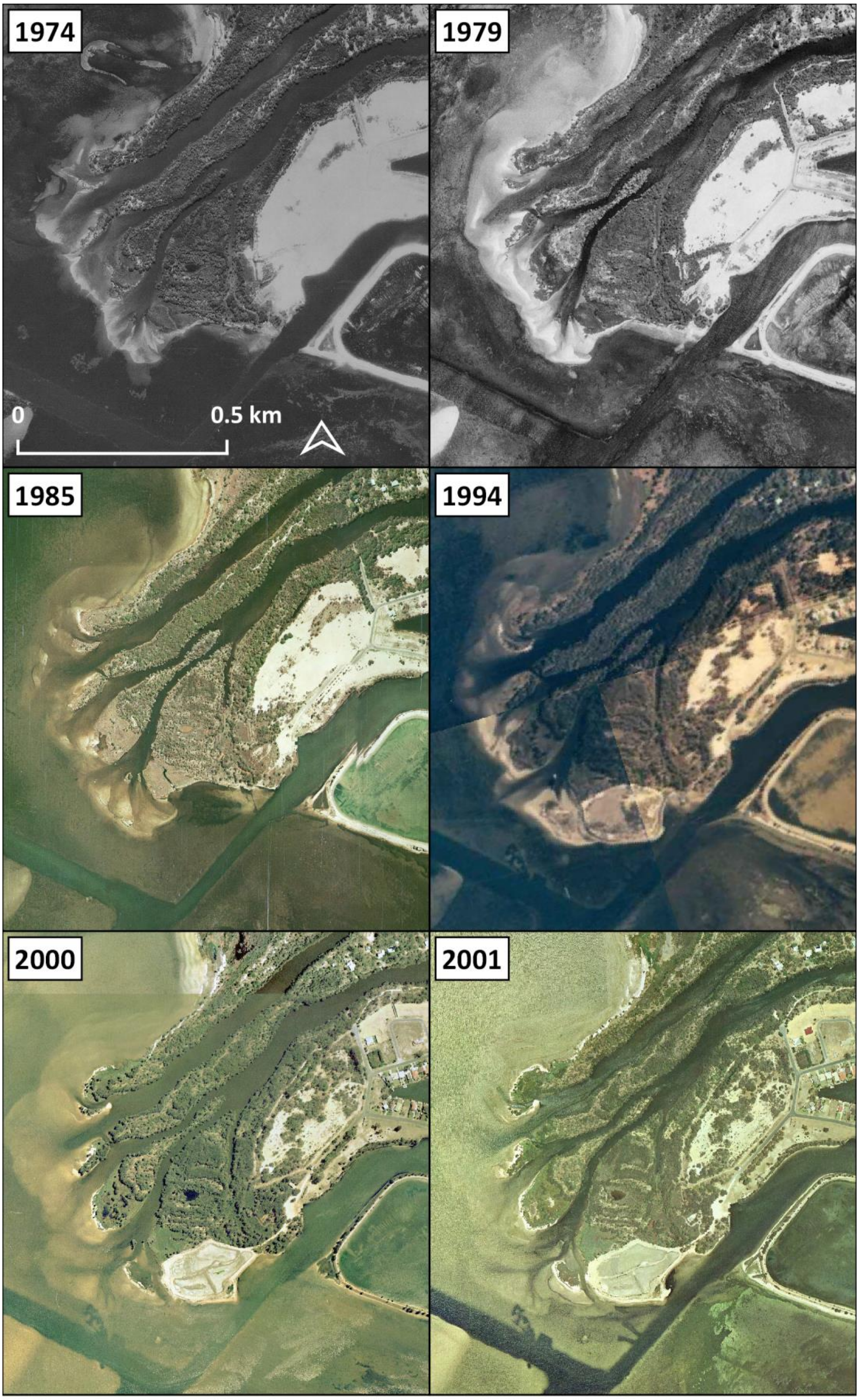
1974
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0.5 km
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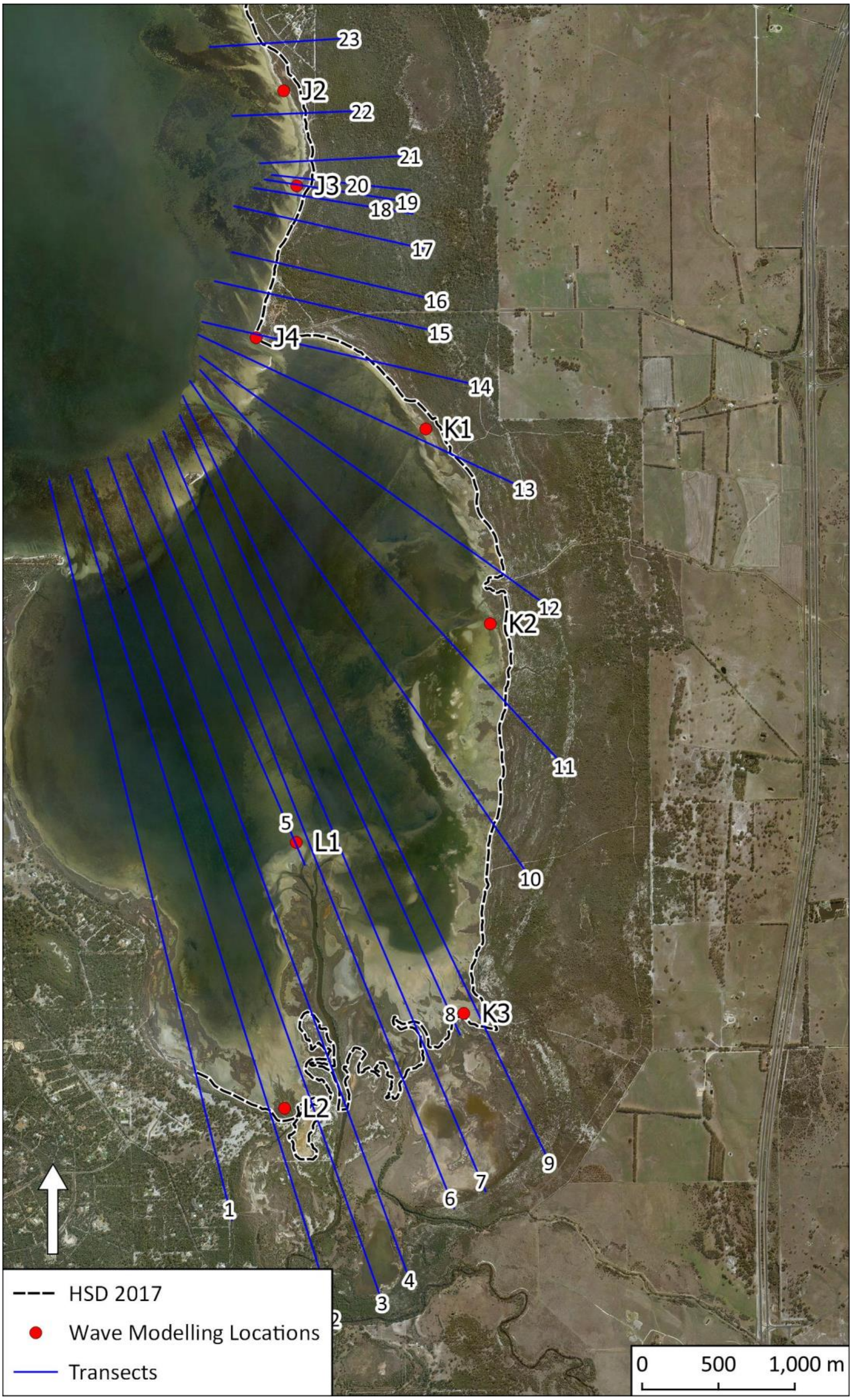
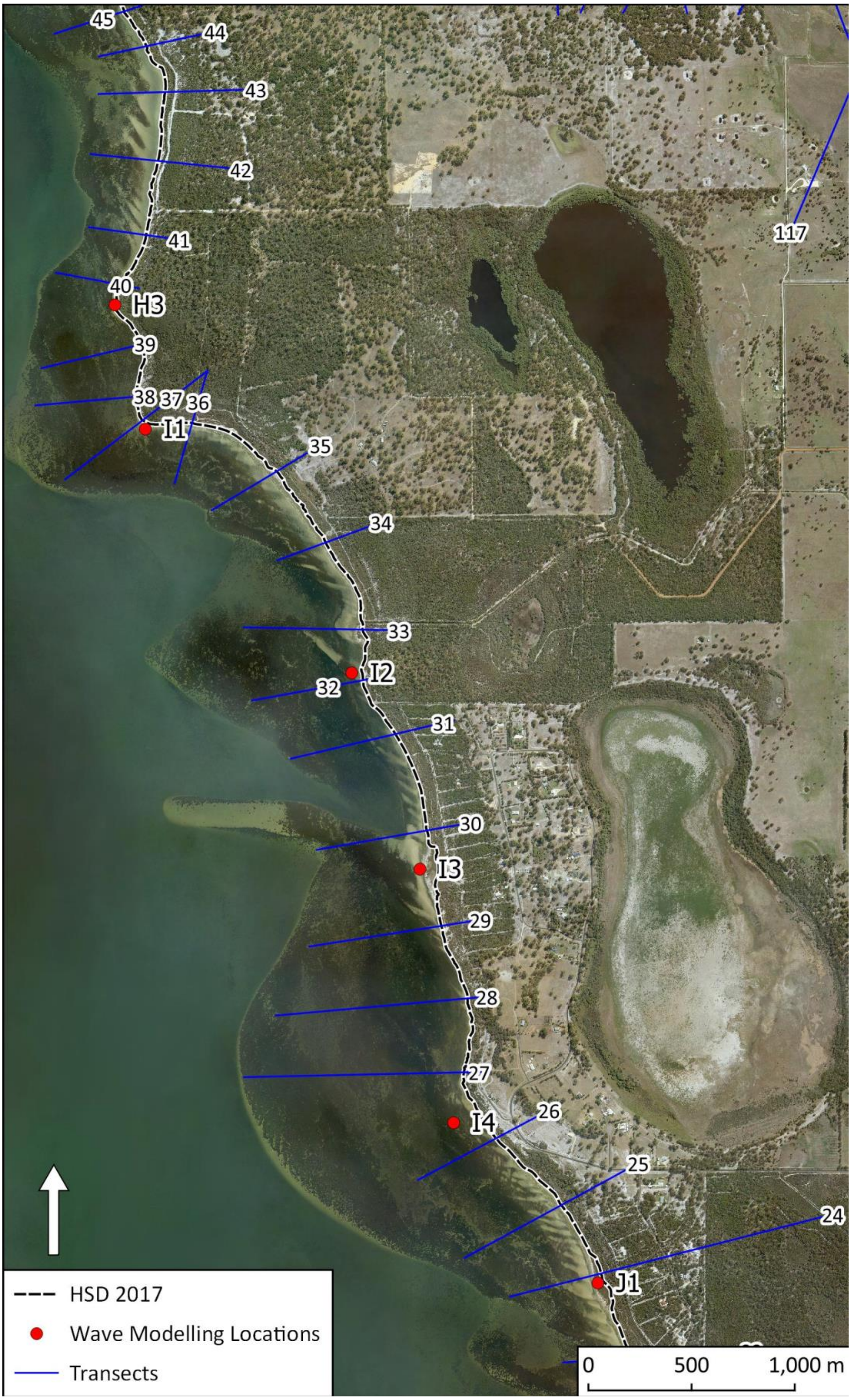
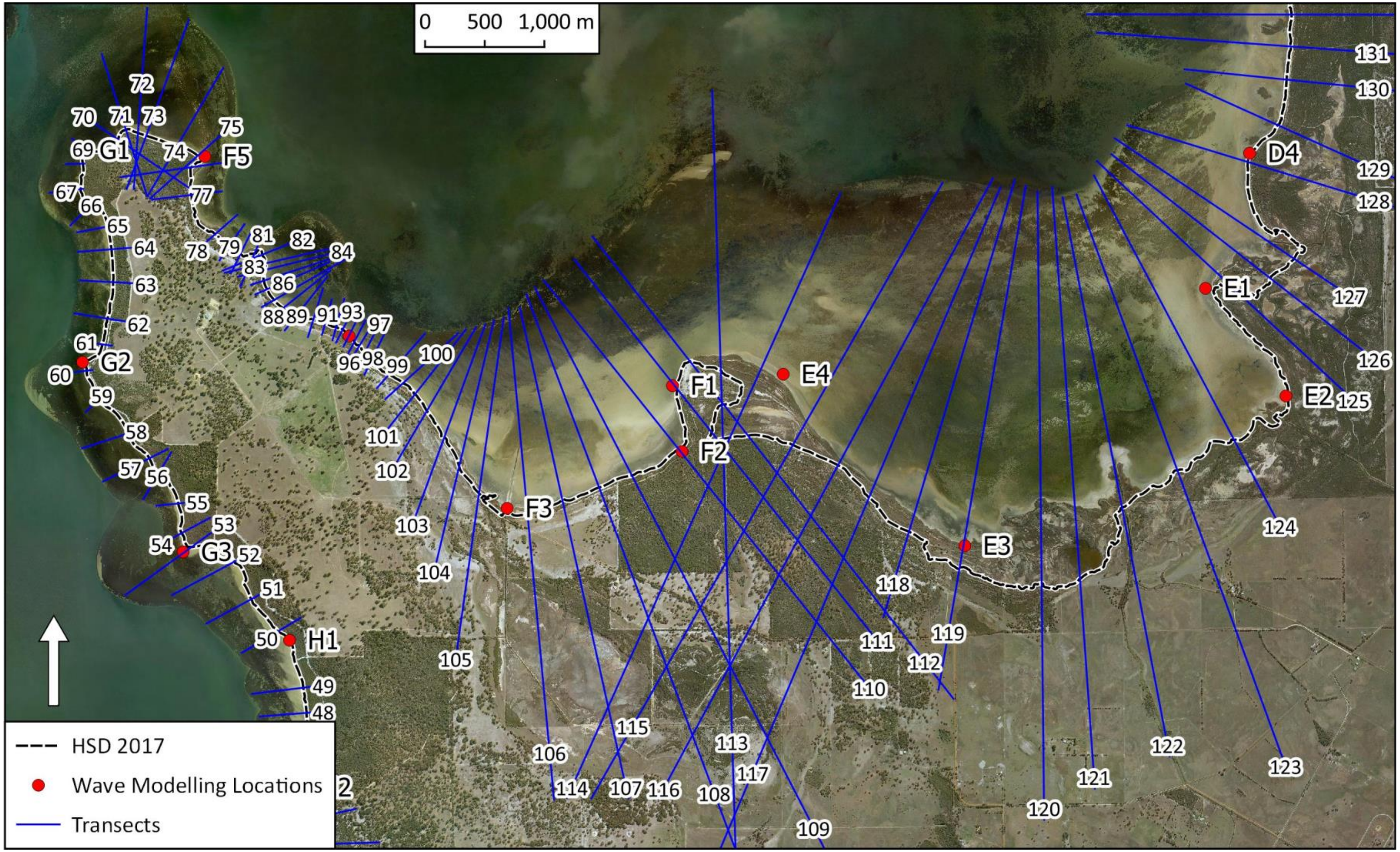
Appendix E – Profiles Used to Evaluate Response to SLR




45
44
43
42
41
40
H3
39
38
37
36
I1
35
34
33
I2
32
31
30
I3
29
28
27
I4
26
25
24
J1
117
HSD 2017
Wave Modelling Locations
Transects
0
500
1,000 m


0 500 1,000 m
HSD 2017
Wave Modelling Locations
Transects
G1
G2
G3
F1
F2
F3
F5
E1
E2
E3
E4
D4
H1
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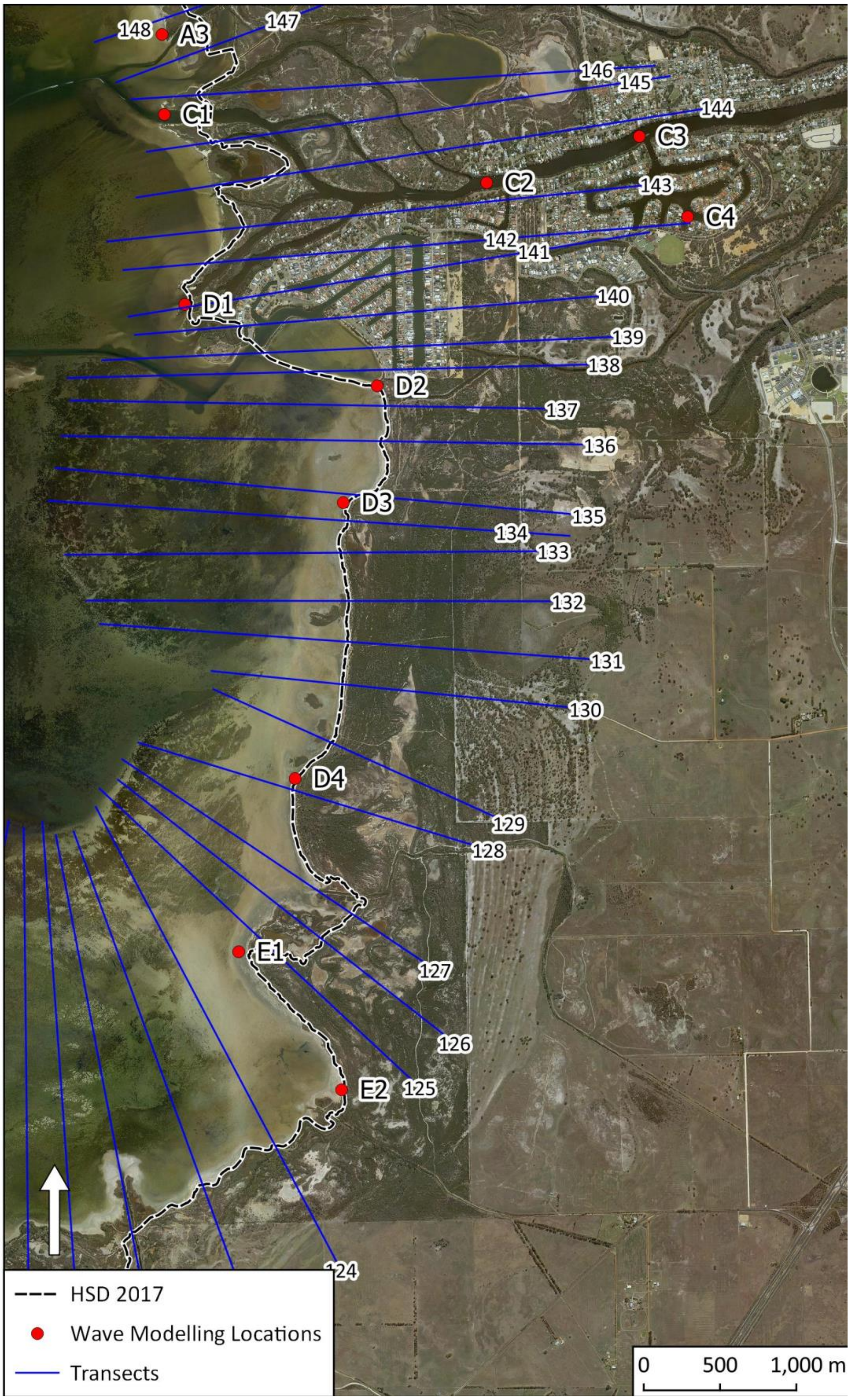

Note: Profiles 138 to 143 include oblique angles to parts of the shore, which will bias local determination of storm erosion & response to sea level rise. However, these effects were refined locally, due to influences of structures and low-lying topography.


HSD 2017
Wave Modelling Locations
Transects
0
500
1,000 m
A0
A1
A2
A3
B1
B2
B3
B4
B5
146
147
148
149
150
151
152
153
154
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Appendix F – Peel-Harvey Bathymetric Change

Evaluation of large-scale estuarine bed change within Peel Inlet and Harvey Estuary was reported previously in Damara WA (2019) and has been included here.

Measurement of the whole estuary bed has been conducted twice:

1. Through a set of leadline surveys in the 1970s, prior to undertaking substantial dredging works for navigation. This set of surveys, along with post-dredging surveys, was later collated by the Department of Marine and Harbours to support numerical modelling for the proposed Dawesville Channel.
2. Detailed LIDAR bathymetry survey conducted in 2016, on behalf of the Department of Water.

Comparison of estuary bed levels between the two surveys summarises estuarine change over more than 40 years, including changes that resulted from Dawesville Channel construction. However, differences in survey techniques constrain this comparison, with the earlier set of surveys having coarse coverage and relatively lower vertical precision.

For comparative analysis, two surfaces were developed with a grid spacing of 20m. The 1970s surface was generated through automated interpolation between coarse survey lines. The 2016 surface was generated through kriging, which develops a weighted average of the levels within each cell. A consequence of the different surveys and surface generation was a very smooth 1970s surface, including planar sections across areas of sparse data. By contrast, even after averaging over the grid cells, the 2016 surface retains substantial texture, indicating ripples, ridges, splays and other bedforms.

A difference plot was generated by subtracting the levels of the 1970s surface from those of the 2016 surface. Initial comparison of net change highlighted that the overall change was inconsistent with reporting to the relative vertical datums (i.e. the difference plot indicated a massive bed lowering across most of the estuary, which does not reflect observations). Identification of bed change was subsequently developed by assuming near zero volume change. The resulting vertical difference was approximately 0.21m, which matches a datum jump identified in Peel inlet tide gauge record (Appendix A).

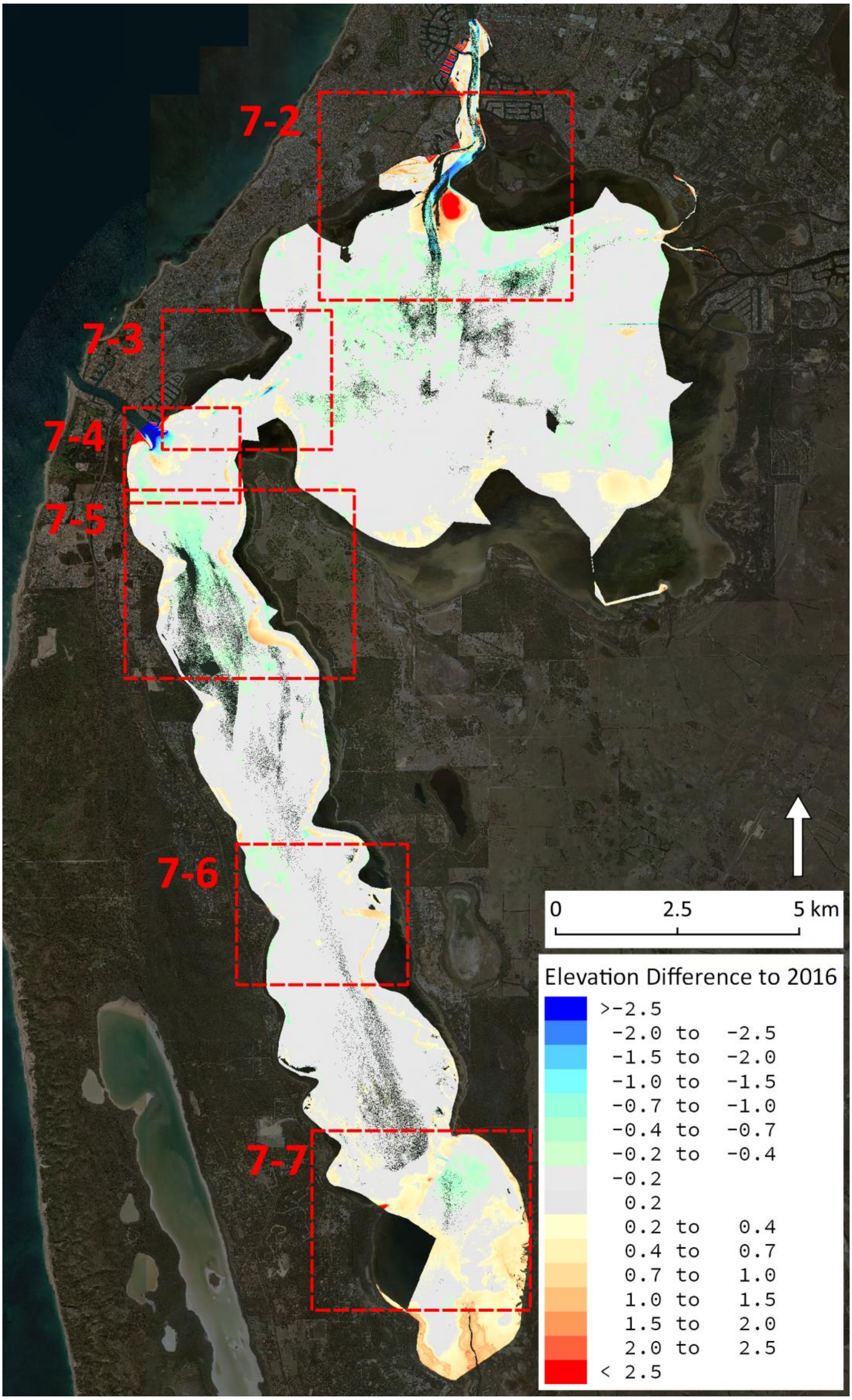


Figure F-1: Bathymetric Comparison

The survey comparison shows six areas of substantial change:

1) Sticks Channel and Channel Island (Figure F-2) were developed through dredging and reclamation in the 1980s (Paul & Hutton 1985).

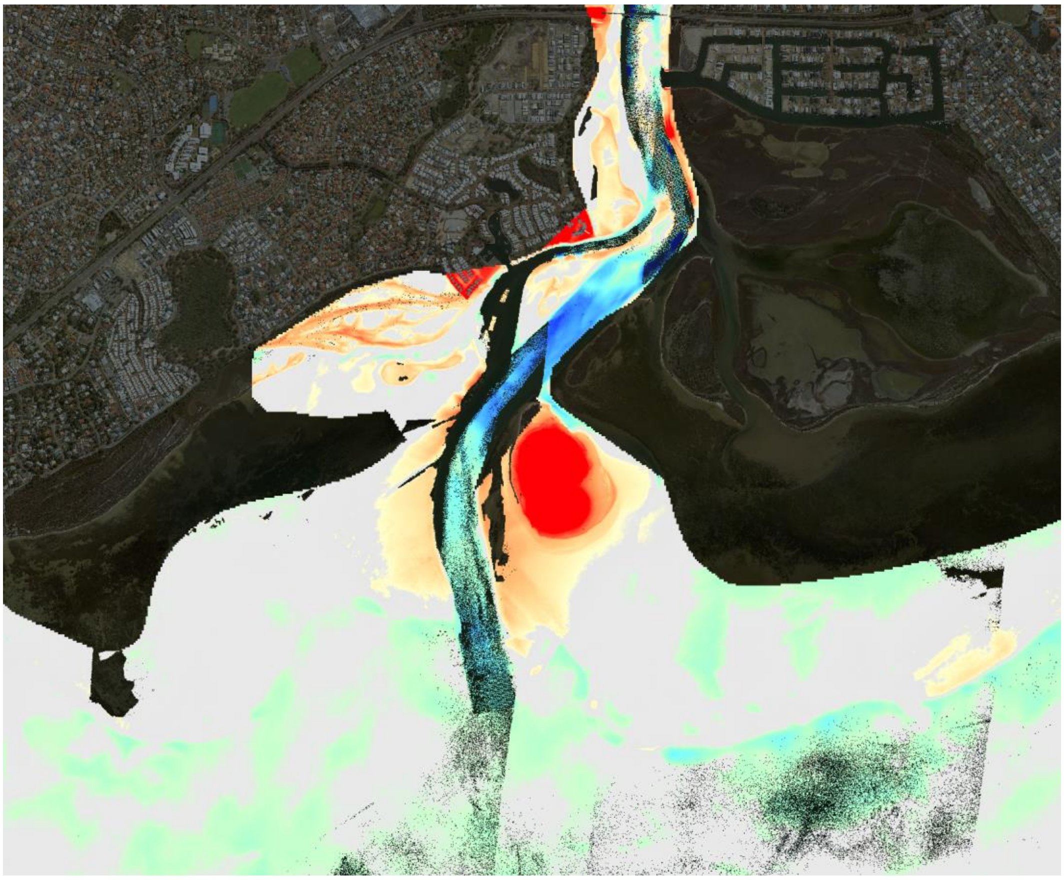


Figure F-2: Bathymetric Change near Sticks Channel

2) Grey Channel, between Peel Inlet and Harvey Estuary has experienced deepening, with some minor sedimentation of adjacent areas. This pattern is consistent with predictions of increased flow speeds through Grey Channel predicted as a response to construction of Dawesville Channel.

   A broad area of minor deepening was indicated east of Grey Channel, for approximately the western third of Peel Inlet. The cause of this pattern is unclear, as it may plausibly be a result of bed scour following construction of Dawesville Channel, loss of benthic vegetation; or a systematic vertical difference due to the difference between survey techniques.

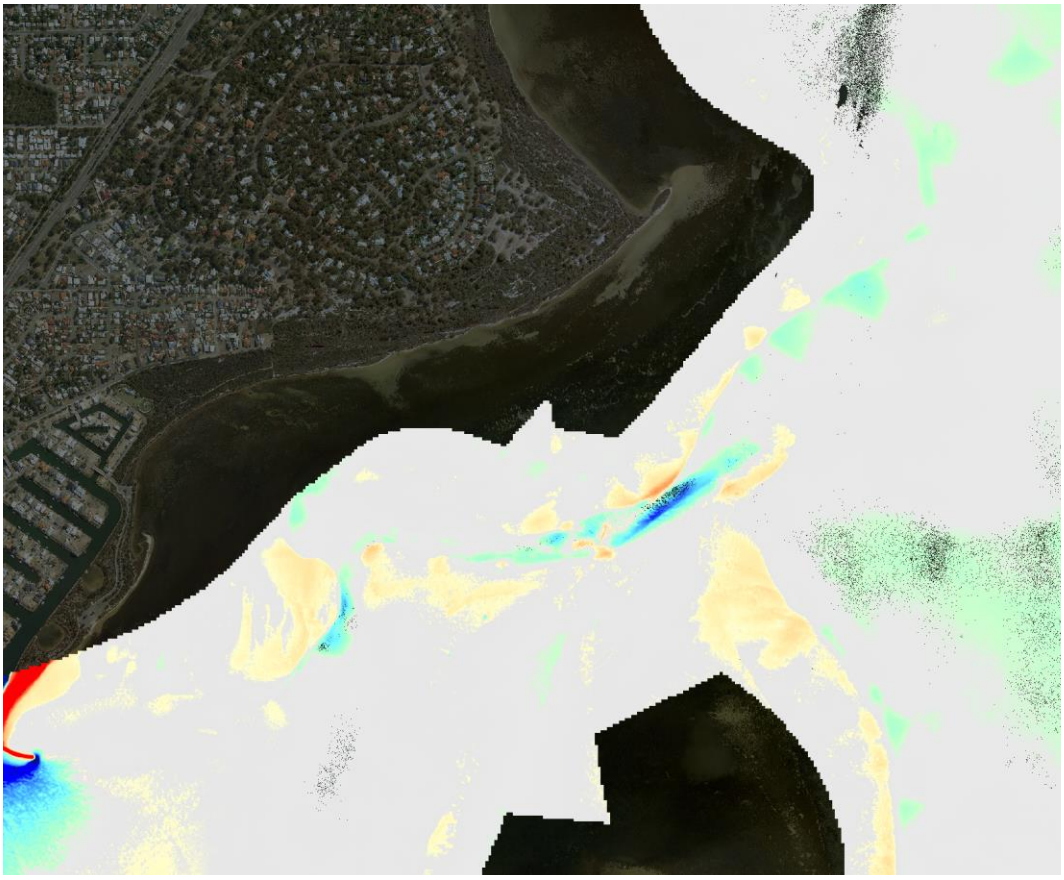


Figure F-3: Bathymetric Change near Grey Channel

The eastern end of Dawesville Channel exhibits characteristics of construction and subsequent evolution. The major 'bell mouth' feature that was constructed is now surrounded by a raised arc typical of flood sill. Secondary features occur inside the channel, including a sand shoal on the southern side, with a series of ridges connected to the shoal running part way across the channel. This creates a rippled bed structure for the flow in and out of the channel.

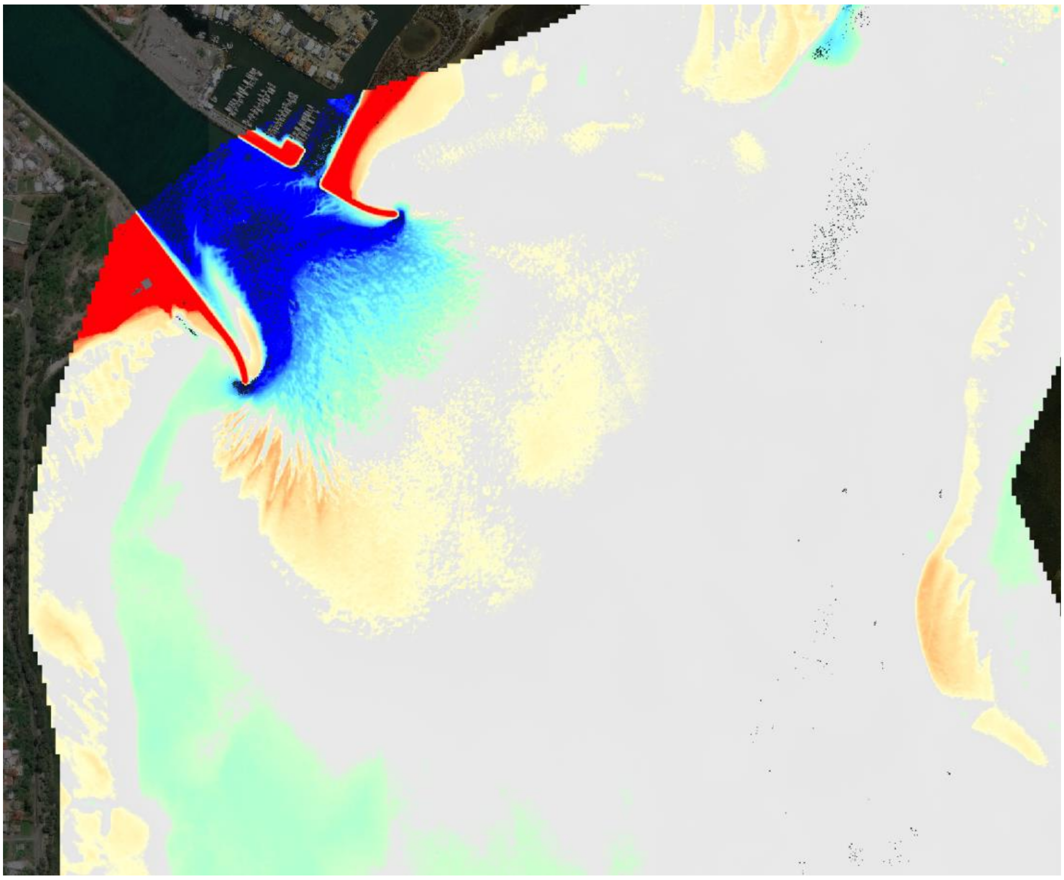


Figure F-4: Bathymetric Change near Dawesville Channel

3) South of Dawesville Channel, an area of bed lowering is indicated at the slight constriction across Harvey Estuary developed between two forelands. This is consistent with locally increased tidal currents following excavation of Dawesville Channel. The survey comparison also indicates deposition along the intertidal terrace east of the eroded area. Although this deposition is possibly where the eroded sediment was moved towards, it is also possible that this feature is created due to differences between the surveys, as coverage was extremely sparse on the terrace during the 1970s survey.

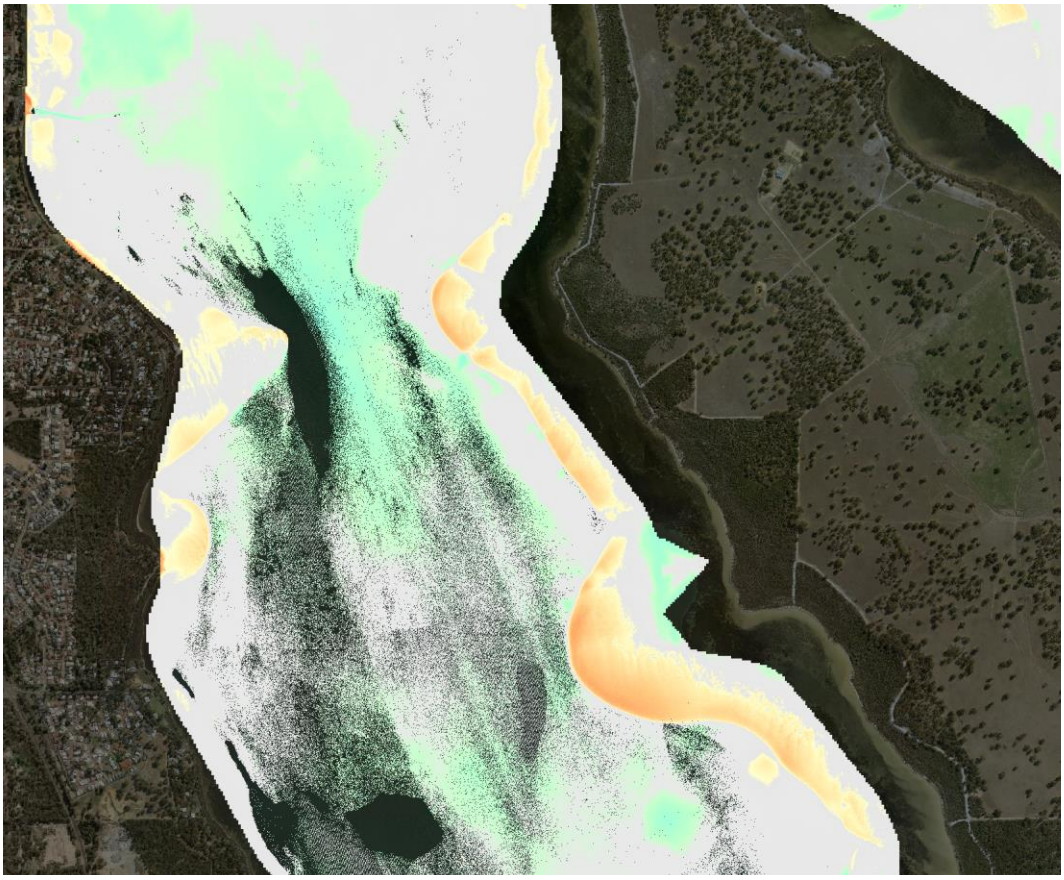


Figure F-5: Bathymetric Change south of Dawesville Channel

4) An extended linear shoal has developed on the eastern side of Harvey Estuary, which is also evident in aerial imagery. This feature started to develop in the 1980s and consequently its origin is unrelated to Dawesville Channel. The orientation of the shoal is similar to smaller transverse bars nearby along the eastern shore of Harvey Estuary. These are typically developed through a combination of wave action and tidal flows. Extended transverse bars normally occur where there is regular sediment supply such as a drainage outlet, however no such drain has been identified at this shoal.

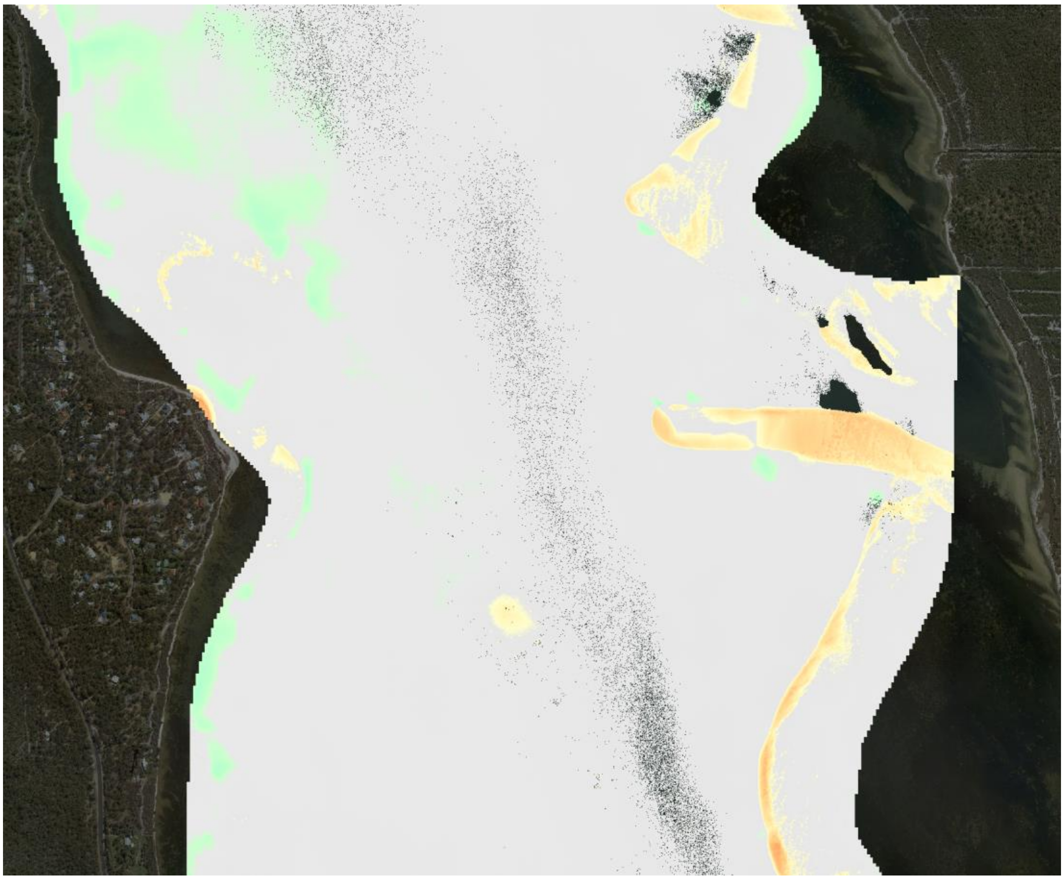


Figure F-6: Bathymetric Change near Birchmont

5) The 'Ford' between Island Point and Herron Point is a tidal sill, with survey comparison showing areas of erosion and accretion. Some of this change is due to survey differences, as the 1970s surveys had limited resolution of the channels. However, the dynamic nature of the sill feature is apparent from aerial imagery, with changes in the width of the sill and channel positions. Surveys should therefore be considered snapshots, rather than indicative of a long-term trend.

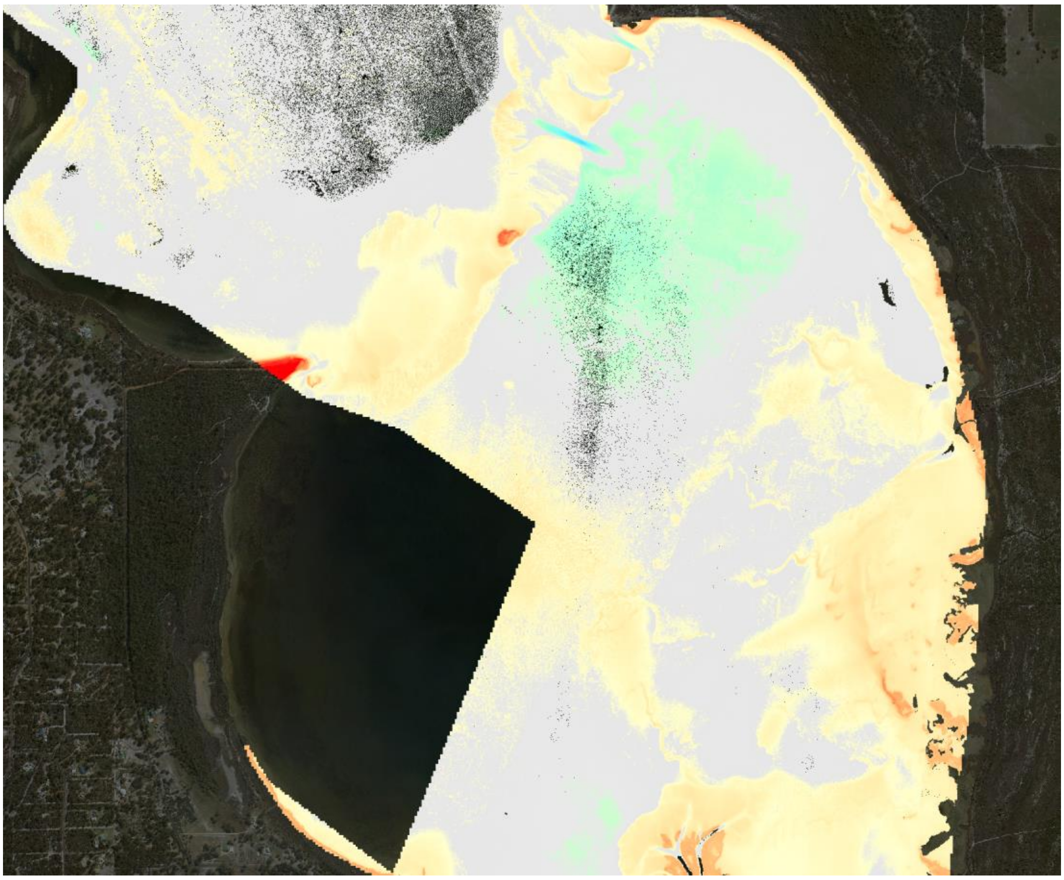
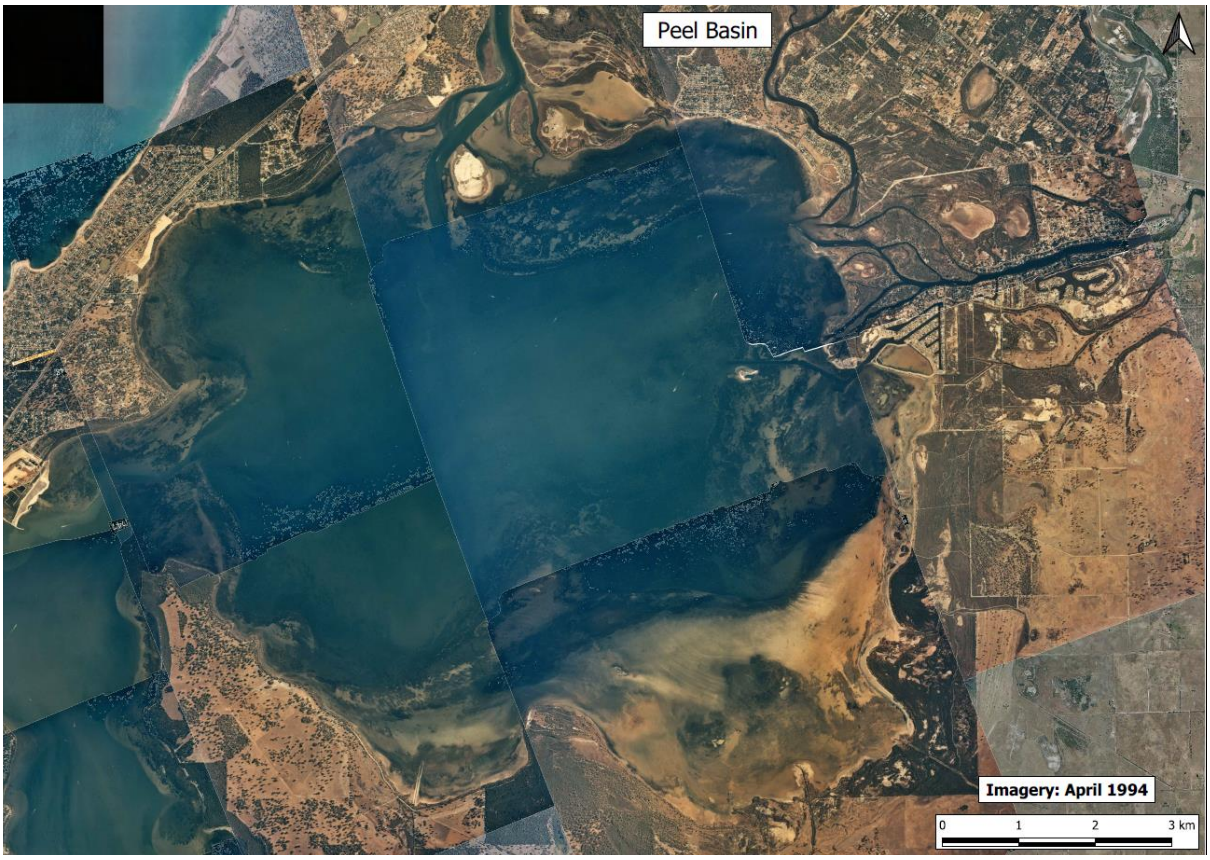
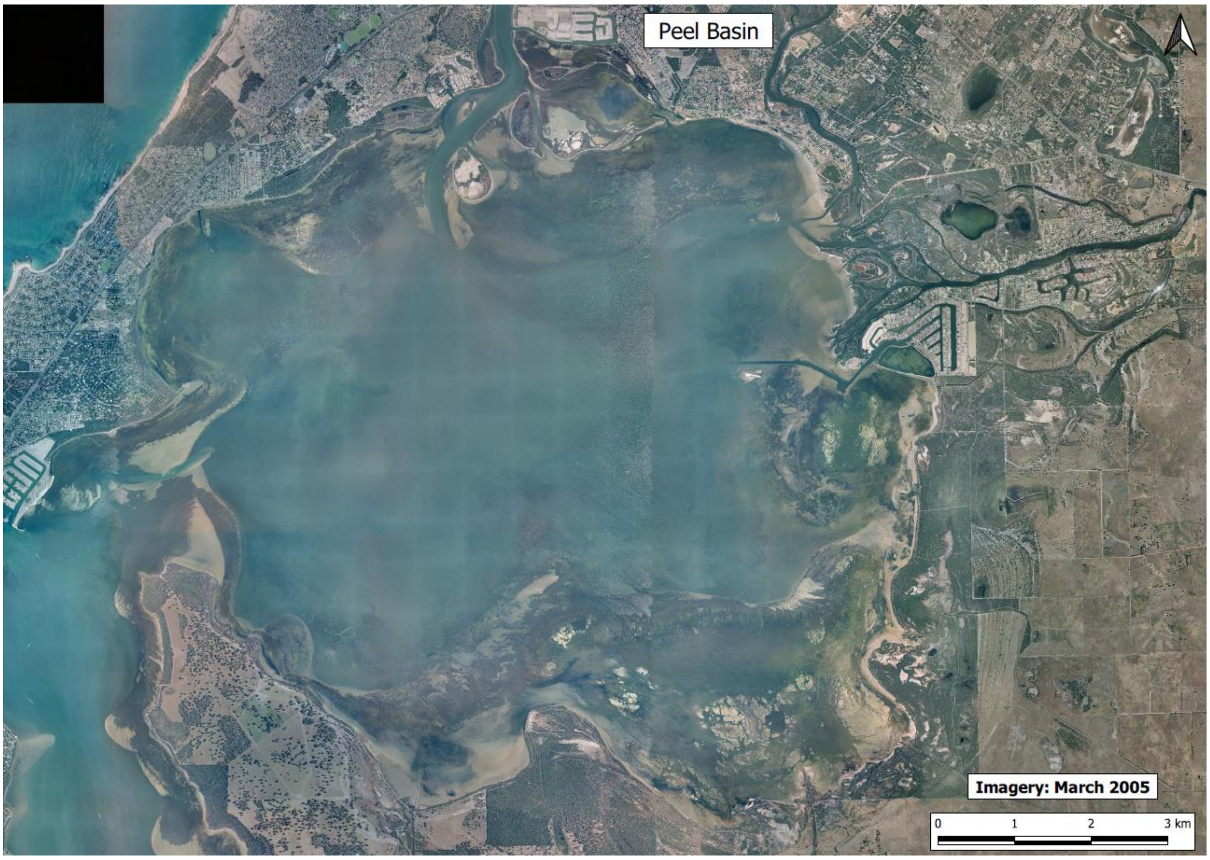
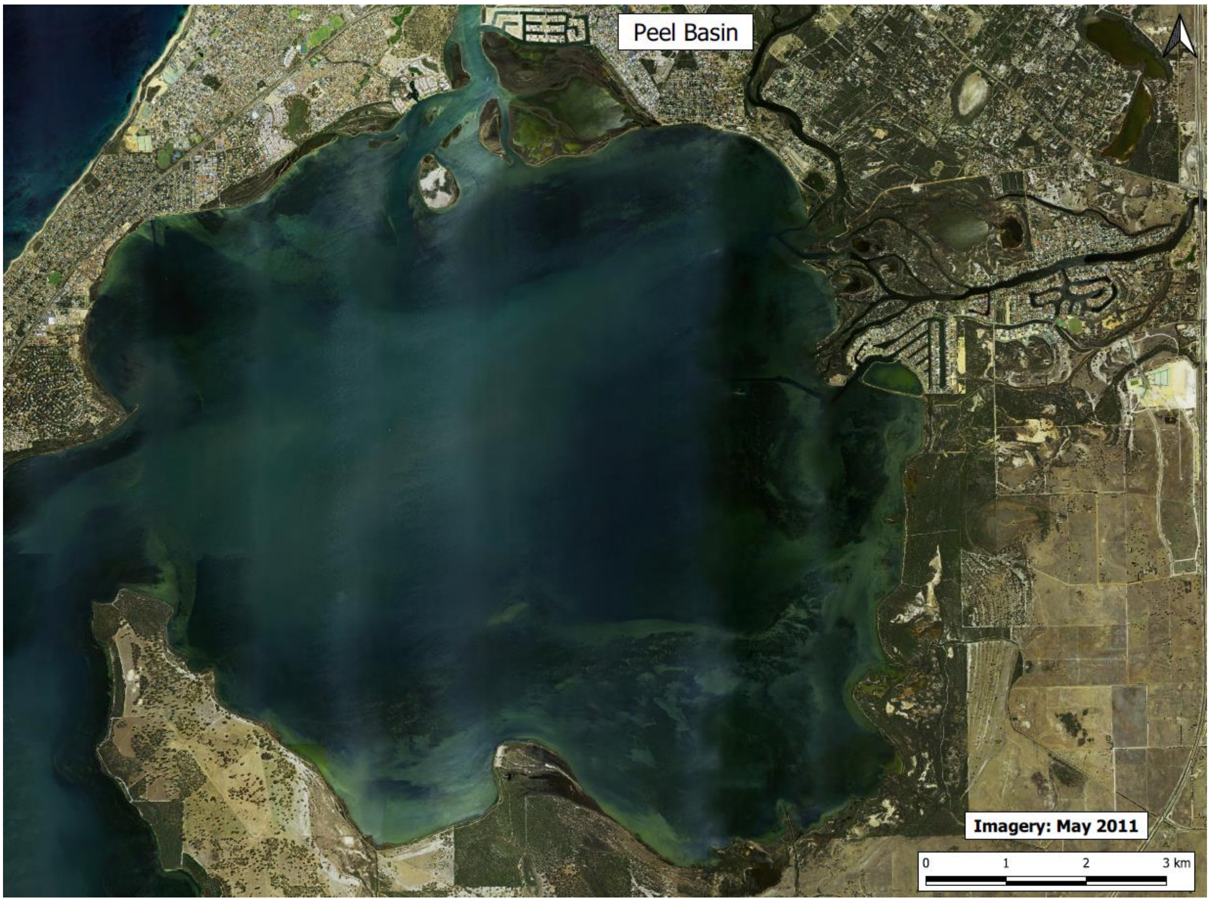


Figure F-7: Bathymetric Change near Island Point

Appendix G – Variability of Benthic Coverage






Peel Basin
Imagery: May 2011
0
1
2
3 km


Peel Basin
Imagery: May 2012
0
1
2
3 km


Peel Basin
Imagery: November 2015
0
1
2
3 km


Peel Basin
Imagery: October 2016
0
1
2
3 km


Peel Basin
Imagery: April 2017
0
1
2
3 km

Appendix H – Wave Hindcast Modelling Report

SW

Peel-Harvey Estuary Wave Modelling

Draft Report

25/05/2018

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Revision History

Revision Ref / Date Issued	Amendments	Issued to
1.0 (Draft) / 25 May 2018	-	ME

Contract

This report describes work commissioned by Matt Eliot, on behalf of Damara WA Pty Ltd, by an email from Matt Eliot on the 3rd of April 2018. Damara WA Pty Ltd's representative for the contract was Matt Eliot. Johnny Coyle and Daniel Rodger of JBP carried out this work.

Prepared by ....Johnny Coyle BSc MSc
Assistant Analyst

Approved by ....Daniel Rodger BSc MEng CEng CMarEng MIEAust MICE IMarEST
RPEQ 17794

Director

Purpose

This document has been prepared as a Draft Report for Damara WA Pty Ltd. JBP accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared.

JBP has no liability regarding the use of this report except to Damara WA Pty Ltd.

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Executive Summary

JBP has been commissioned by Damara WA Pty Ltd to undertake wave modelling of the Peel-Harvey estuary to produce nearshore wave estimates along the shoreline for a range of scenarios. The modelling has used SWAN (Simulating WAves Nearshore), a third-generation wave model incorporating various wave transformation processes including wave-wave growth, propagation, shoaling, refraction, and breaking. The wave model was then used to simulate 224 design scenarios with varying wind speeds, directions and water levels, producing outputs at 964 locations.

Contents

List of Figures

List of Tables

1 Introduction

1.1 Background

JBP has been commissioned by Damara WA Pty ltd to produce a wave model of the Peel-Harvey Estuary near Mandurah, in Western Australia. The wave model was used to estimate nearshore wave conditions along the shoreline for a range of wind speed, wind direction and water level scenarios.

1.2 Site under investigation

The Peel-Harvey Estuary is a tidal water body in Western Australia, 60km south of Perth. It is relatively shallow, with depths rarely exceeding 3m below AHD. Described in terms of its component areas, the Harvey estuary is 21km long and 3km wide orientated north-north-east, and the Peel estuary is 7-10km wide (refer to Figure 1-1).

Figure 1-1: Peel-Harvey Estuary

2 Wave transformation modelling

Numerical wave modelling was undertaken to estimate wave growth and transformation within the estuary. The modelling approach, assumptions and results are described in this chapter.

2.1 Approach

Modelling has been undertaken using the SWAN (Simulating WAves Nearshore) wave model. SWAN is a third-generation wave model incorporating complex physics for the description of wave growth and transformation processes. It is an open source package and is capable of simulating various wave transformation processes in 2D, including, shoaling, refraction, wind-wave interaction, breaking and dissipation.

The following assumptions have been made:

1. Uniform still water levels exist throughout the estuaries.

The modelling assumed a uniform water level throughout the estuary. No information on water level gradients was available, and given the small scale of the model domain, was deemed appropriate.

2. No influence of ocean generated swell waves:

Only waves generated from wind within the estuary was considered. No additional boundary conditions were applied to consider ocean swell.

3. Uniform wind field:

The model assumed a uniform wind speed and direction throughout the domain.

2.2 Computational mesh

The mesh was constructed as an ADCIRC grid in SMS, with the landward boundary extending to the 2-3mAHD contours adjacent to the estuary.

Mesh spacing was varied around the model boundary, with higher mesh resolution in Mandura, Dawesville, Brunswick Island and Point Grey. Maximum node spacing along the shoreline was approximately 200m at the southern estuary, increasing to a 20m resolution at the Dawesville Channel, Mandura Channel and Serpentine River. The computational mesh is shown in Figure 2-1.

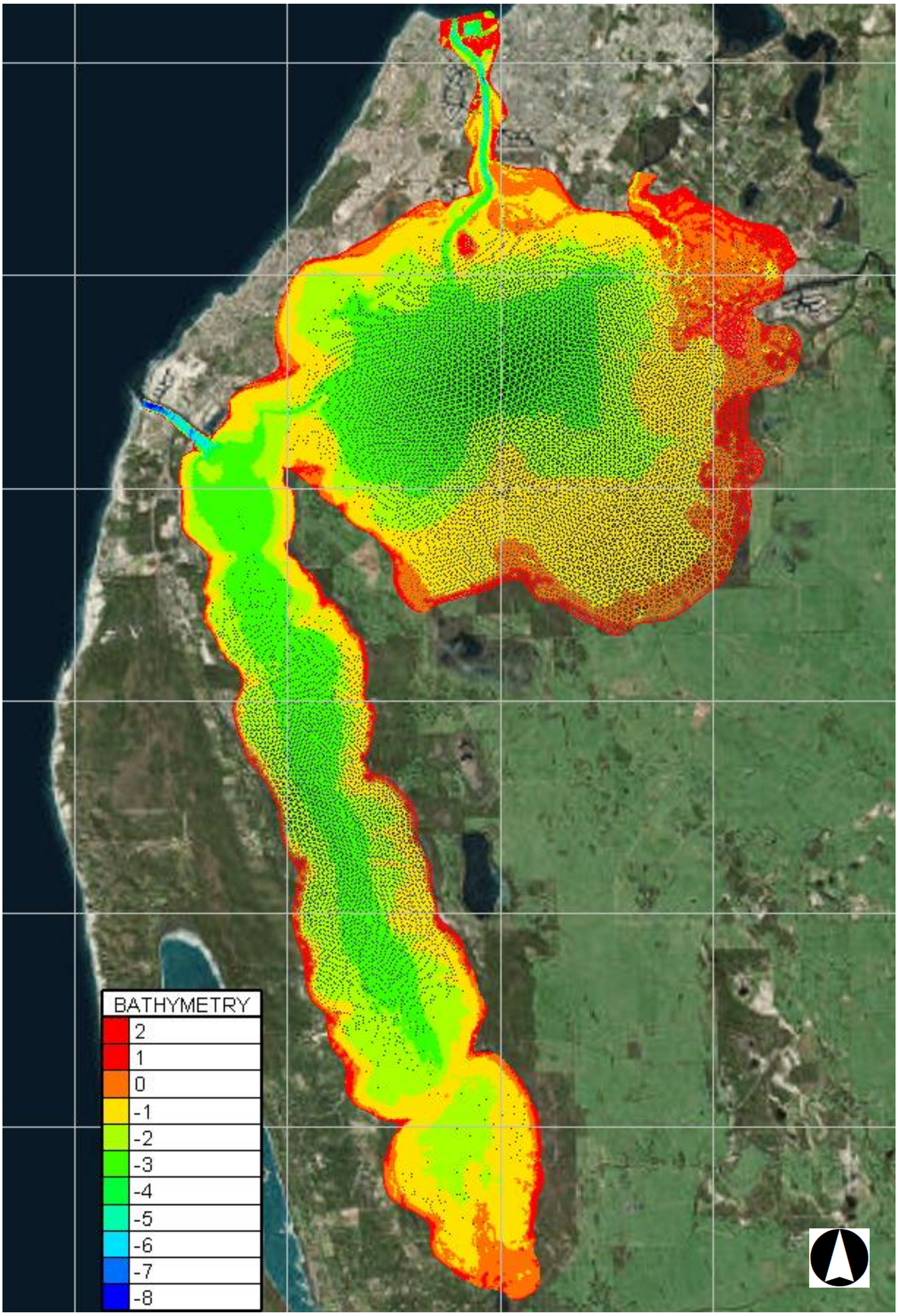

Figure 2-1: Model mesh and bathymetry

2.3 Model setup

2.3.1 Bathymetry

Model bathymetry was obtained from a 20m resolution point-cloud containing X,Y,Z data, supplied by the client. This was integrated into the model by sampling the depth at the mesh node locations.

2.3.2 Water level

A constant water level was applied throughout the domain.

2.3.3 Calibration

No observed wave parameters were available within the estuary for use in calibration. As a result, no formal calibration wave undertaken against observed data, and default model parameters were adopted for wave growth and bottom friction schemes (JONSWAP and Komen, respectively).

2.3.4 Convergence

Testing of the default parameters under a range of wind conditions was undertaken, with the model shown to converge to 99 or 99.5%. This was deemed acceptable for the model purpose.

2.3.5 Model sensitivity

The sensitivity of the model to different model parameters was tested at a location in the middle of the Harvey estuary at -2.27mAHD (374422E , 6386530S MGA zone 50, SWAN Node 13564). A constant water level, wind speed and direction were applied across the domain, and a range of physics and bottom friction terms altered. The resulting change in wave conditions are presented in Table 2-1.

Table 2-1: Model sensitivity to bottom friction and physics parameters

Physics	Bottom Friction	Hs (m)	Tp (sec)	Peak Direction
***JONSWAP**	***Komen et al.**	0.71	2.63	355
Janssen	*Komen et al.*	0.83	2.62	005
Westhuysen	*Komen et al.*	0.77	2.59	355
JONSWAP	*Collins*	0.72	2.65	355
JONSWAP	*Madsen et al.*	0.54	2.16	355
* Default				

2.4 Model simulations

The wave model was run for 224 iterations of wind and water level. The Mean Sea Level MSL (-0.17mAHD) was used for 144 simulations, with an additional 40 simulations under a high water level (+0.13m) and low water level (-0.47m) condition. The forcing conditions for these runs are displayed in Table 2-2 to Table 2-3.

Output wave conditions have been produced at of 964 locations situated around the shoreline of the estuary. These locations were all situated at approximately -1mAHD contour.

Outputs were supplied as 964 CSV datasheets, listing the toe number, output coordinates, input conditions, and estimated wave conditions.

Table 2-2: Modelled wind speeds and directions for Mean Sea Level simulations

Direction (Deg/N)	Windspeed (Km/hr)									
	10% of year	*3.0% of year*	*1.0% of year*	*0.3% of year*	*0.1% of year*	*1-yr ARI*	*3-yr ARI*	*10-yr ARI*	*30-yr ARI*	*100-yr ARI*
000.0			37.5	45.0	51.0	56.0	60.3	64.0	67.4	70.3
022.5		24.7	33.7	40.5	45.9	50.4	54.3	57.6	60.6	63.3
045.0		20.4	27.9	33.5	38.0	41.7	44.9	47.7	50.2	52.4
067.5		17.3	23.7	28.4	32.2	35.4	38.1	40.4	42.5	44.4
090.0		16.0	21.9	26.3	29.8	32.7	35.2	37.4	39.3	41.1
112.5		16.4	22.4	26.8	30.4	33.4	36.0	38.2	40.2	42.0
135.0	7.6	17.1	23.4	28.1	31.9	35.0	37.7	40.0	42.1	44.0
157.5	8.1	18.3	25.0	30.0	34.0	37.4	40.2	42.7	44.9	46.9
180.0		19.3	26.4	31.7	35.9	39.4	42.5	45.1	47.4	49.5
202.5		20.8	28.5	34.2	38.7	42.5	45.8	48.6	51.1	53.4
225.0		22.0	30.1	36.1	41.0	45.0	48.4	51.4	54.1	56.5
247.5		24.7	33.7	40.5	45.9	50.4	54.2	57.6	60.6	63.3
270.0		28.3	38.7	46.5	52.7	57.9	62.3	66.2	69.6	72.7
292.5		29.4	40.2	48.3	54.7	60.1	64.7	68.7	72.3	75.5
315.0		30.4	41.5	49.9	56.5	62.1	66.8	71.0	74.6	78.0
337.5			40.0	48.0	54.4	59.8	64.3	68.3	71.9	75.1

Table 2-3: Modelled wind speeds and directions for high and low sea level simulations (+/- 0.3m)

Direction (Deg/N)	Windspeed (Km/hr)				
	1.0% of year	*0.1% of year*	*1-yr ARI*	*10-yr ARI*	*100-yr ARI*
000.0	37.48	51.00	55.99	64.02	70.34
045.0	27.94	38.02	41.74	47.73	52.44
067.5	23.66	32.20	35.36	40.43	44.42
090.0	21.88	29.78	32.70	37.38	41.08
112.5	22.35	30.41	33.39	38.18	41.95
135.0	23.42	31.87	35.00	40.01	43.96
157.5	25.00	34.01	37.35	42.70	46.92
180.0	26.39	35.91	39.43	45.08	49.53

3 Summary

A wave model was developed for the Peel-Harvey Estuary to estimate nearshore wave conditions along the shoreline for a range of wind speed, wind direction and water level scenarios.

Output wave conditions have been produced at of 964 locations situated around the shoreline of the estuary. These locations were all situated at approximately -1mAHD contour.

A Appendix A: SWAN output samples

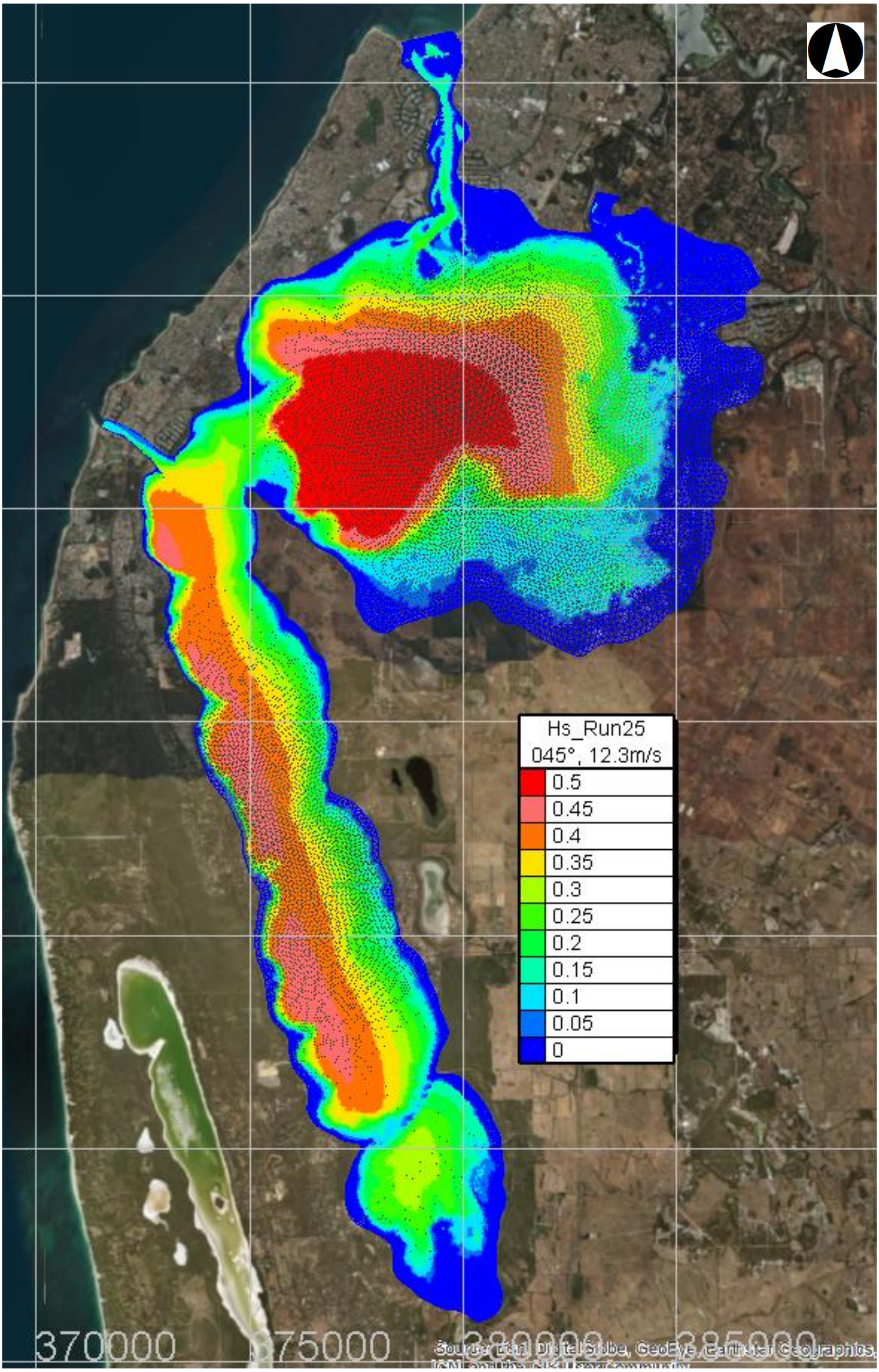

Figure A-1: Significant Wave Height for run 25 using a 12 m/s wind from 045º

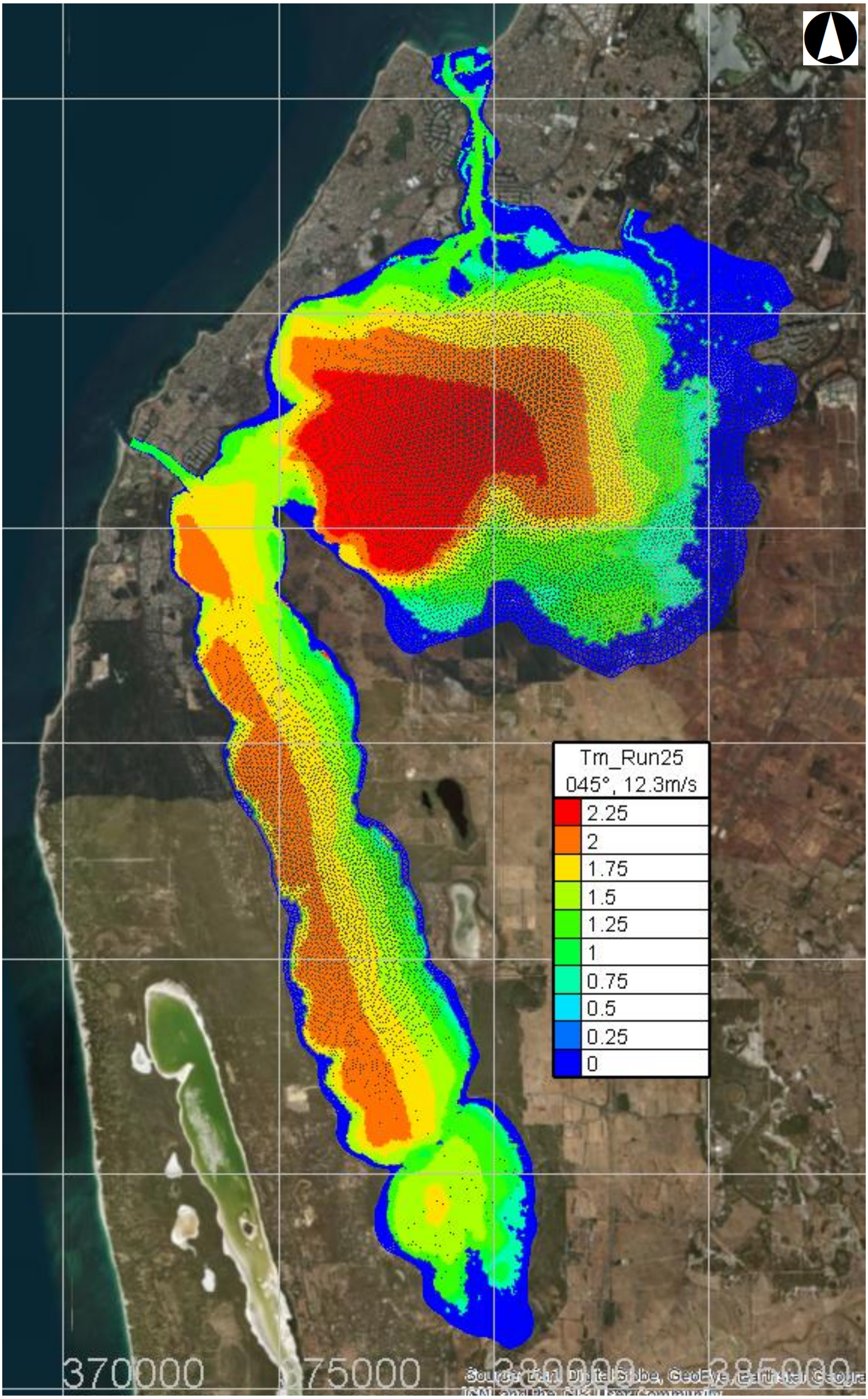

Figure A-2: Mean wave period for run 25 using a 12 m/s wind from 045º

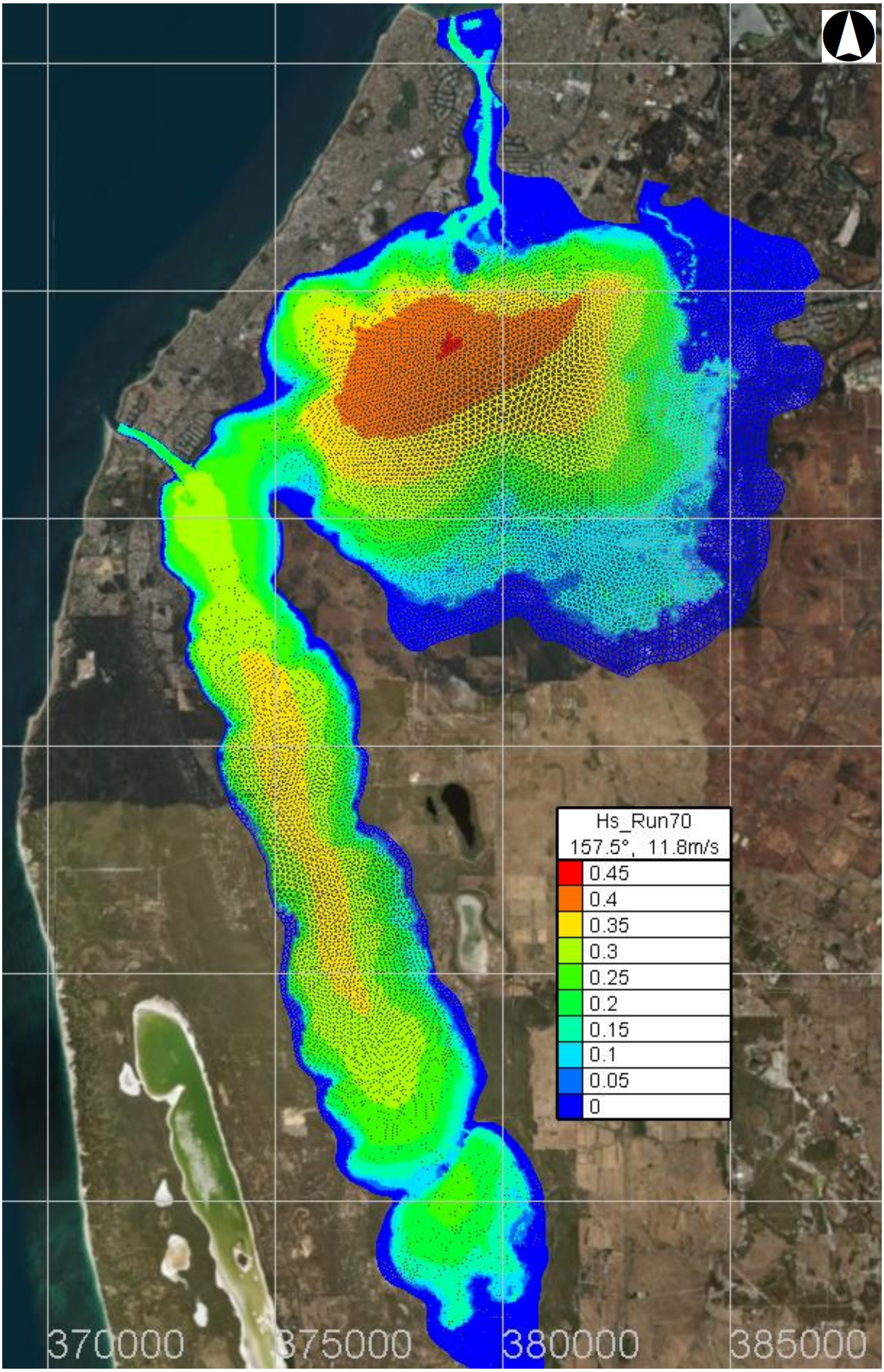

Figure A-3: Significant Wave Height for run 70 using a 11.8 m/s wind from 157.5º

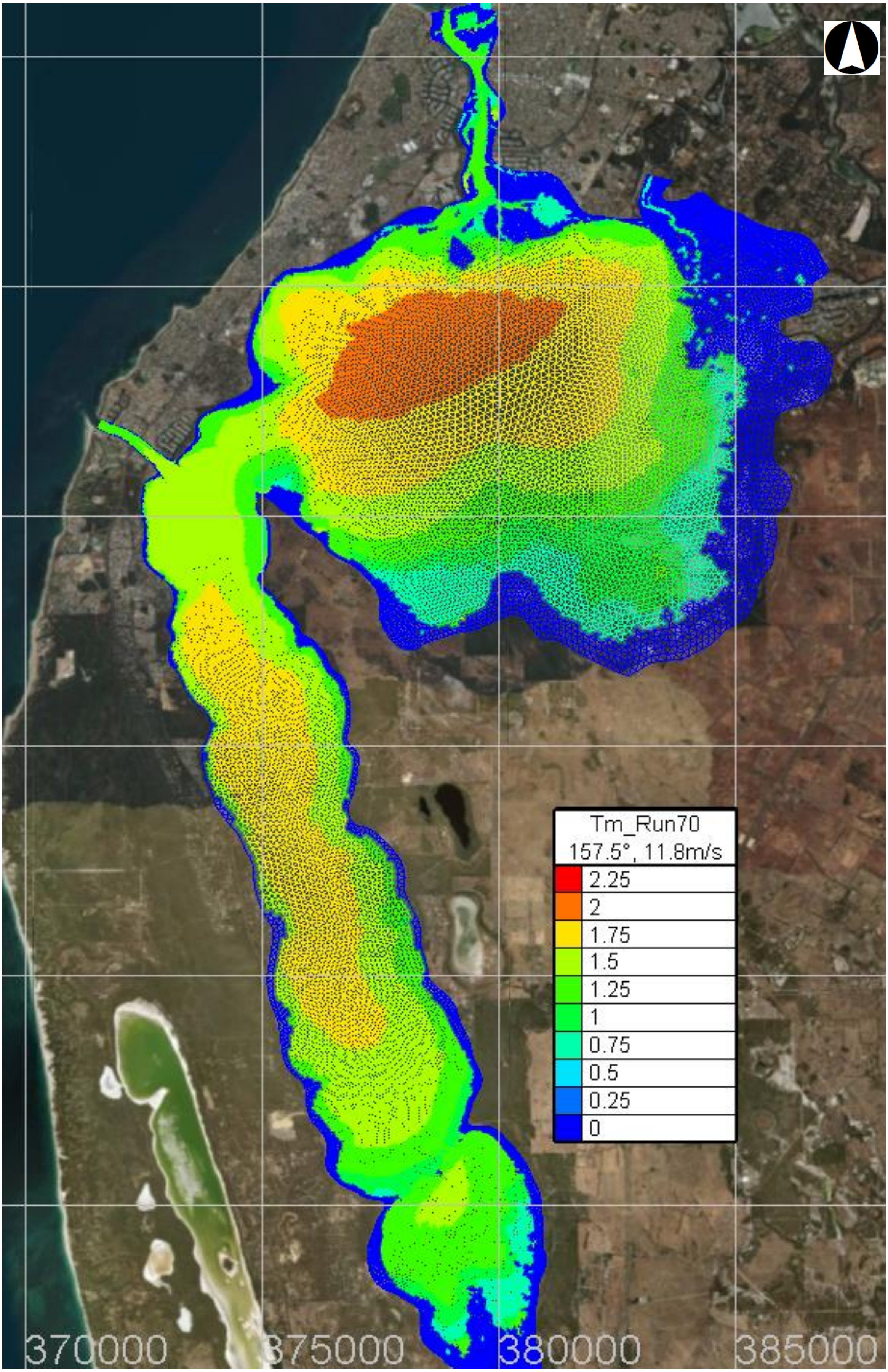

Figure A-4:: Mean Wave period for run 70 using a 11.8 m/s wind from 157.5º

B Appendix B: Sample output data

RunID	SWAN Node	Output Node	X	Y	Hs	Tm	PkDir	Dir	Wave length	Bottom Level	dHS	WL	Wdir	WSpeed_m/s
1	6737	16	378999	6377094	0.30	1.94	305	311	2.85	1.17	0.00	-0.17	0	12.5
2	6737	16	378999	6377094	0.33	2.03	295	308	3.05	1.17	0.00	-0.17	0	14.2
3	6737	16	378999	6377094	0.35	2.09	295	307	3.12	1.17	0.00	-0.17	0	15.6
4	6737	16	378999	6377094	0.36	2.12	295	306	3.16	1.17	0.00	-0.17	0	16.7
5	6737	16	378999	6377094	0.36	2.14	295	306	3.15	1.17	0.00	-0.17	0	17.8
6	6737	16	378999	6377094	0.37	2.15	295	306	3.14	1.17	0.00	-0.17	0	18.7
7	6737	16	378999	6377094	0.37	2.15	295	307	3.15	1.17	0.00	-0.17	0	19.5
8	6737	16	378999	6377094	0.14	1.36	315	330	1.52	1.17	0.00	-0.17	23	6.9
9	6737	16	378999	6377094	0.20	1.54	315	332	1.87	1.17	0.00	-0.17	23	9.4
10	6737	16	378999	6377094	0.23	1.67	315	329	2.16	1.17	0.00	-0.17	23	11.3
11	6737	16	378999	6377094	0.26	1.76	315	328	2.35	1.17	0.00	-0.17	23	12.8
12	6737	16	378999	6377094	0.28	1.83	305	326	2.53	1.17	0.00	-0.17	23	14.0
13	6737	16	378999	6377094	0.30	1.88	305	324	2.61	1.17	0.00	-0.17	23	15.1
14	6737	16	378999	6377094	0.31	1.93	305	323	2.74	1.17	0.00	-0.17	23	16.0
15	6737	16	378999	6377094	0.32	1.96	305	322	2.79	1.17	0.00	-0.17	23	16.8
16	6737	16	378999	6377094	0.33	1.98	305	321	2.79	1.17	0.00	-0.17	23	17.6
17	6737	16	378999	6377094	0.07	1.13	315	324	1.06	1.17	0.00	-0.17	45	5.7
18	6737	16	378999	6377094	0.12	1.25	325	342	1.27	1.17	0.00	-0.17	45	7.8
19	6737	16	378999	6377094	0.16	1.34	335	349	1.47	1.17	0.00	-0.17	45	9.3
20	6737	16	378999	6377094	0.18	1.42	335	352	1.68	1.17	0.00	-0.17	45	10.6
21	6737	16	378999	6377094	0.20	1.47	335	352	1.76	1.17	0.00	-0.17	45	11.6
22	6737	16	378999	6377094	0.21	1.50	335	352	1.80	1.17	0.00	-0.17	45	12.5

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Appendix I – Extreme Storm Flooding Assessment

Working Note

Project/Proposal Number :	13064.101	**Date**	7 October 2020
Staff Member :	RLW		
Title :	Shire of Murray Design Storm Summary		
Summary / Description :	Overview of the modelling carried out to define a water level under design storm conditions at Mandurah, WA, for defining a design storm water level within the Peel-Harvey Estuary		
File Reference :	13064.101.W.RLW.RevA_ShireofMurrayDesignStormSummary		

Model Setup

Baird's established and validated numerical model of the West Australian coast, developed and validated for a recent inundation study for the Shire of Gingin, has been utilised for modelling of the design storm water level outside of the Peel-Harvey Estuary. The Delft-FM model extent covers the entire west coast of Western Australia from Northwest Cape to Cape Leeuwin as shown in Figure 1. There is varying model resolution, highest along the coastline areas, with Figure 2 showing resolution and observation points used in the modelling outside of the Peel-Harvey Estuary.

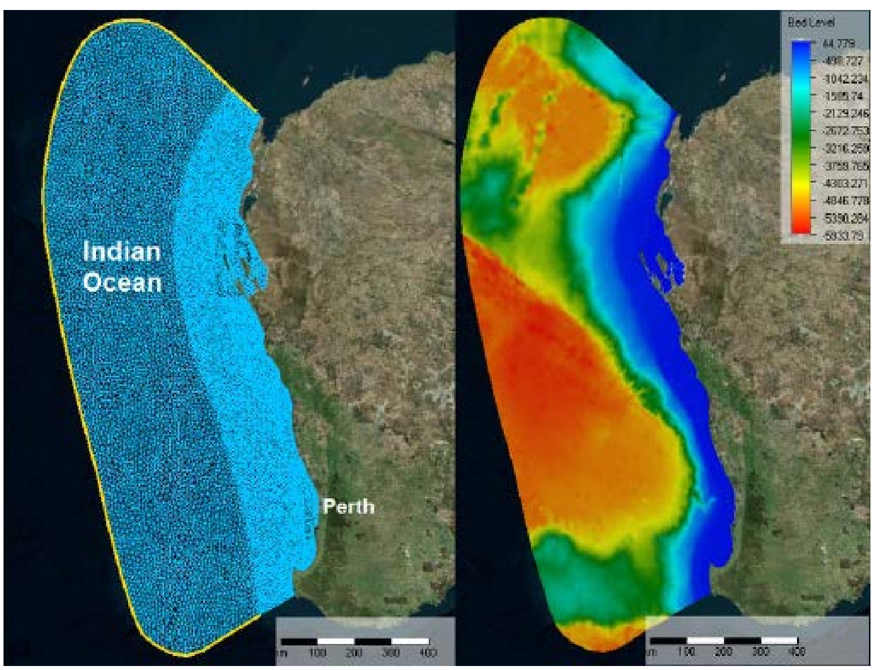

Figure 1: Model resolution and bathymetry

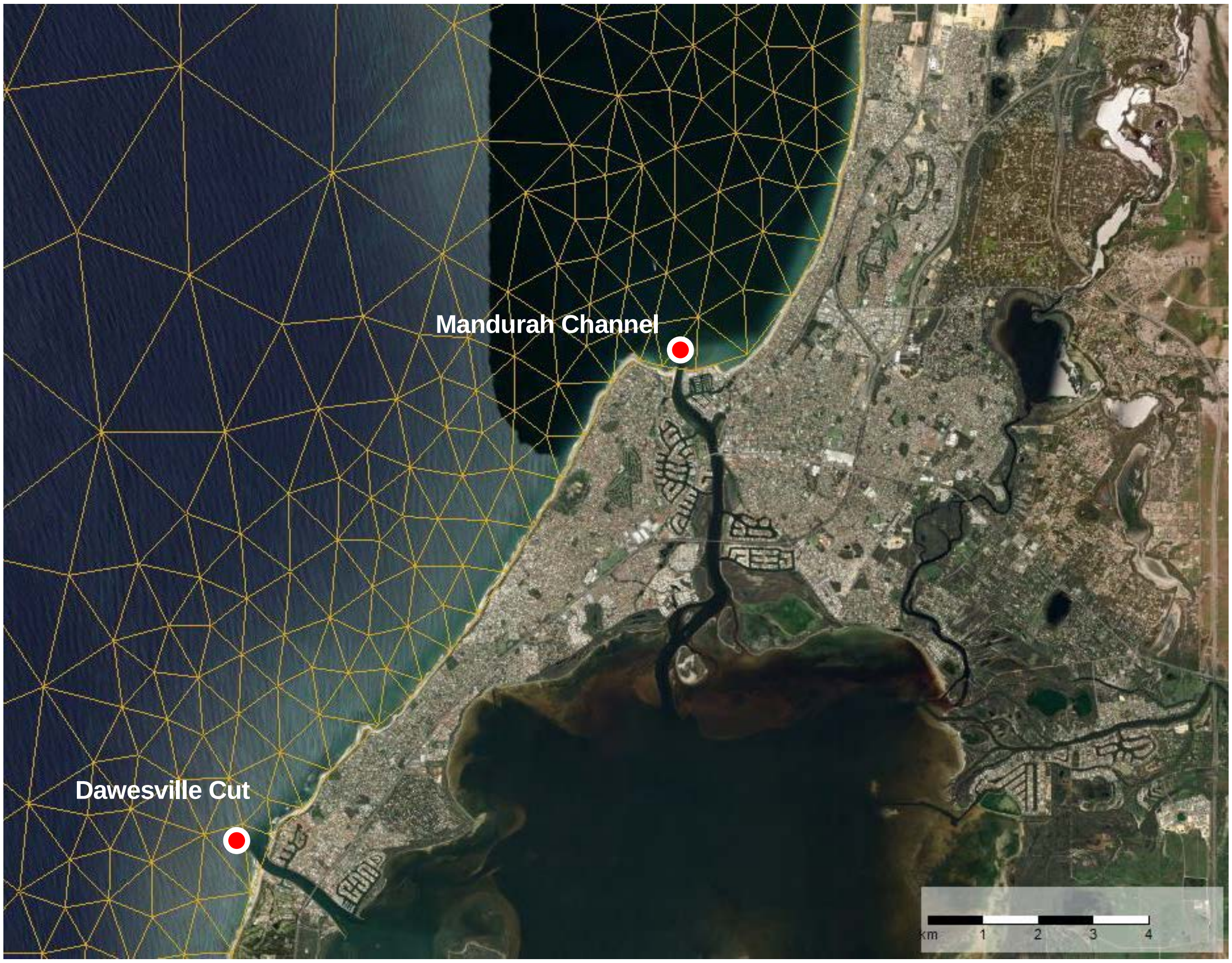

Figure 2: Model resolution outside of the Peel-Harvey Estuary, with observation points used in the modelling

Wave Model

The wave model adopted for the simulation of wave conditions in this assessment is the industry standard SWAN wave model (Simulating Waves Near Shore) developed at Delft University of Technology in the Netherlands. SWAN is a third-generation spectral wave model which computes wave propagation, wave generation by wind, non-linear wave-wave interactions and dissipation, for a given bottom topography, wind field, water level and current field (Deltares 2019).

The SWAN model accounts for (refractive) propagation due to current and depth and represents the processes of wave generation by wind, dissipation due to whitecapping, bottom friction and depth-induced wave breaking and non-linear wave-wave interactions (both quadruplets and triads) explicitly with state-of-the-art formulations. Wave blocking by currents is also explicitly represented in the model (Deltares 2019).

For the Gingin study, a coupled SWAN model was established across the same extent as the hydrodynamic model, comprised of five nested grids which increase in resolution approaching the Gingin Study area at 5km, 1km, 500m, 100m and 50m resolutions. For this study, the outer grid, covering the coast down to Mandurah, has been used to model the waves (Figure 3). It should be noted that this outer grid resolution is low to accurately estimate wave setup. In line with this, it is likely that the wave setup is being overestimated by the model as the wave model resolution is too low to define the breaking zone in detail. This model limitation should be taken into consideration when assessing model results.

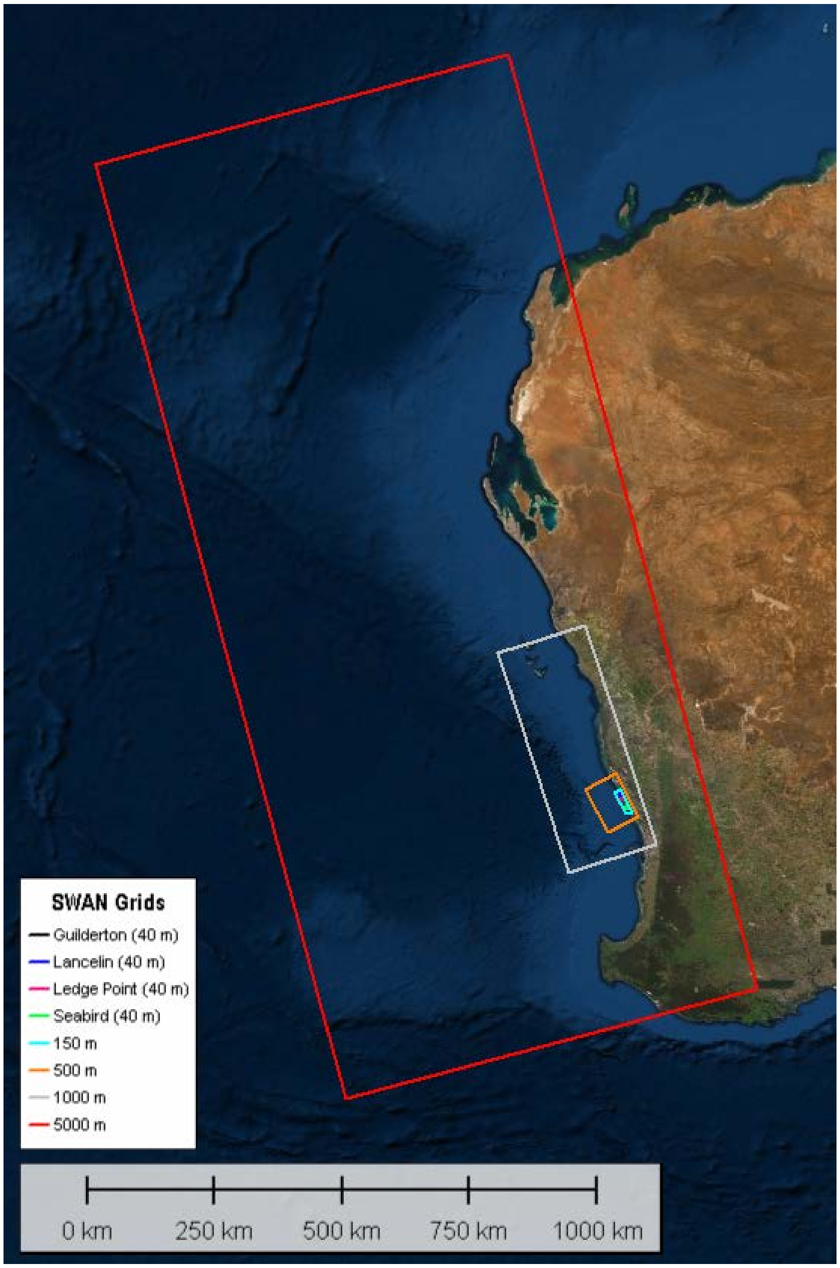

Figure 3: SWAN Model Grid extending across entire D-FM Model Domain (5000m grid size)

Wind Model

The wind model adopted in this study is Baird's Cycwind model system that adopts a Holland (2010) spatial cyclone vortex model. The cyclone wind field has adopted track parameters from the BoM's best track database (BoM, 2019) with adjustment of the Radius to Gales (R34) and Radius to Outer Closed Isobar (ROCI) parameters to better describe the windfield along the coastal waters of southwestern WA as the system track south. The design cyclone tracks for the Peel study area presented in Seashore Engineering (2020) are based on the TC Ned track and the TC Alby Track. Further information on the cyclone wind field model including validation for historical events is presented in Baird (2020b).

Maximum winds experienced for the Peel region during the passage of the design cyclones are detailed in Table 1.

Table 1: Maximum wind speeds across the Peel Region during passage of Seashore Engineering Design Cyclones

Design Cyclone	Peel Region Maximum Wind Speed (m/s)
TC Alby	39.5
TC Ned	43

Design Storms

Design storms based on Tropical Cyclone Ned (Figure 4) and Tropical Cyclone Alby (Figure 5) are presented below, including the central pressure associated with the cyclone track. Table 2 and Table 3 tabulate the central pressure and radius to maximum winds associated with each design storm.

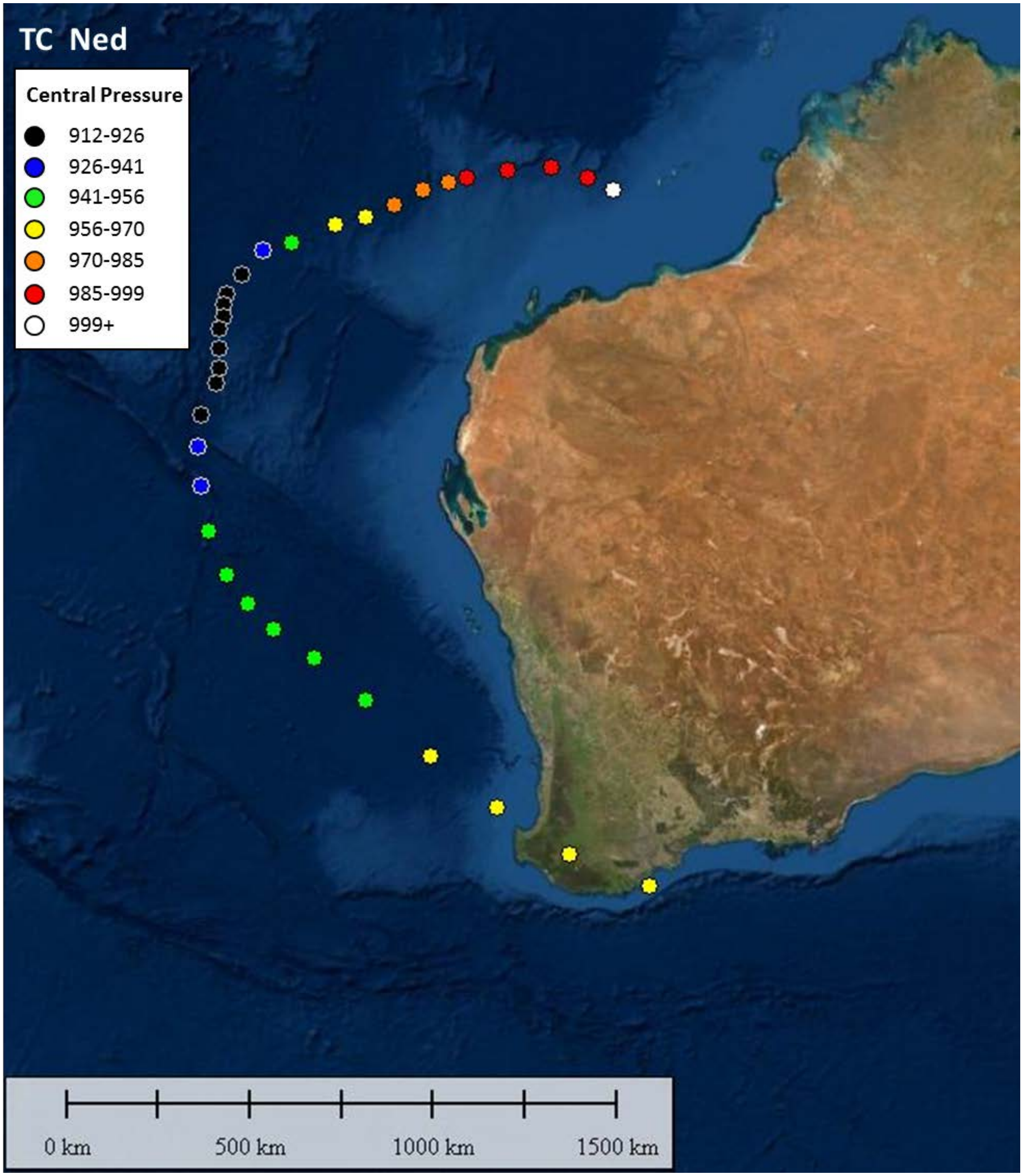

Figure 4: Path of Design Storm for Peel, based on Tropical Cyclone Ned, showing a scale of central pressure

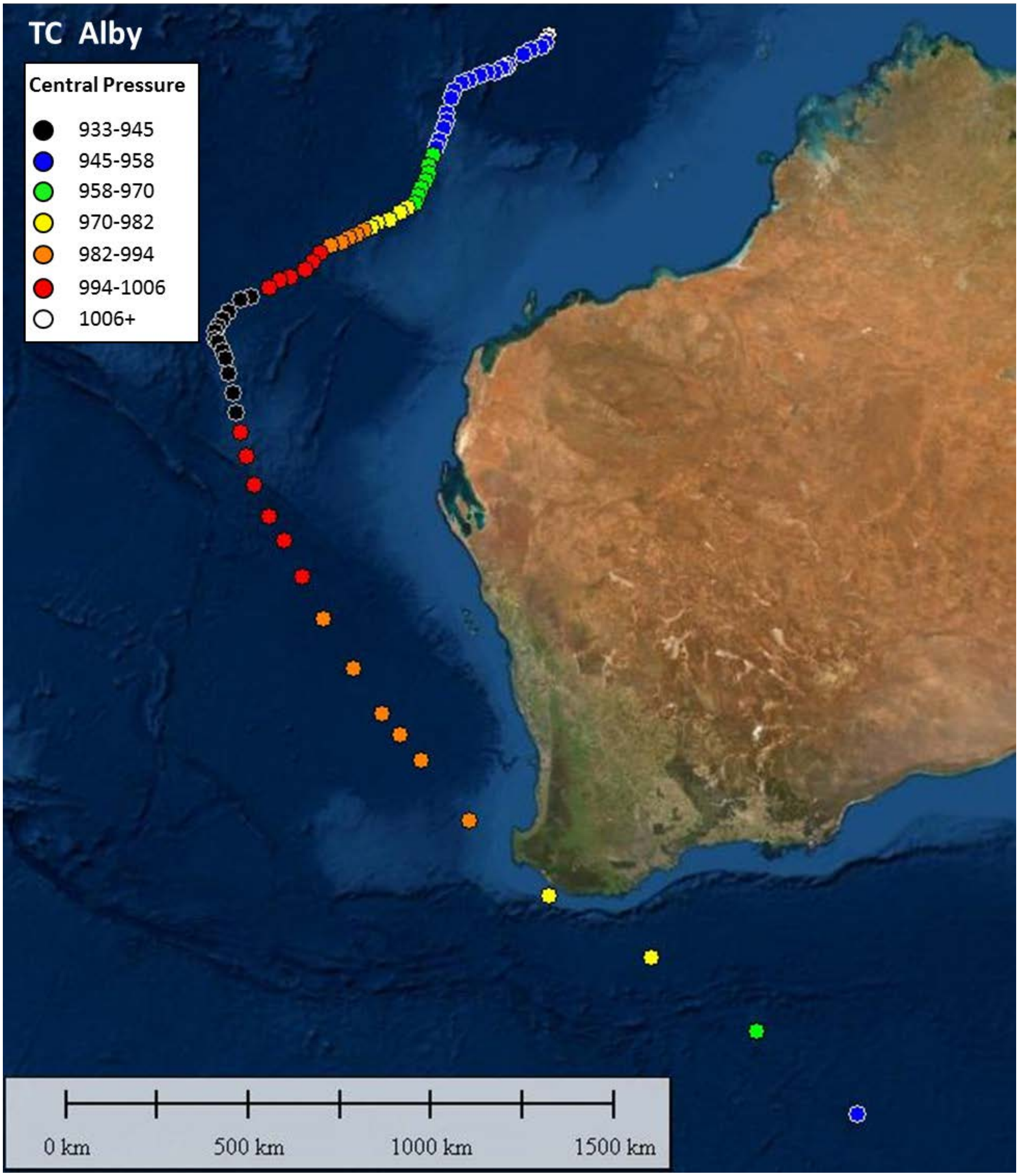

Figure 5: Path of Design Storm for Peel, based on Tropical Cyclone Ned, showing a scale of central pressure

Table 2: Central Pressure and Radius to Maximum Winds for the Design Storm for Peel Based on TC Alby

Date / Time	Long	Lat	CP	Rmax
27/03/1978 1:00	116.0	13.6	1006.3	54
27/03/1978 4:00	115.9	13.7	1006.3	54
27/03/1978 7:00	115.9	13.8	1005.4	54
27/03/1978 10:00	115.8	13.9	1005.4	54
27/03/1978 13:00	115.5	14.0	1004.4	54
27/03/1978 16:00	115.3	14.1	1004.4	54
27/03/1978 19:00	114.9	14.4	1004.4	54
27/03/1978 22:00	114.8	14.5	1003.5	54
28/03/1978 1:00	114.7	14.5	1002.5	54
28/03/1978 4:00	114.5	14.6	1001.5	54
28/03/1978 7:00	114.3	14.6	1000.6	54
28/03/1978 10:00	114.1	14.7	998.7	54
28/03/1978 13:00	113.8	14.8	998.7	54
28/03/1978 16:00	113.6	14.9	998.7	54
28/03/1978 19:00	113.4	15.1	997.7	54
28/03/1978 22:00	113.3	15.3	997.7	54
29/03/1978 1:00	113.2	15.7	997.7	54
29/03/1978 4:00	113.2	15.9	996.8	54
29/03/1978 7:00	113.1	16.1	995.8	54
29/03/1978 10:00	113.0	16.4	995.8	54
29/03/1978 13:00	112.9	16.6	994.9	54
29/03/1978 16:00	112.8	16.8	993.9	54
29/03/1978 19:00	112.7	17.1	993.0	54
29/03/1978 22:00	112.7	17.3	992.0	54
30/03/1978 1:00	112.6	17.5	991.0	54
30/03/1978 4:00	112.5	17.7	988.2	54
30/03/1978 7:00	112.4	17.9	985.3	54
30/03/1978 10:00	112.3	18.1	983.4	54
30/03/1978 13:00	112.1	18.2	981.5	54
30/03/1978 16:00	111.9	18.3	978.6	54
30/03/1978 19:00	111.6	18.5	975.8	54
30/03/1978 22:00	111.3	18.6	973.9	54
31/03/1978 1:00	111.1	18.7	972.0	54
31/03/1978 4:00	110.9	18.8	969.1	54
31/03/1978 7:00	110.7	18.9	967.2	54
31/03/1978 10:00	110.5	19.0	964.3	54
31/03/1978 13:00	110.3	19.1	962.4	54

31/03/1978 16:00	110.0	19.2	959.5	54
31/03/1978 19:00	109.7	19.4	957.6	54
31/03/1978 22:00	109.5	19.6	954.8	54
1/04/1978 1:00	109.3	19.8	952.9	54
1/04/1978 4:00	108.9	20.0	950.0	54
1/04/1978 7:00	108.6	20.1	948.1	54
1/04/1978 10:00	108.3	20.3	946.2	54
1/04/1978 13:00	107.8	20.5	943.3	54
1/04/1978 16:00	107.5	20.6	940.5	54
1/04/1978 19:00	107.2	20.9	937.6	54
1/04/1978 22:00	107.0	21.1	935.7	54
2/04/1978 1:00	106.9	21.3	933.8	54
2/04/1978 4:00	106.8	21.4	934.7	54
2/04/1978 7:00	106.8	21.6	935.7	54
2/04/1978 10:00	106.9	21.7	936.6	54
2/04/1978 13:00	107.0	21.9	938.5	54
2/04/1978 16:00	107.1	22.1	939.5	54
2/04/1978 19:00	107.2	22.5	940.5	54
2/04/1978 22:00	107.3	23.0	941.4	54
3/04/1978 1:00	107.4	23.5	943.3	54
3/04/1978 4:00	107.5	24.0	945.2	54
3/04/1978 7:00	107.7	24.6	947.1	54
3/04/1978 10:00	107.9	25.3	950.0	55
3/04/1978 13:00	108.3	26.1	952.9	65
3/04/1978 16:00	108.7	26.7	954.8	75
3/04/1978 19:00	109.2	27.6	957.6	85
3/04/1978 22:00	109.8	28.6	959.5	100
4/04/1978 1:00	110.6	29.8	962.4	120
4/04/1978 4:00	111.4	30.9	964.3	160
4/04/1978 6:00	111.9	31.4	965.3	190
4/04/1978 7:00	112.5	32.0	967.2	220
4/04/1978 10:00	113.8	33.4	969.1	240
4/04/1978 13:00	116.0	35.1	972.0	280
4/04/1978 16:00	118.8	36.5	979.6	360
4/04/1978 19:00	121.7	38.1	990.1	360
4/04/1978 22:00	124.5	39.9	1000.6	360

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Table 3: Central Pressure and Radius to Maximum Winds for the Design Storm for Peel Based on TC Ned

Date / Time	Long	Lat	CP	Rmax
25/03/1989 6:00	117.7	17.8	999.0	54
25/03/1989 12:00	117.0	17.5	996.2	54
25/03/1989 18:00	116.0	17.2	993.4	54
26/03/1989 0:00	114.8	17.3	990.6	54
26/03/1989 6:00	113.7	17.5	987.8	54
26/03/1989 12:00	113.2	17.6	983.6	54
26/03/1989 18:00	112.5	17.8	979.4	54
27/03/1989 0:00	111.7	18.2	975.2	54
27/03/1989 6:00	110.9	18.5	969.6	54
27/03/1989 12:00	110.1	18.7	962.6	54
27/03/1989 18:00	108.9	19.2	948.6	54
28/03/1989 0:00	108.1	19.4	930.4	54
28/03/1989 6:00	107.5	20.0	922.0	54
28/03/1989 12:00	107.1	20.5	917.8	54
28/03/1989 18:00	107.0	20.8	913.6	54
29/03/1989 0:00	107.0	21.1	912.2	54
29/03/1989 6:00	106.9	21.4	915.0	54
29/03/1989 12:00	106.9	21.9	920.6	54
29/03/1989 18:00	106.9	22.4	922.0	54
30/03/1989 0:00	106.8	22.8	922.0	54
30/03/1989 6:00	106.4	23.6	926.2	54
30/03/1989 12:00	106.3	24.4	931.8	61
30/03/1989 18:00	106.4	25.4	936.0	68
31/03/1989 0:00	106.6	26.5	943.0	75
31/03/1989 6:00	107.1	27.6	947.2	90
31/03/1989 9:00	107.7	28.3	947.2	100
31/03/1989 12:00	108.4	28.9	950.0	110
31/03/1989 15:00	109.5	29.6	954.2	120
31/03/1989 18:00	110.9	30.6	954.2	140
31/03/1989 21:00	112.7	31.9	961.2	180
1/04/1989 0:00	114.5	33.1	961.2	230
1/04/1989 3:00	116.5	34.2	964.0	250
1/04/1989 6:00	118.7	34.9	968.2	270

Model Validation

The hydrodynamic model has been validated against predicted water levels at key locations in southwest WA as reported in Baird Australia (2020a and 2020b). The model validation is shown in Figure 6 and Figure 7and and shows excellent agreement with time series and validation statistics for modelled and predicted tides from the model at Hillary's, Jurien Bay, Lancelin and Two Rocks Marina. The validation metrics are excellent with little bias and RMS error of about 0.01-0.02 m between Fremantle and Bunbury. The model validation provides confidence the hydrodynamic model can be applied as a basis for the study in the phases to follow. Model validation for storm surge is presented in Baird (2020a and 2020b).

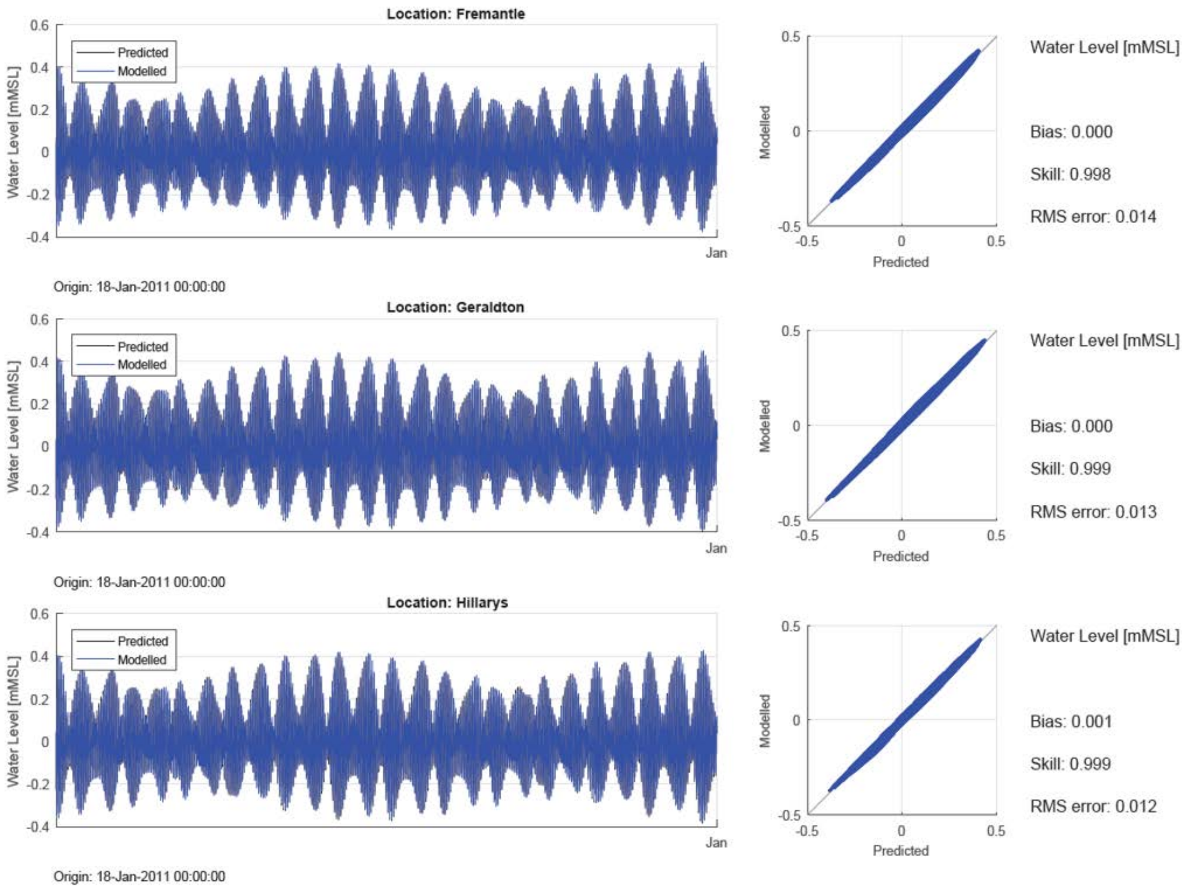


Figure 6: Time series comparisons of predicted (black), and simulated (blue) water levels for Fremantle, Geraldton, and Hillarys in 2011

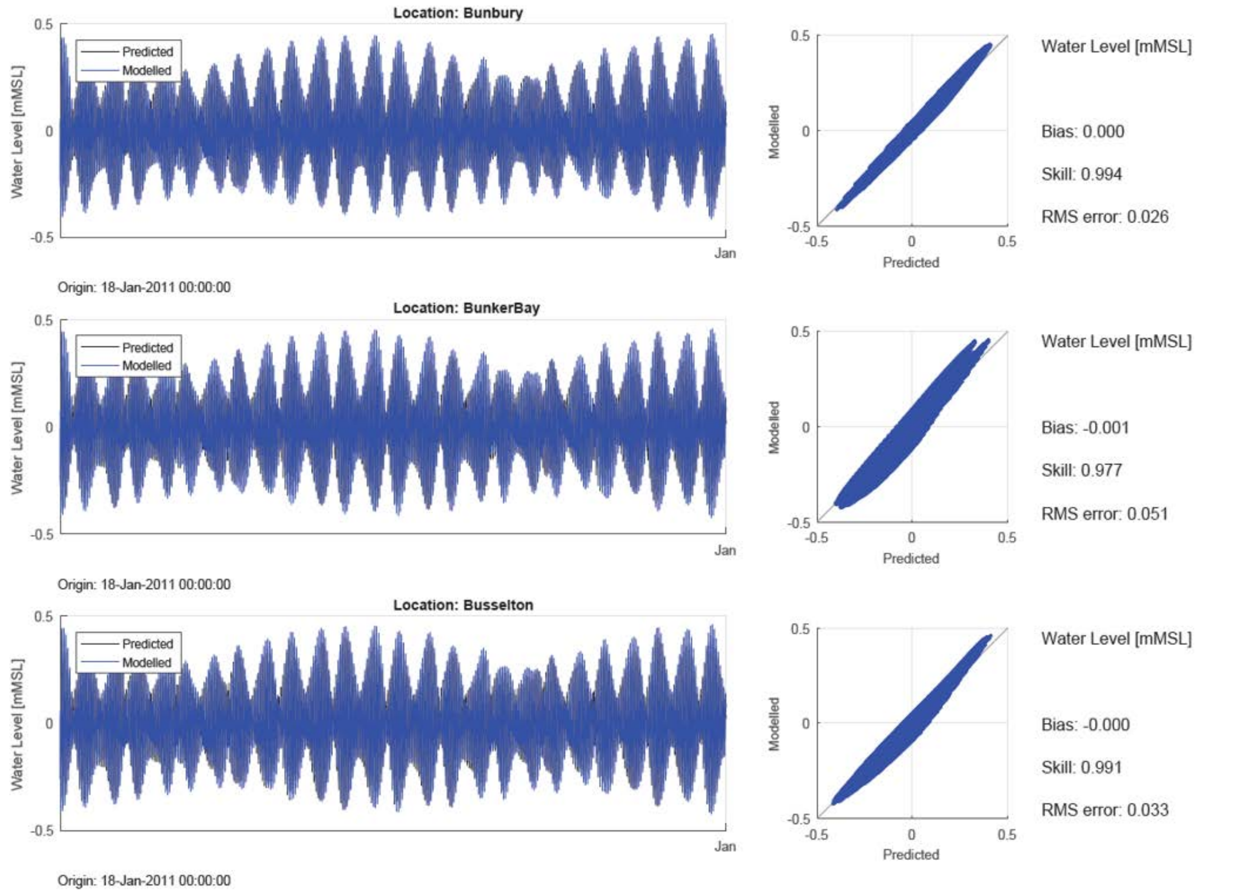


Figure 7: Time series comparisons of predicted (black), and simulated (blue) water levels for Bunbury, Bunker Bay, and Busselton in 2011.

Model Results

Model results were taken from just outside of Mandurah Channel and just outside of the Dawesville Cut, as seen in Figure 2. Results are presented from Figure 8 Figure 11, with the top panel showing the influence on water levels due to changes to water level (tide) only, as well as due to changes in wave conditions and the bottom panel showing the associated significant wave height.

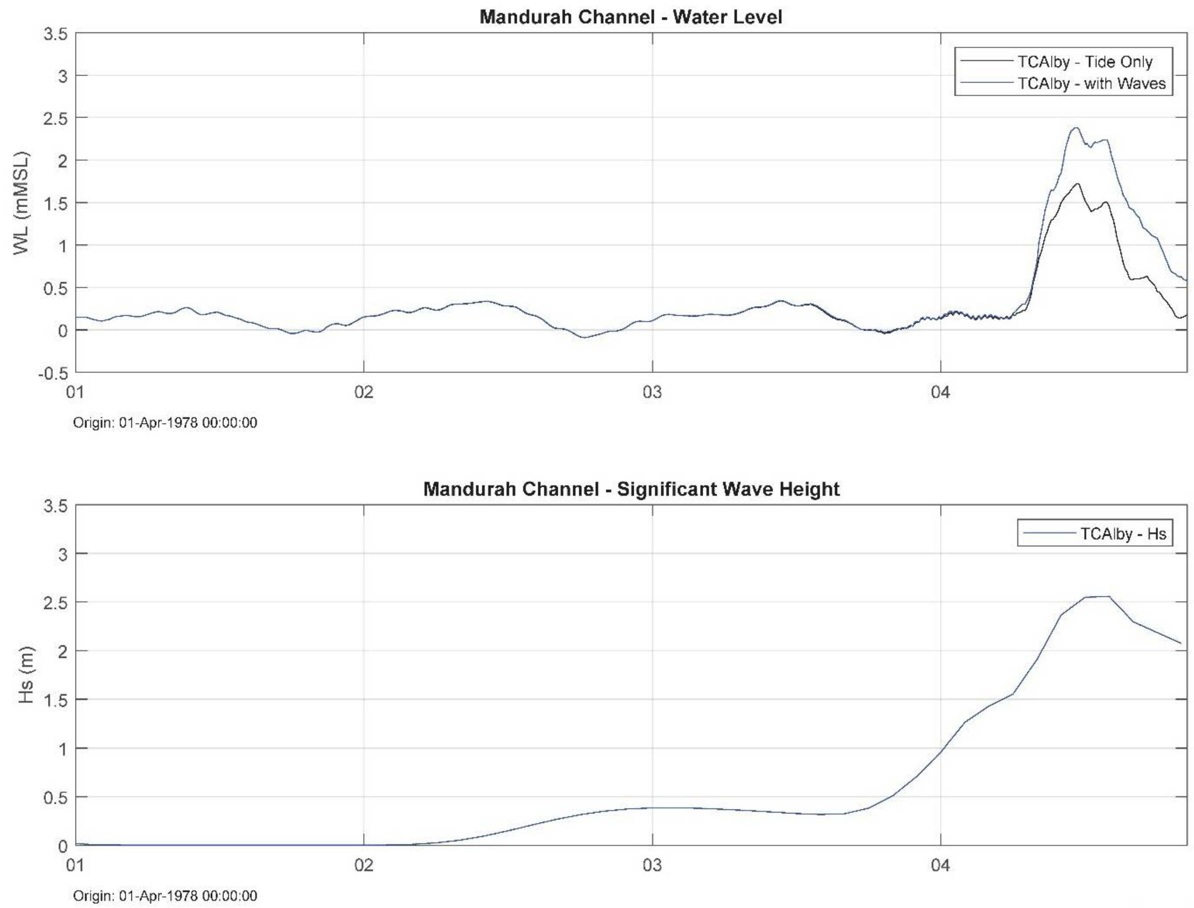


Figure 8: Water level and significant wave height modelled offshore of Mandurah Channel during a design storm based on Tropical Cyclone Alby

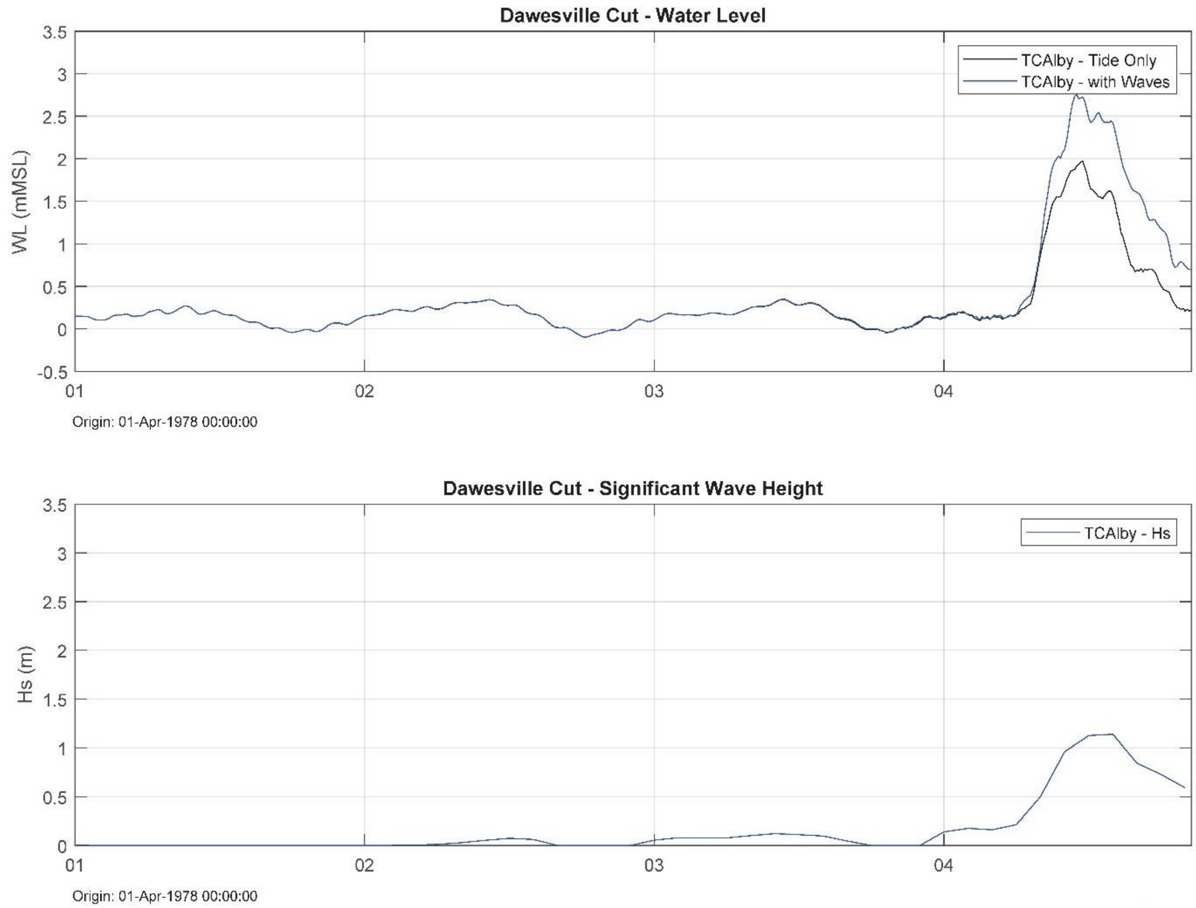


Figure 9: Water level and significant wave height modelled offshore of Dawesville Cut during a design storm based on Tropical Cyclone Alby

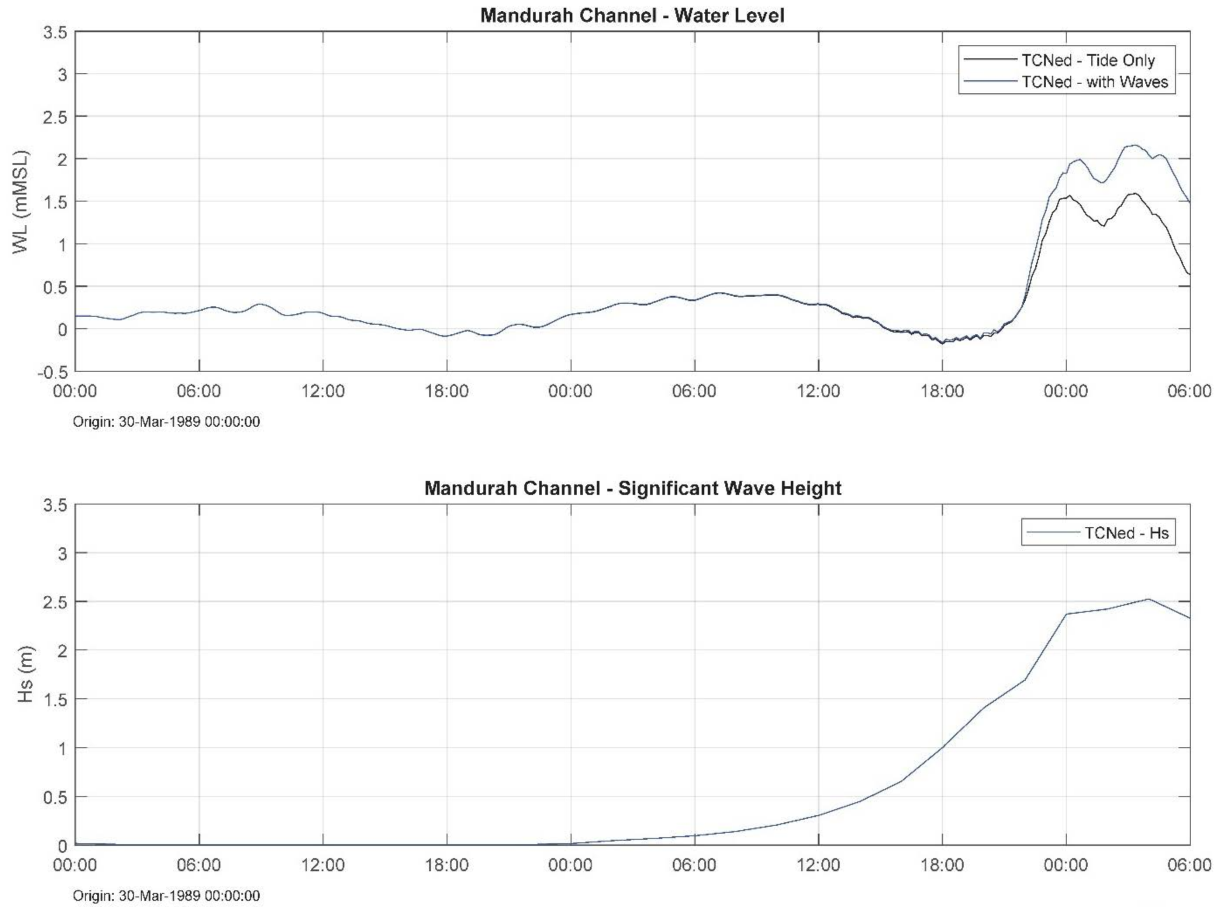
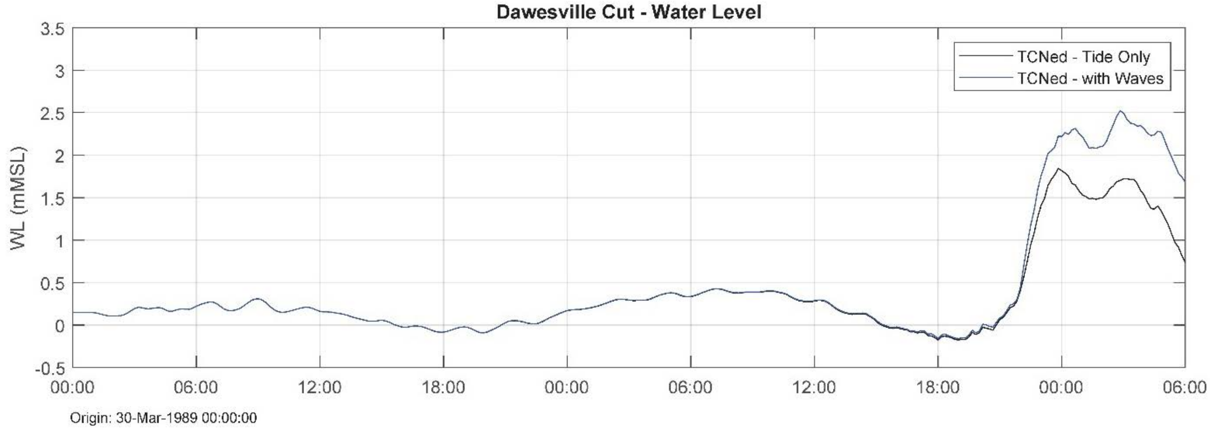


Figure 10: Water level and significant wave height modelled offshore of Mandurah Channel during a design storm based on Tropical Cyclone Ned



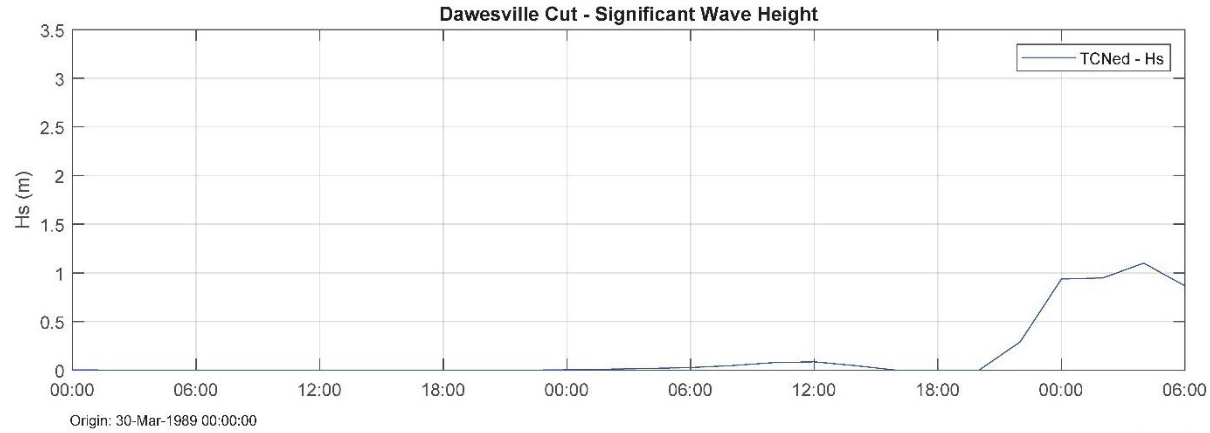


Figure 11: Water level and significant wave height modelled offshore of Dawesville Cut during a design storm based on Tropical Cyclone Ned

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C.2 Coastal Processes Allowance. Erosion Allowance for Peel-Harvey Shorelines

Shire of Murray
Coastal Hazard Flood Mapping

Coastal Processes Allowances
(Erosion Setback)

Horizontal Setback Datum

Setbacks

- 2020
- 2030
- 2050
- 2070
- 2120

This map has been prepared by Baird Australia on behalf of the Shire of Murray as part of the Shire of Murray Coastal Hazard Risk Management and Adaptation Planning Project. The coastal setbacks have been adopted from the Coastal Hazard assessment completed for the Shire of Murray by Seashore (2021).

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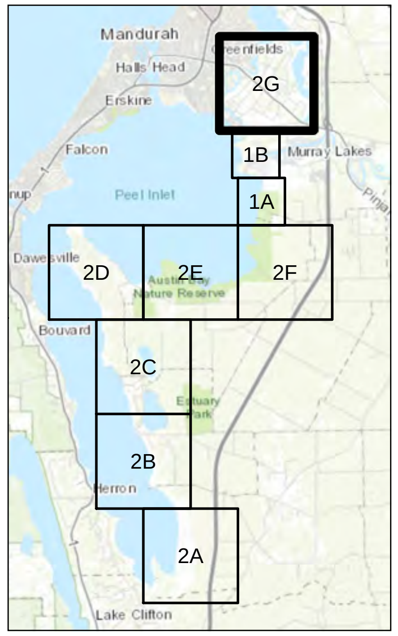
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2021.
Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).

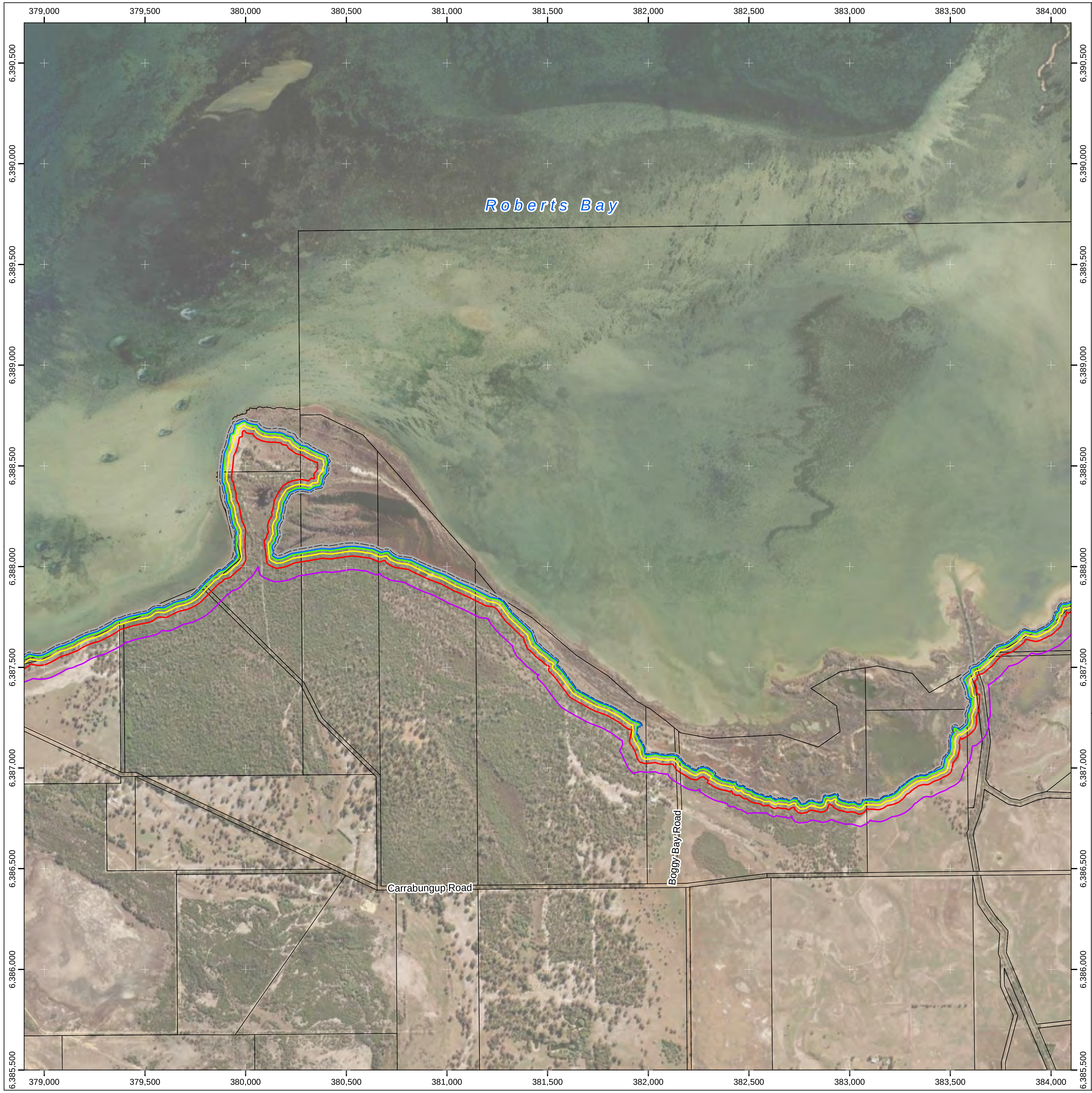


Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 20 Apr. 2021

Mapsheet: 2G



Shire of Murray
Coastal Hazard Flood Mapping

Coastal Processes Allowances
(Erosion Setback)

Horizontal Setback Datum

Setbacks

- 2020
- 2030
- 2050
- 2070
- 2120

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Basemap Image: ESRI World Imagery © 2021.
Spatial Reference: GDA 1994 MGA Zone 50

N W E S

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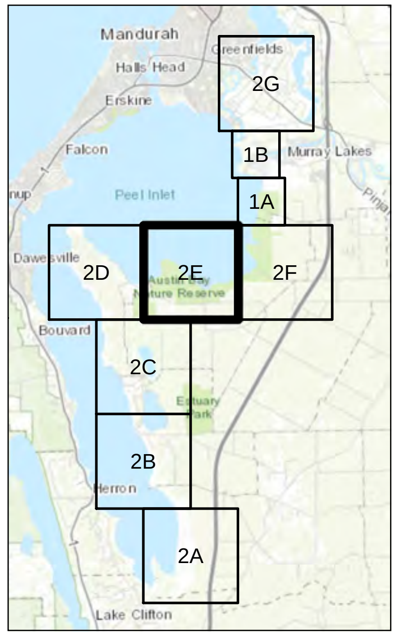

Shire of Murray

1915 Pinjarra Rd
Pinjarra WA 6208

https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 20 Apr. 2021

Mapsheet: 2E

Shire of Murray
Coastal Hazard Flood Mapping

Coastal Processes Allowances (Erosion Setback)

Horizontal Setback Datum

Setbacks

- 2020
- 2030
- 2050
- 2070
- 2120

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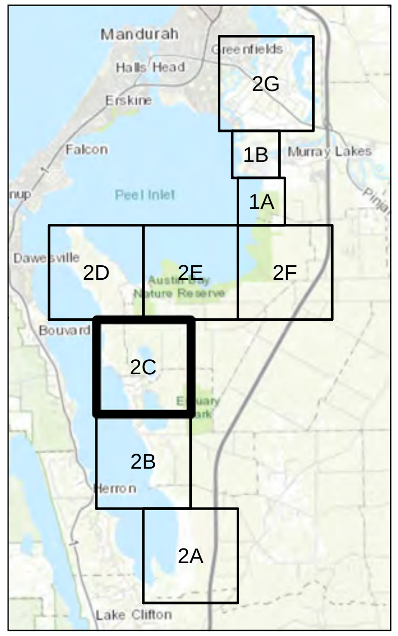
Basemap Image: ESRI World Imagery © 2021.
Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 20 Apr. 2021

Mapsheet: 2C

Shire of Murray
Coastal Hazard Flood Mapping

Coastal Processes Allowances
(Erosion Setback)

Horizontal Setback Datum

Setbacks

- 2020
- 2030
- 2050
- 2070
- 2120

This map has been prepared by Baird Australia on behalf of the Shire of Murray as part of the Shire of Murray Coastal Hazard Risk Management and Adaptation Planning Project. The coastal setbacks have been adopted from the Coastal Hazard assessment completed for the Shire of Murray by Seashore (2021).

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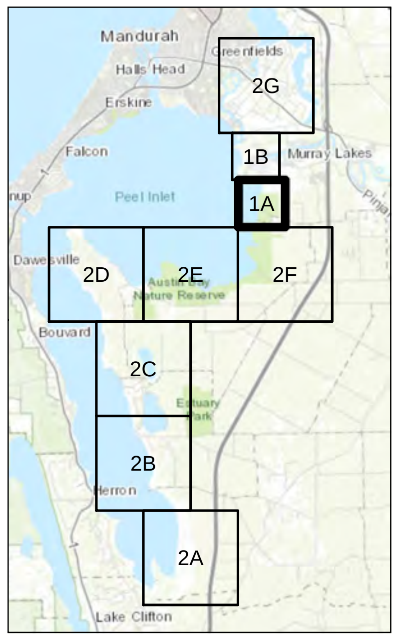
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2021.
Spatial Reference: GDA 1994 MGA Zone 50

N W E S

0 100 200 300 400 500 m

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray

1915 Pinjarra Rd
Pinjarra WA 6208

https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 20 Apr. 2021

Mapsheet: 1A

Shire of Murray
Coastal Hazard Flood Mapping

Coastal Processes Allowances (Erosion Setback)

Horizontal Setback Datum

Setbacks

- 2020
- 2030
- 2050
- 2070
- 2120

This map has been prepared by Baird Australia on behalf of the Shire of Murray as part of the Shire of Murray Coastal Hazard Risk Management and Adaptation Planning Project. The coastal setbacks have been adopted from the Coastal Hazard assessment completed for the Shire of Murray by Seashore (2021).

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Spatial Reference: GDA 1994 MGA Zone 50

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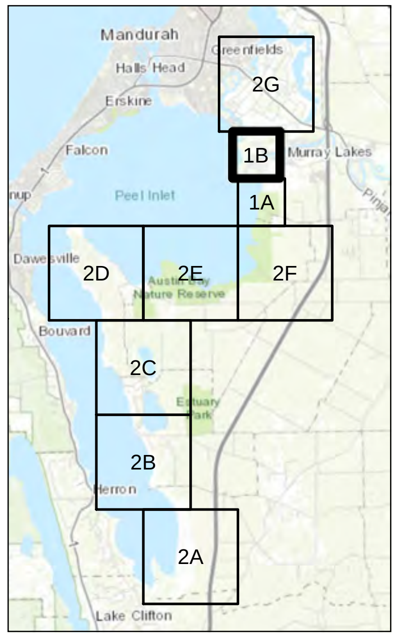


Shire of Murray

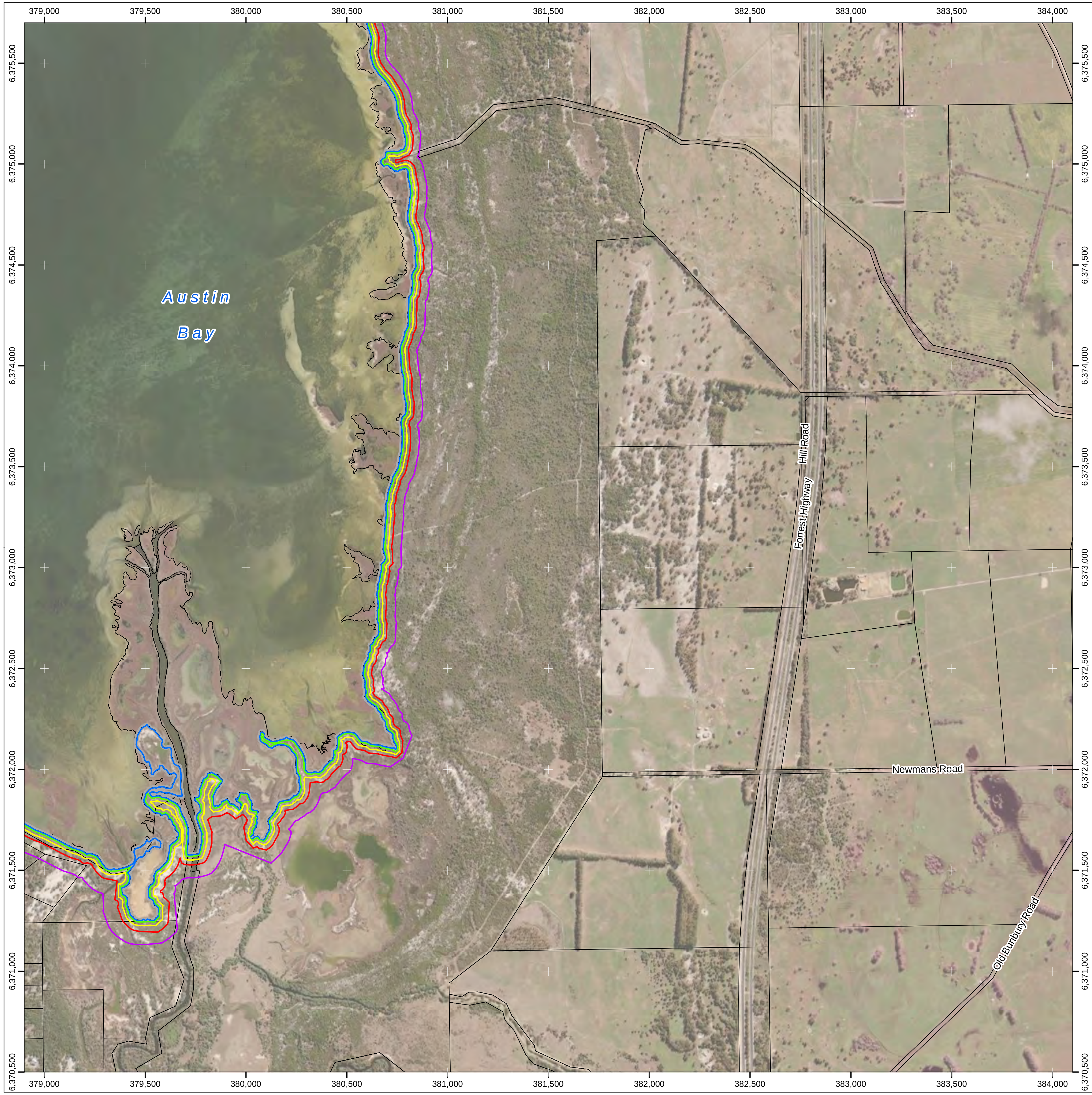
1915 Pinjarra Rd
Pinjarra WA 6208

https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 20 Apr. 2021

Mapsheet: 1B



Shire of Murray
Coastal Hazard Flood Mapping

Coastal Processes Allowances (Erosion Setback)

Horizontal Setback Datum

Setbacks

- 2020
- 2030
- 2050
- 2070
- 2120

This map has been prepared by Baird Australia on behalf of the Shire of Murray as part of the Shire of Murray Coastal Hazard Risk Management and Adaptation Planning Project. The coastal setbacks have been adopted from the Coastal Hazard assessment completed for the Shire of Murray by Seashore (2021).

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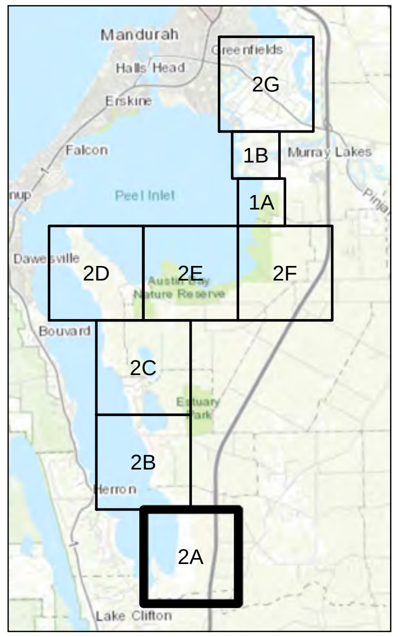
Basemap Image: ESRI World Imagery © 2021.
Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

N W E S

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray

1915 Pinjarra Rd
Pinjarra WA 6208

https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 20 Apr. 2021

Mapsheet: 2A

Shire of Murray
Coastal Hazard Flood Mapping

Coastal Processes Allowances (Erosion Setback)

Horizontal Setback Datum

Setbacks

- 2020
- 2030
- 2050
- 2070
- 2120

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Spatial Reference: GDA 1994 MGA Zone 50

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N W E S

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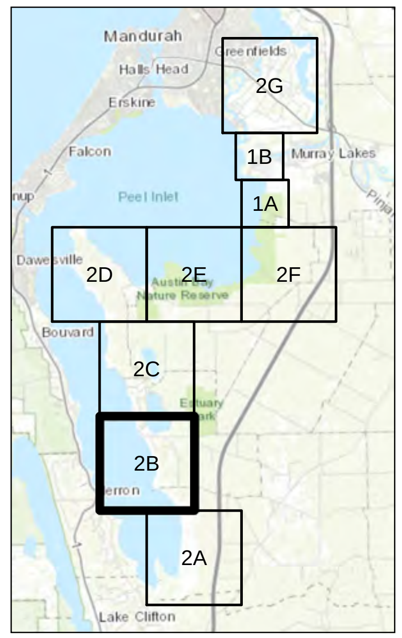

Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 20 Apr. 2021

Mapsheet: 2B

Shire of Murray
Coastal Hazard Flood Mapping

Coastal Processes Allowances (Erosion Setback)

Horizontal Setback Datum

Setbacks

- 2020
- 2030
- 2050
- 2070
- 2120

This map has been prepared by Baird Australia on behalf of the Shire of Murray as part of the Shire of Murray Coastal Hazard Risk Management and Adaptation Planning Project. The coastal setbacks have been adopted from the Coastal Hazard assessment completed for the Shire of Murray by Seashore (2021).

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Spatial Reference: GDA 1994 MGA Zone 50

N W E S

0 200 400 600 800 1,000 m

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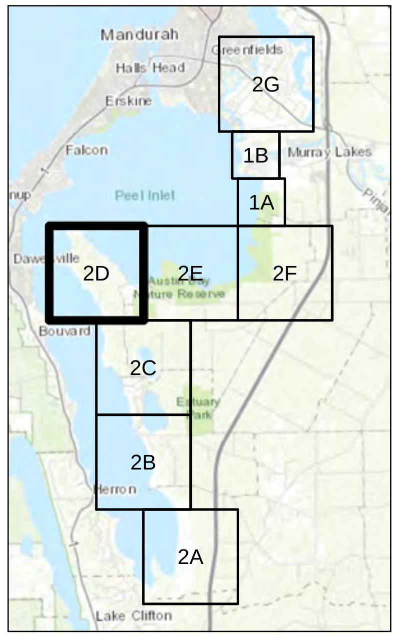
Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
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https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 20 Apr. 2021

Mapsheet: 2D

Shire of Murray
Coastal Hazard Flood Mapping

Coastal Processes Allowances (Erosion Setback)

Horizontal Setback Datum

Setbacks

- 2020
- 2030
- 2050
- 2070
- 2120

This map has been prepared by Baird Australia on behalf of the Shire of Murray as part of the Shire of Murray Coastal Hazard Risk Management and Adaptation Planning Project. The coastal setbacks have been adopted from the Coastal Hazard assessment completed for the Shire of Murray by Seashore (2021).

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Basemap Image: ESRI World Imagery © 2021.
Spatial Reference: GDA 1994 MGA Zone 50

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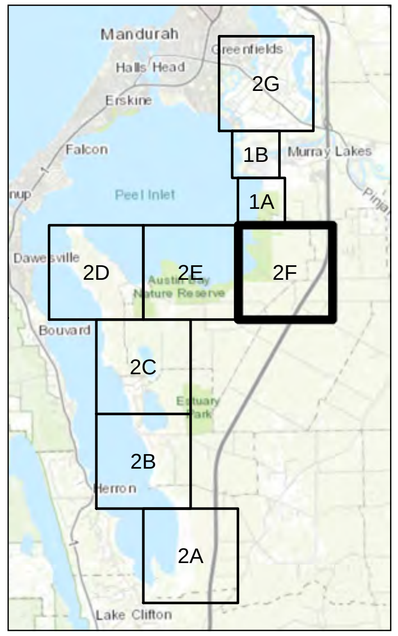


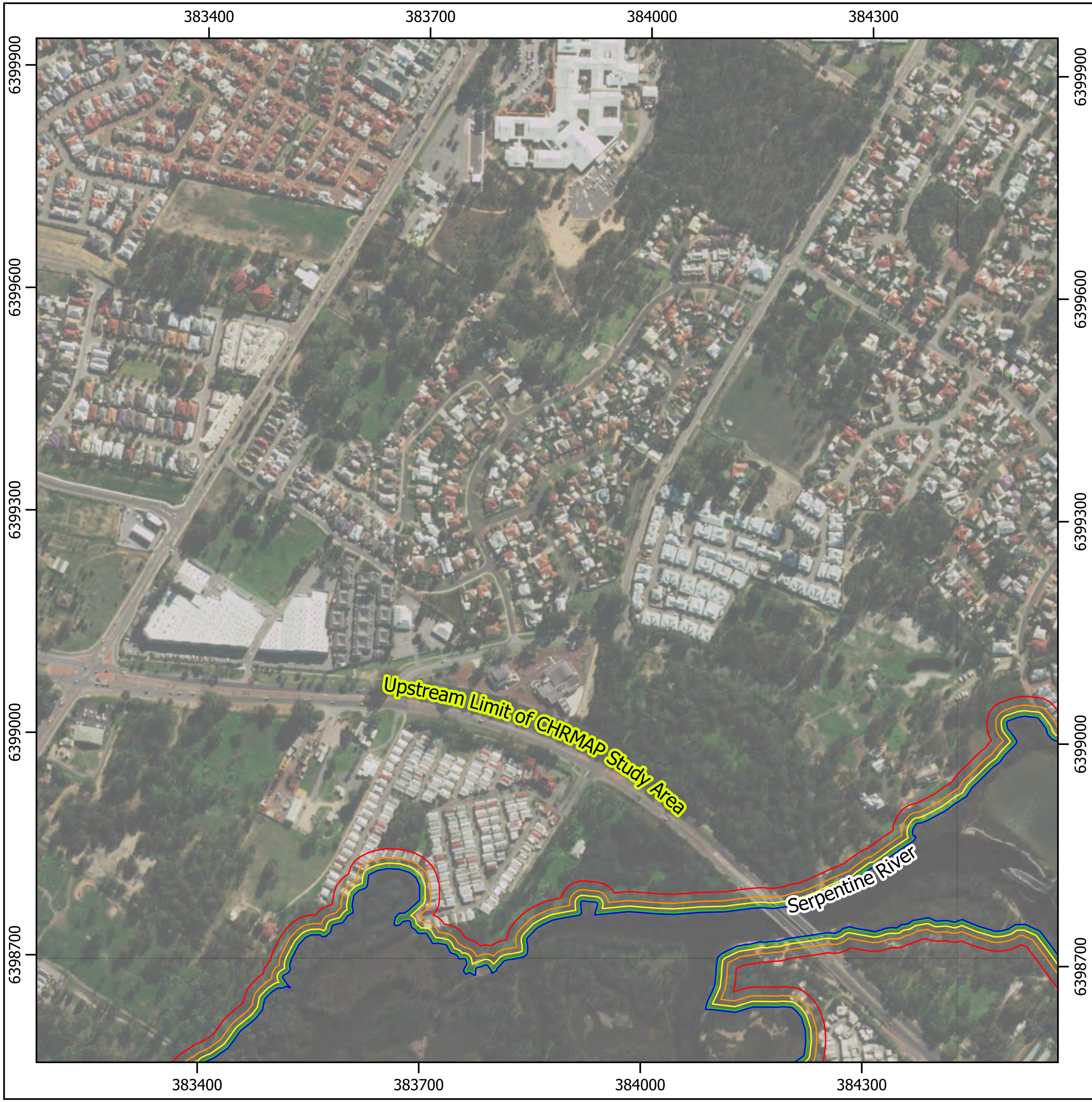
Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 20 Apr. 2021

Mapsheet: 2F

C.3 Erosion Hazard for Lower Murray and Serpentine Rivers



Shire of Murray

Coastal Processes Allowances (Erosion Setback - Rivers)

Erosion Hazard

- 2120
- 2070
- 2050
- 2030
- 2020

N

0 100 200 300 m

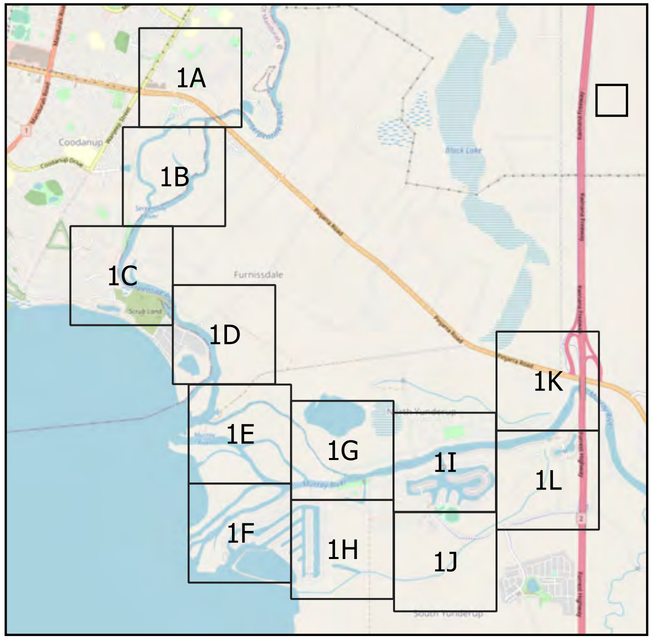
13064.101 | May-2021
Imagery: ESRI Basemap
Street Name Data: © OpenStreetMap contributors
Spatial Reference: GDA 2020 MGA Zone 50

This map has been prepared by Baird Australia on behalf of the Shire of Murray as part of the Shire of Murray Coastal Hazard Risk Management and Adaptation Planning Project. The coastal setbacks used to create the erosion likelihoods have been adopted from the Coastal Hazard assessment completed for the Shire of Murray by Seashore (2021).

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

Shire of Murray Baird.

Map 1A



Shire of Murray

Coastal Processes Allowances
(Erosion Setback - Rivers)

Erosion Hazard

- 2120
- 2070
- 2050
- 2030
- 2020

N

0 100 200 300 m

13064.101 | May-2021
Imagery: ESRI Basemap
Street Name Data: © OpenStreetMap contributors
Spatial Reference: GDA 2020 MGA Zone 50

This map has been prepared by Baird Australia on behalf of the Shire of Murray as part of the Shire of Murray Coastal Hazard Risk Management and Adaptation Planning Project. The coastal setbacks used to create the erosion likelihoods have been adopted from the Coastal Hazard assessment completed for the Shire of Murray by Seashore (2021).

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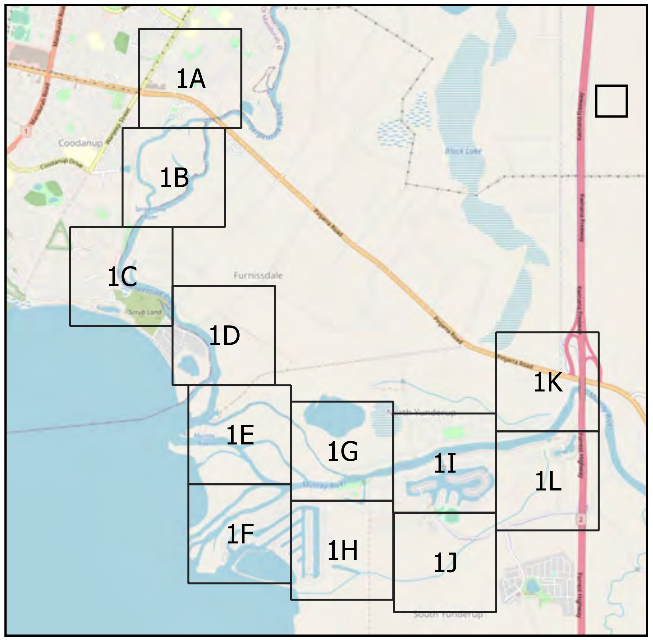
Shire of Murray Baird.

Map 1B



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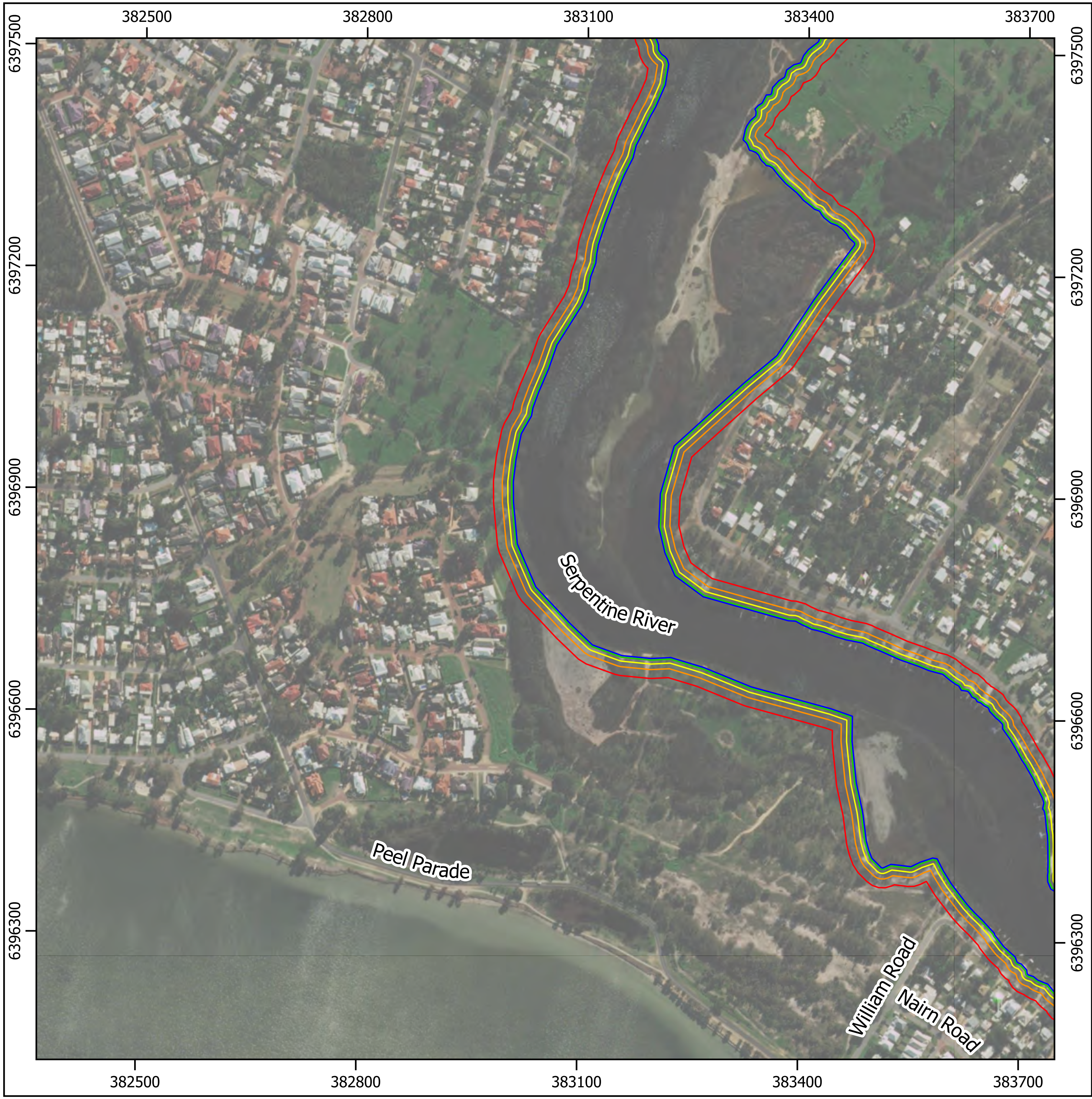


Shire of Murray

Coastal Processes Allowances
(Erosion Setback - Rivers)

Erosion Hazard

- 2120
- 2070
- 2050
- 2030
- 2020

N

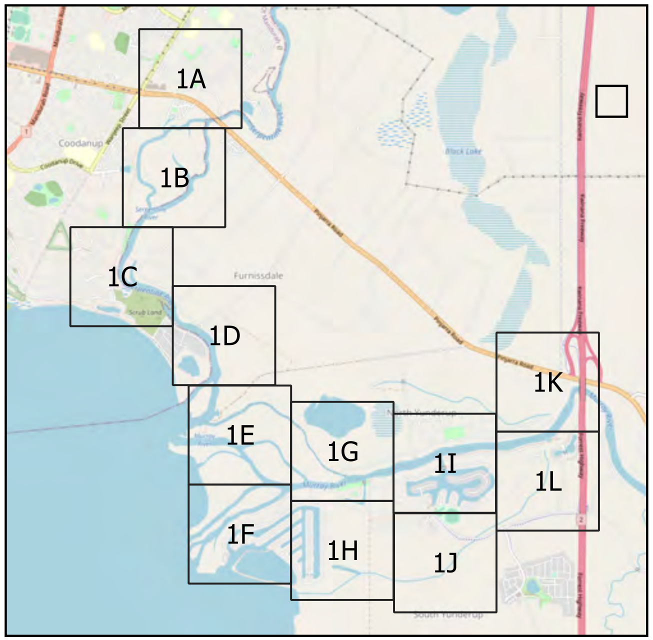
0 100 200 300 m

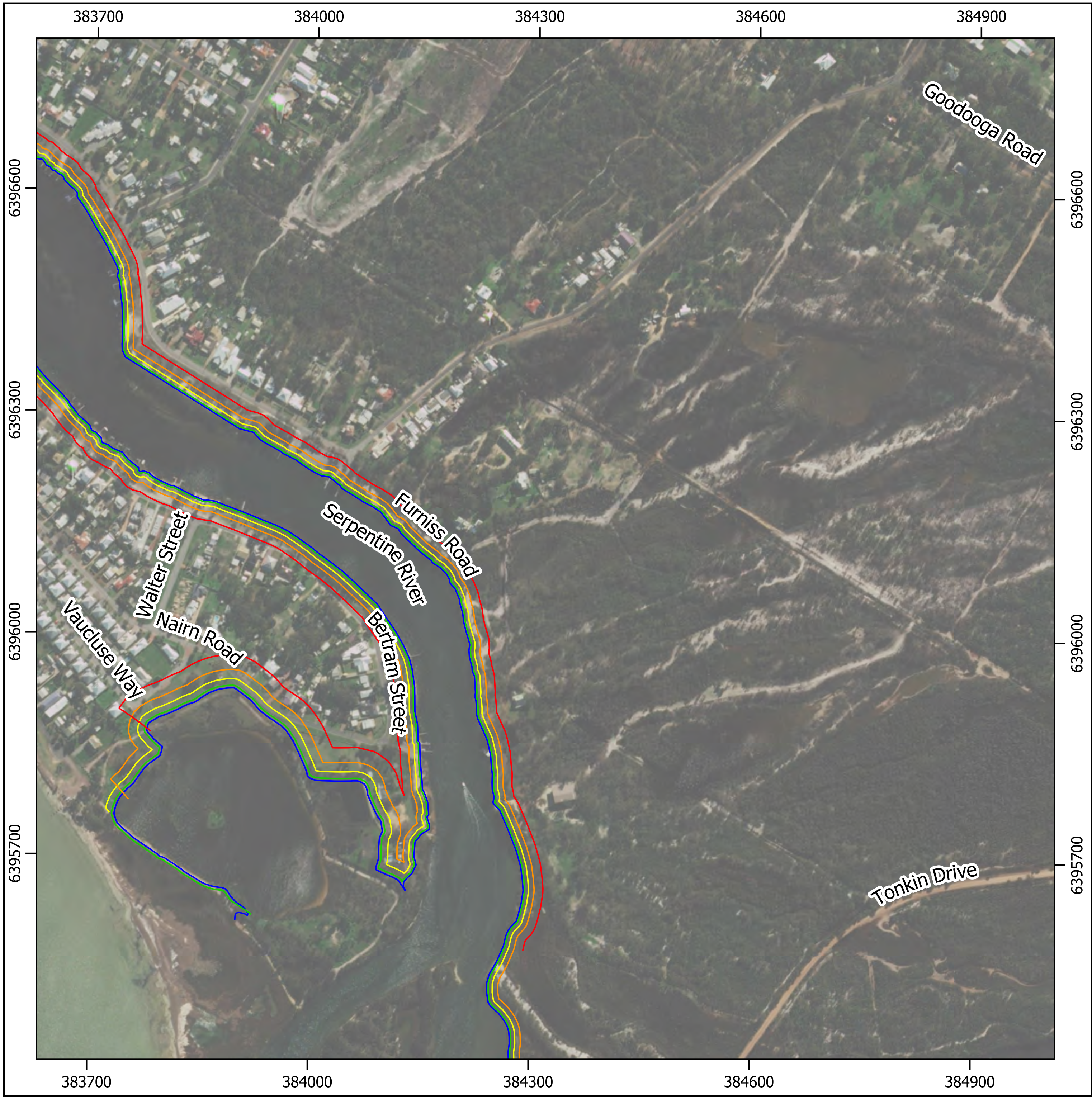
13064.101 | May-2021
Imagery: ESRI Basemap
Street Name Data: © OpenStreetMap contributors
Spatial Reference: GDA 2020 MGA Zone 50

This map has been prepared by Baird Australia on behalf of the Shire of Murray as part of the Shire of Murray Coastal Hazard Risk Management and Adaptation Planning Project. The coastal setbacks used to create the erosion likelihoods have been adopted from the Coastal Hazard assessment completed for the Shire of Murray by Seashore (2021).

Shire of Murray   Baird.

Map 1C





Shire of Murray
Coastal Processes Allowances
(Erosion Setback - Rivers)

Erosion Hazard

- 2120
- 2070
- 2050
- 2030
- 2020

N

0 100 200 300 m

13064.101 | May-2021
Imagery: ESRI Basemap
Street Name Data: © OpenStreetMap contributors
Spatial Reference: GDA 2020 MGA Zone 50

This map has been prepared by Baird Australia on behalf of the Shire of Murray as part of the Shire of Murray Coastal Hazard Risk Management and Adaptation Planning Project. The coastal setbacks used to create the erosion likelihoods have been adopted from the Coastal Hazard assessment completed for the Shire of Murray by Seashore (2021).

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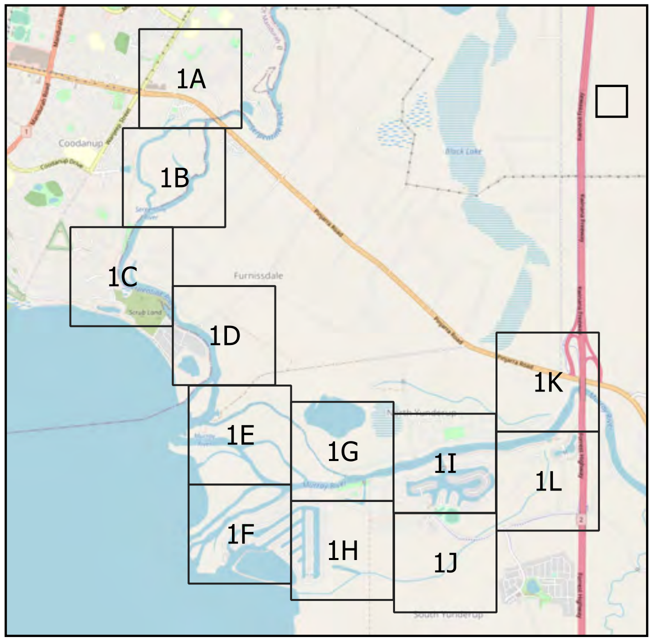
Shire of Murray
Baird.

Map 1D



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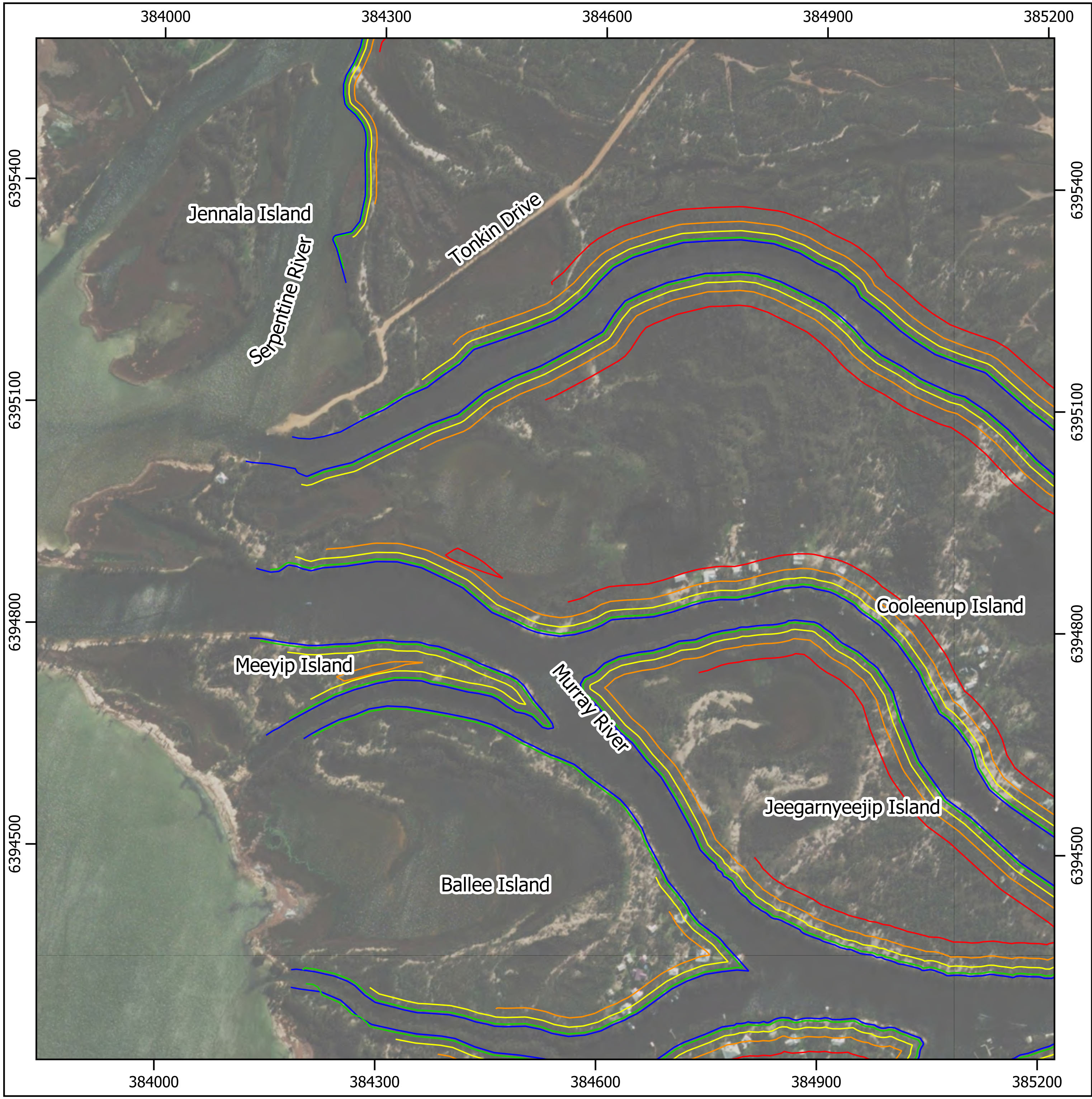


Shire of Murray

Coastal Processes Allowances (Erosion Setback - Rivers)

Erosion Hazard

- 2120
- 2070
- 2050
- 2030
- 2020

N

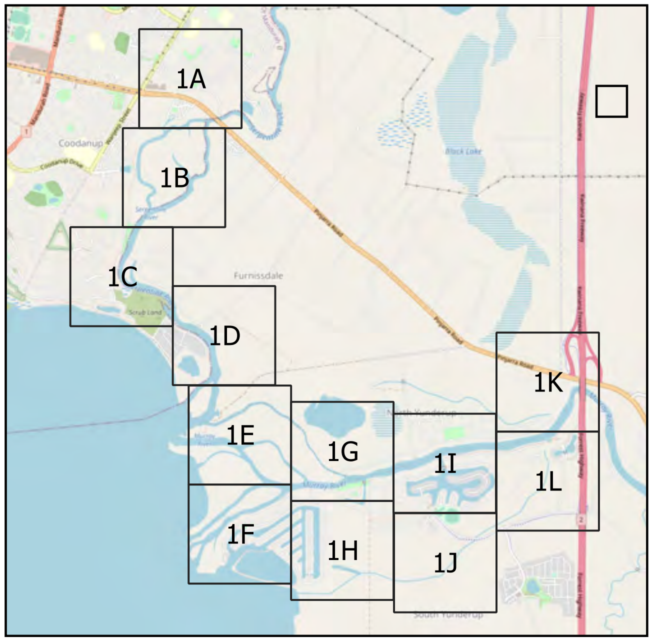
0 100 200 300 m

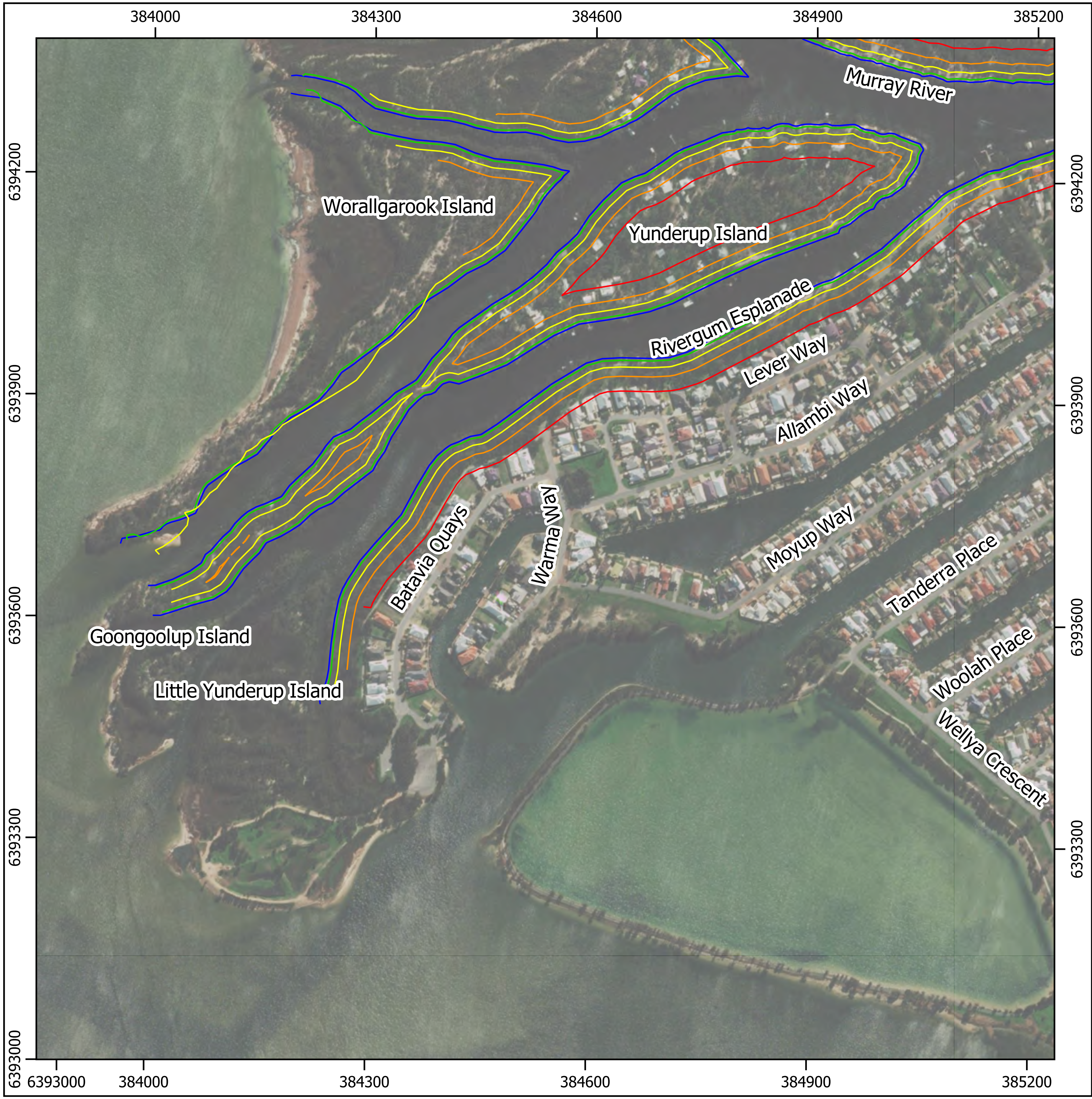
13064.101 | May-2021
Imagery: ESRI Basemap
Street Name Data: © OpenStreetMap contributors
Spatial Reference: GDA 2020 MGA Zone 50

This map has been prepared by Baird Australia on behalf of the Shire of Murray as part of the Shire of Murray Coastal Hazard Risk Management and Adaptation Planning Project. The coastal setbacks used to create the erosion likelihoods have been adopted from the Coastal Hazard assessment completed for the Shire of Murray by Seashore (2021).

Shire of Murray Baird.

Map 1E





Shire of Murray

Coastal Processes Allowances
(Erosion Setback - Rivers)

Erosion Hazard

- 2120
- 2070
- 2050
- 2030
- 2020

N

0 100 200 300 m

13064.101 | May-2021
Imagery: ESRI Basemap
Street Name Data: © OpenStreetMap contributors
Spatial Reference: GDA 2020 MGA Zone 50

This map has been prepared by Baird Australia on behalf of the Shire of Murray as part of the Shire of Murray Coastal Hazard Risk Management and Adaptation Planning Project. The coastal setbacks used to create the erosion likelihoods have been adopted from the Coastal Hazard assessment completed for the Shire of Murray by Seashore (2021).

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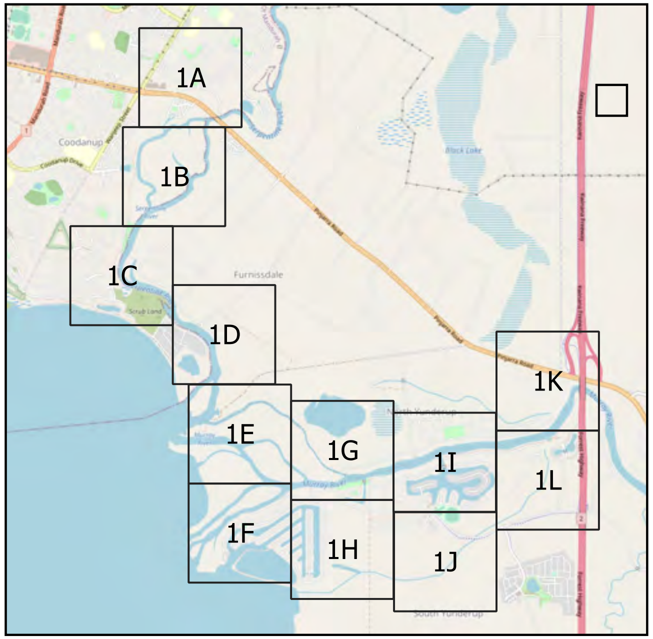
Shire of Murray

Baird.

Map 1F



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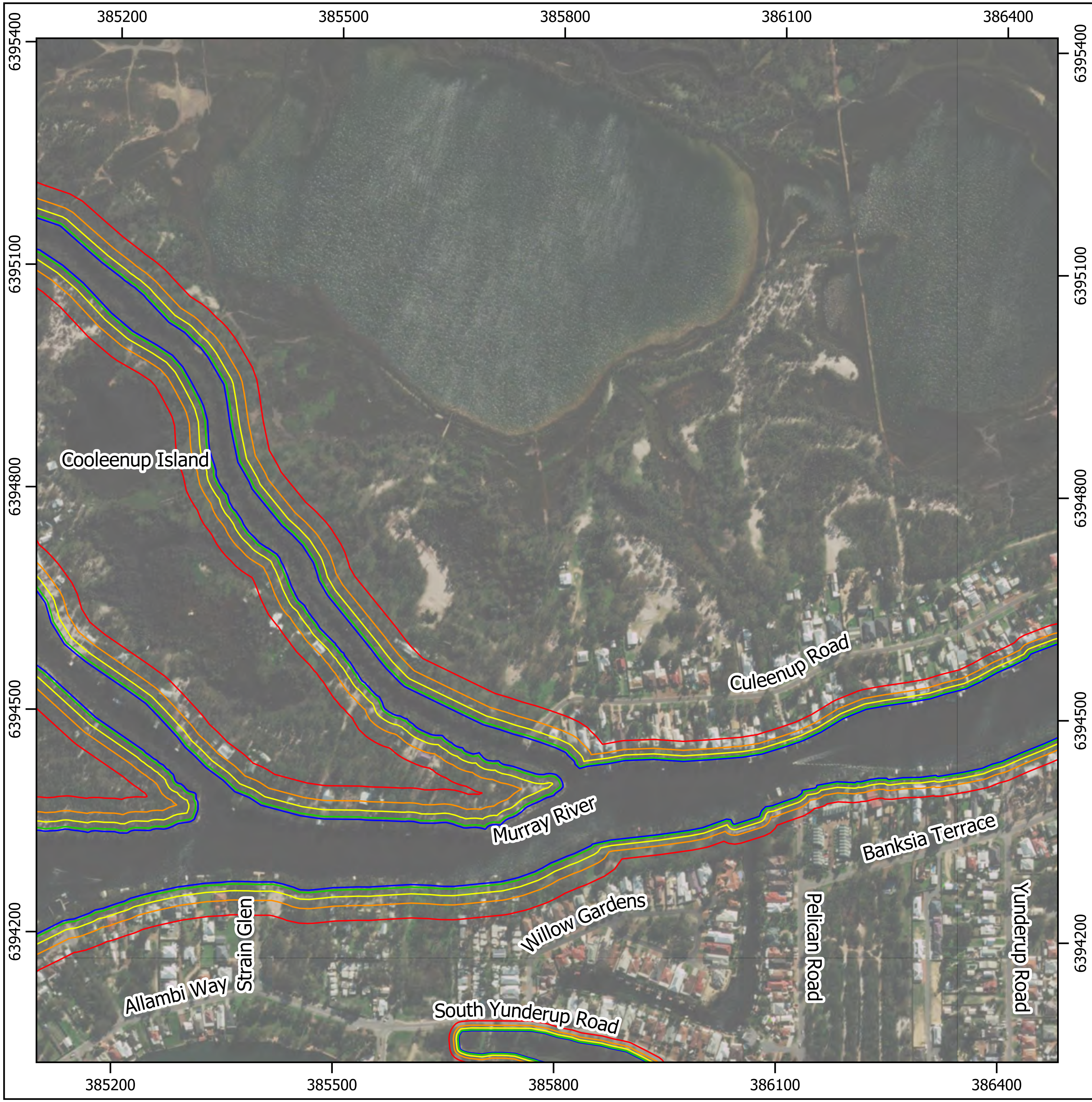

Shire of Murray

Coastal Processes Allowances (Erosion Setback - Rivers)

Erosion Hazard

- 2120
- 2070
- 2050
- 2030
- 2020

N

0 100 200 300 m

13064.101 | May-2021
Imagery: ESRI Basemap
Street Name Data: © OpenStreetMap contributors
Spatial Reference: GDA 2020 MGA Zone 50

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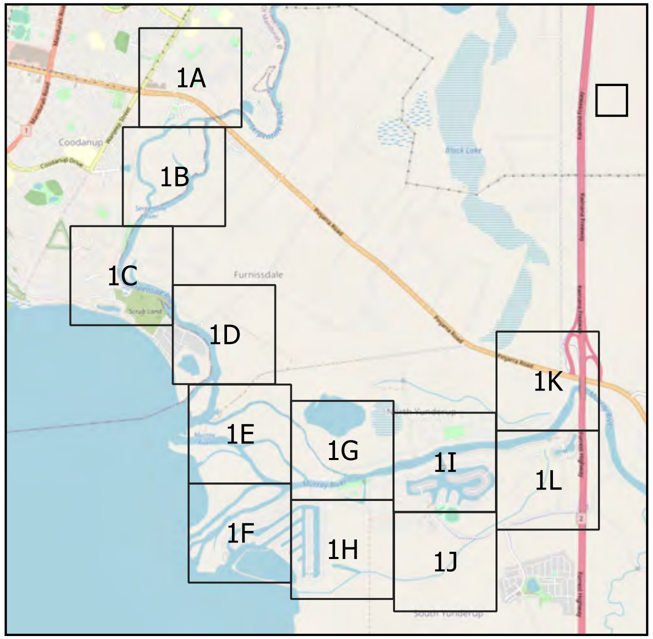
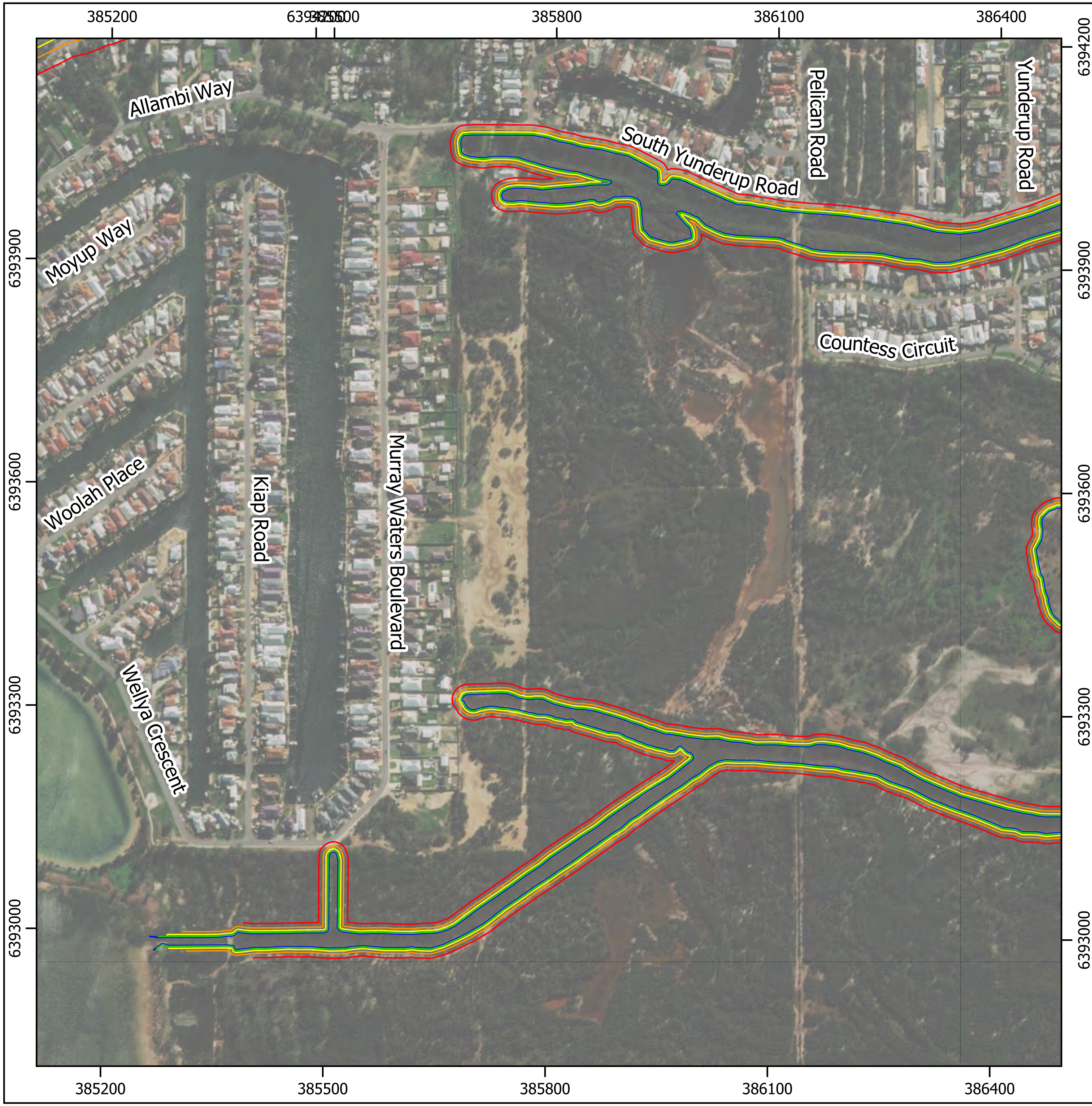
Shire of Murray

Baird.

Map 1G





Shire of Murray

Coastal Processes Allowances (Erosion Setback - Rivers)

Erosion Hazard

- 2120
- 2070
- 2050
- 2030
- 2020

N

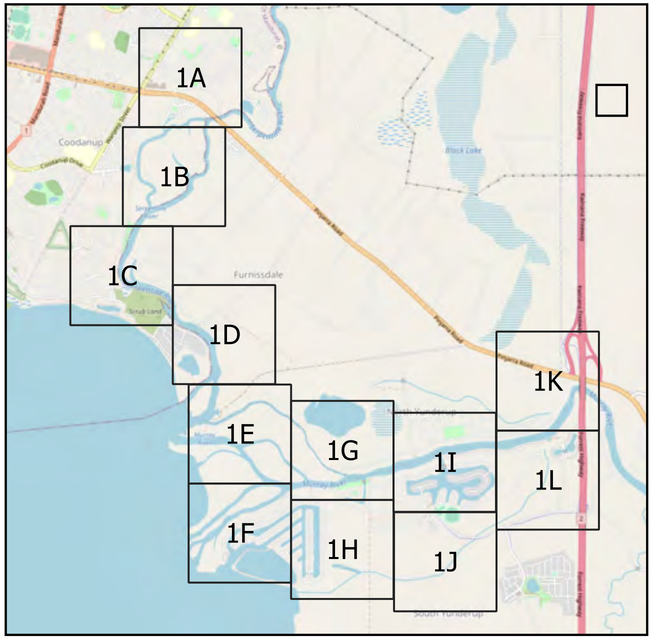
0 100 200 300 m

13064.101 | May-2021
Imagery: ESRI Basemap
Street Name Data: © OpenStreetMap contributors
Spatial Reference: GDA 2020 MGA Zone 50

This map has been prepared by Baird Australia on behalf of the Shire of Murray as part of the Shire of Murray Coastal Hazard Risk Management and Adaptation Planning Project. The coastal setbacks used to create the erosion likelihoods have been adopted from the Coastal Hazard assessment completed for the Shire of Murray by Seashore (2021).

Shire of Murray Baird.

Map 1H



Shire of Murray

Coastal Processes Allowances
(Erosion Setback - Rivers)

Erosion Hazard

- 2120
- 2070
- 2050
- 2030
- 2020

N

0 100 200 300 m

13064.101 | May-2021
Imagery: ESRI Basemap
Street Name Data: © OpenStreetMap contributors
Spatial Reference: GDA 2020 MGA Zone 50

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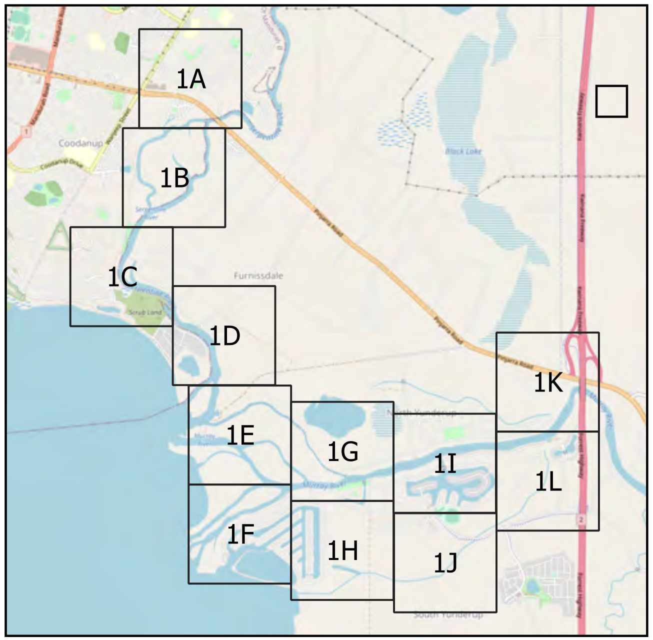
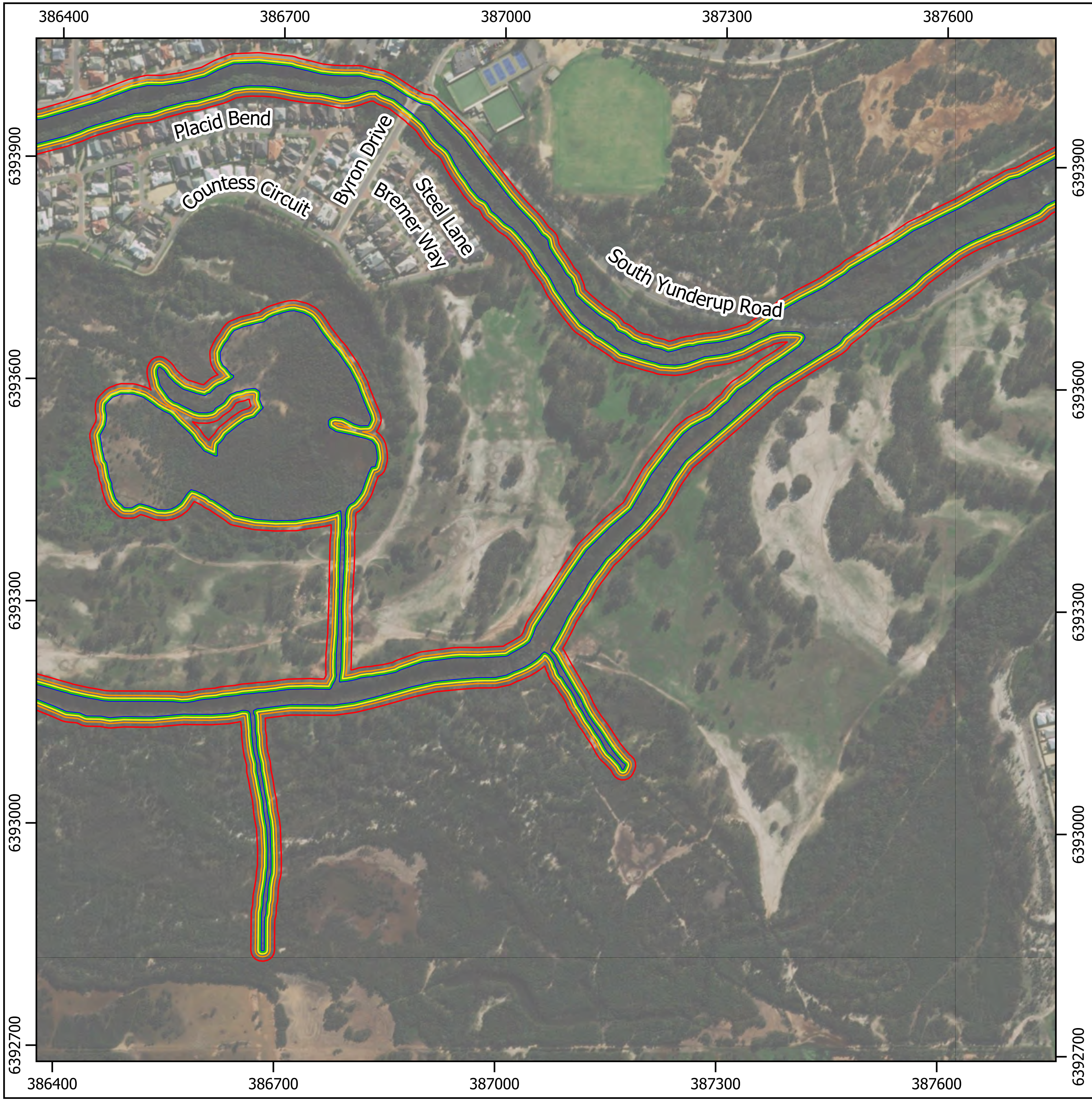
Shire of Murray Baird.

Map 1I





Shire of Murray

Coastal Processes Allowances

(Erosion Setback - Rivers)

Erosion Hazard

- 2120
- 2070
- 2050
- 2030
- 2020

N

0 100 200 300 m

13064.101 | May-2021
Imagery: ESRI Basemap
Street Name Data: © OpenStreetMap contributors
Spatial Reference: GDA 2020 MGA Zone 50

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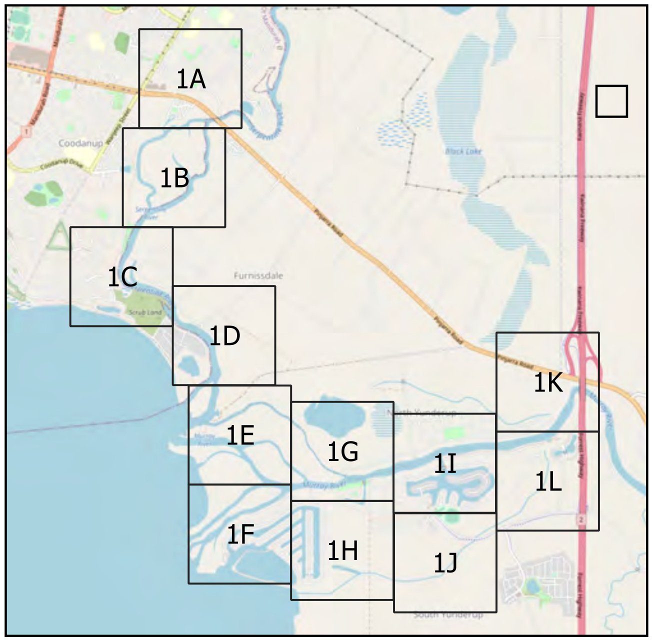
Shire of Murray Baird.

Map 1J



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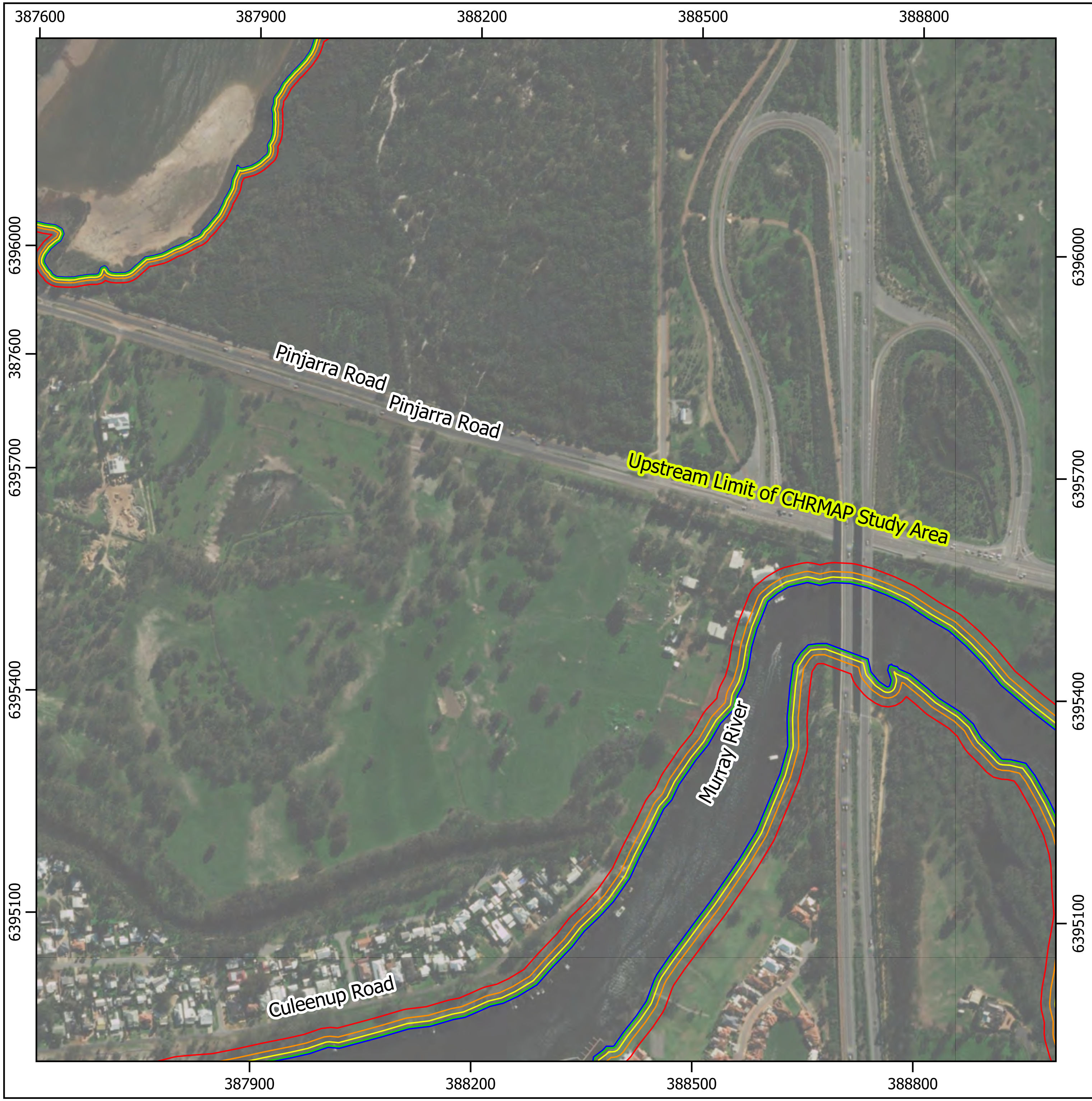

Shire of Murray
Coastal Processes Allowances (Erosion Setback - Rivers)

Erosion Hazard

- 2120
- 2070
- 2050
- 2030
- 2020

N

0 100 200 300 m

13064.101 | May-2021
Imagery: ESRI Basemap
Street Name Data: © OpenStreetMap contributors
Spatial Reference: GDA 2020 MGA Zone 50

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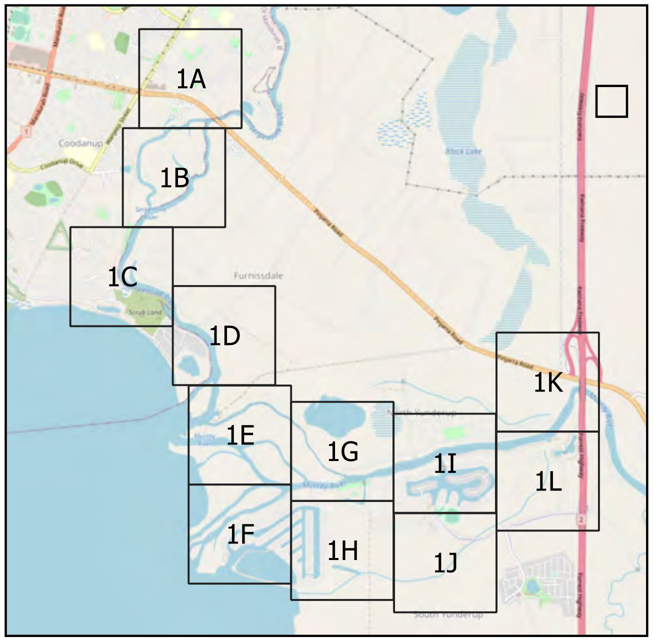
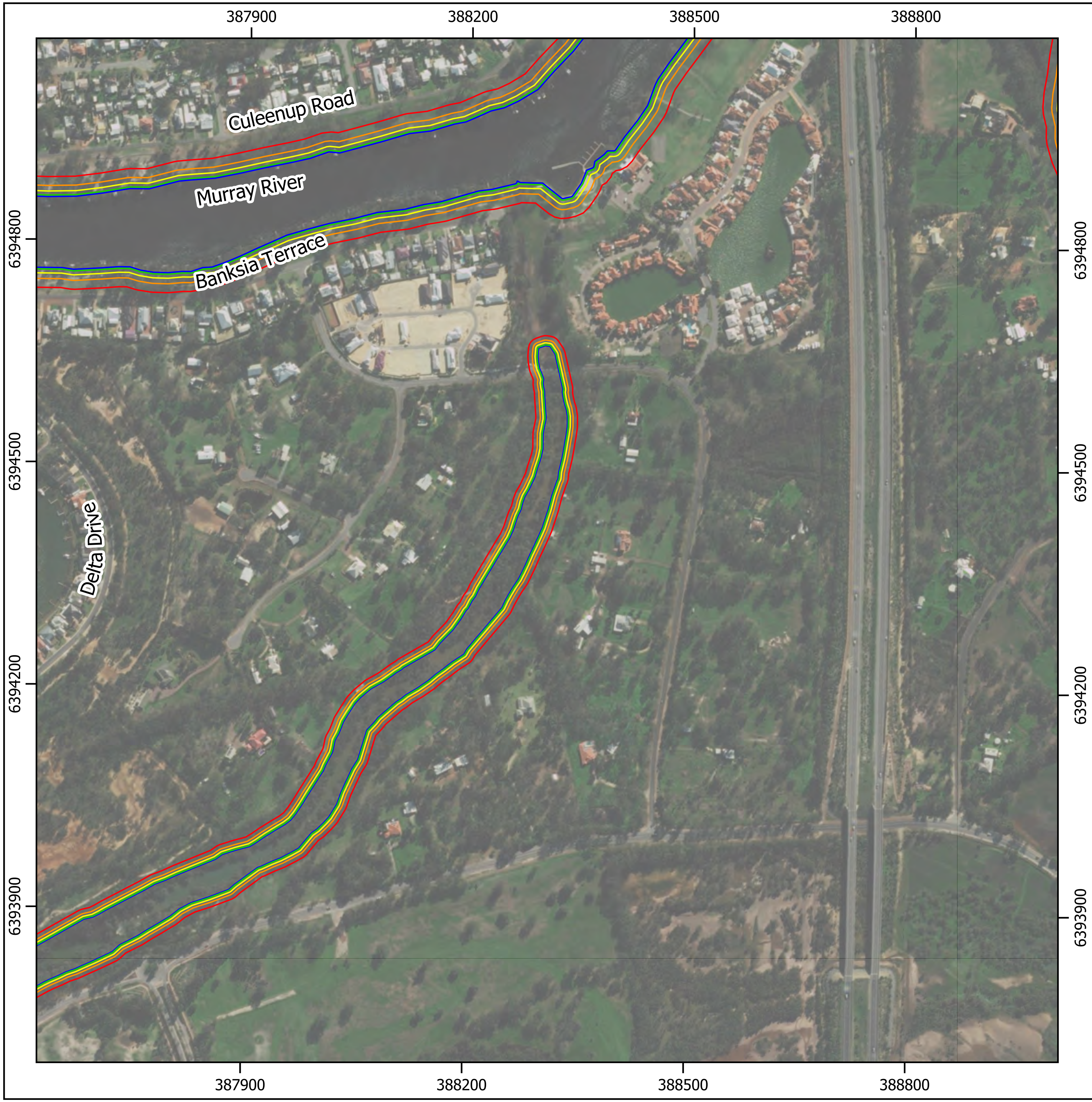
Shire of Murray

Baird.

Map 1K





Shire of Murray

Coastal Processes Allowances (Erosion Setback - Rivers)

Erosion Hazard

- 2120
- 2070
- 2050
- 2030
- 2020

N

0 100 200 300 m

13064.101 | May-2021
Imagery: ESRI Basemap
Street Name Data: © OpenStreetMap contributors
Spatial Reference: GDA 2020 MGA Zone 50

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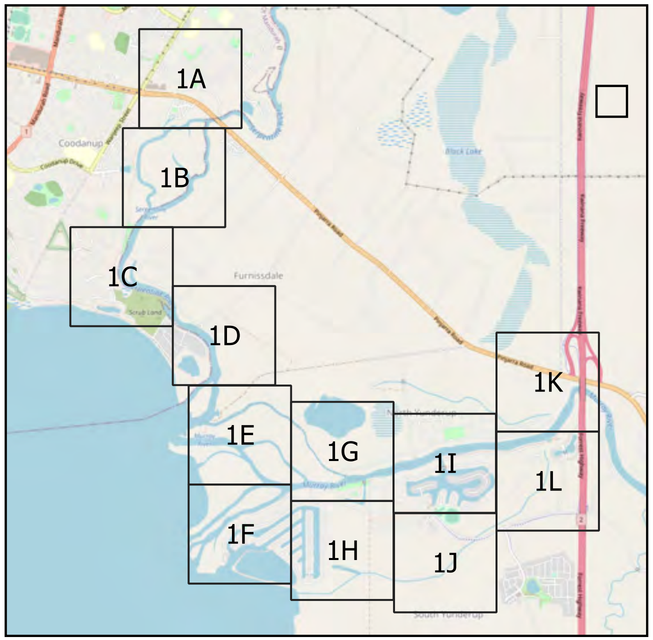
Shire of Murray Baird.

Map 1L



C.4 Coastal Inundation Hazard

C.4.1 Coastal Inundation Hazard – 100yr ARI Scenario, Planning Year 2020 (No Sea Level Rise)

Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.09m AHD (no Sea Level Rise)

Inundation Depth (m)

- > 1.0
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.

Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

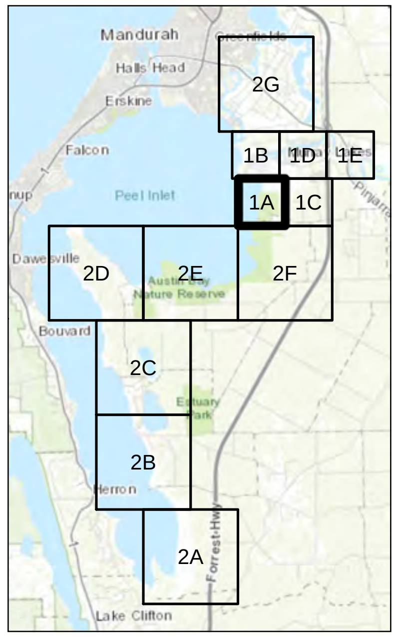
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

N W E S

0 100 200 300 400 500 m

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray

1915 Pinjarra Rd
Pinjarra WA 6208

https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 1A

Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.09m AHD (no Sea Level Rise)

Inundation Depth (m)

- > 1.0
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

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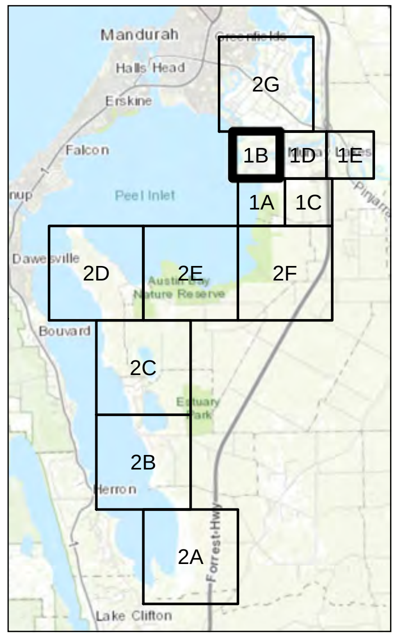
Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 100 200 300 400 500 m

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 1B

Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.09m AHD (no Sea Level Rise)

Inundation Depth (m)

- > 1.0
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

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Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

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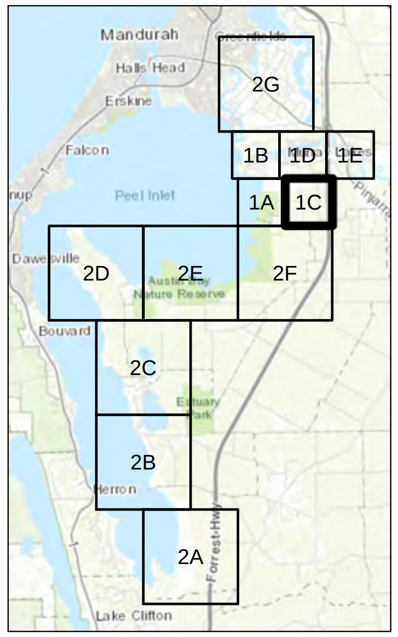
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 100 200 300 400 500 m

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 1C

Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.09m AHD (no Sea Level Rise)

Inundation Depth (m)

- > 1.0
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.

Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

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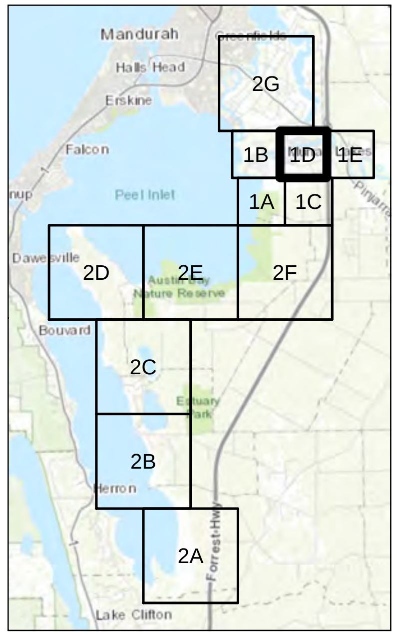
Spatial Reference: GDA 1994 MGA Zone 50

0 100 200 300 400 500 m

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 1D

Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.09m AHD (no Sea Level Rise)

Inundation Depth (m)

- > 1.0
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

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Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

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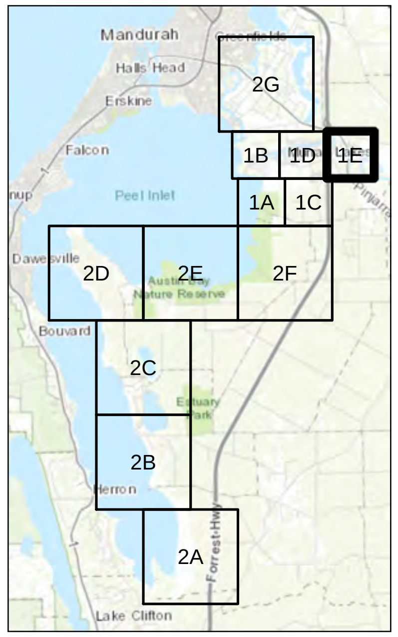
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 100 200 300 400 500 m

N W E S

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray

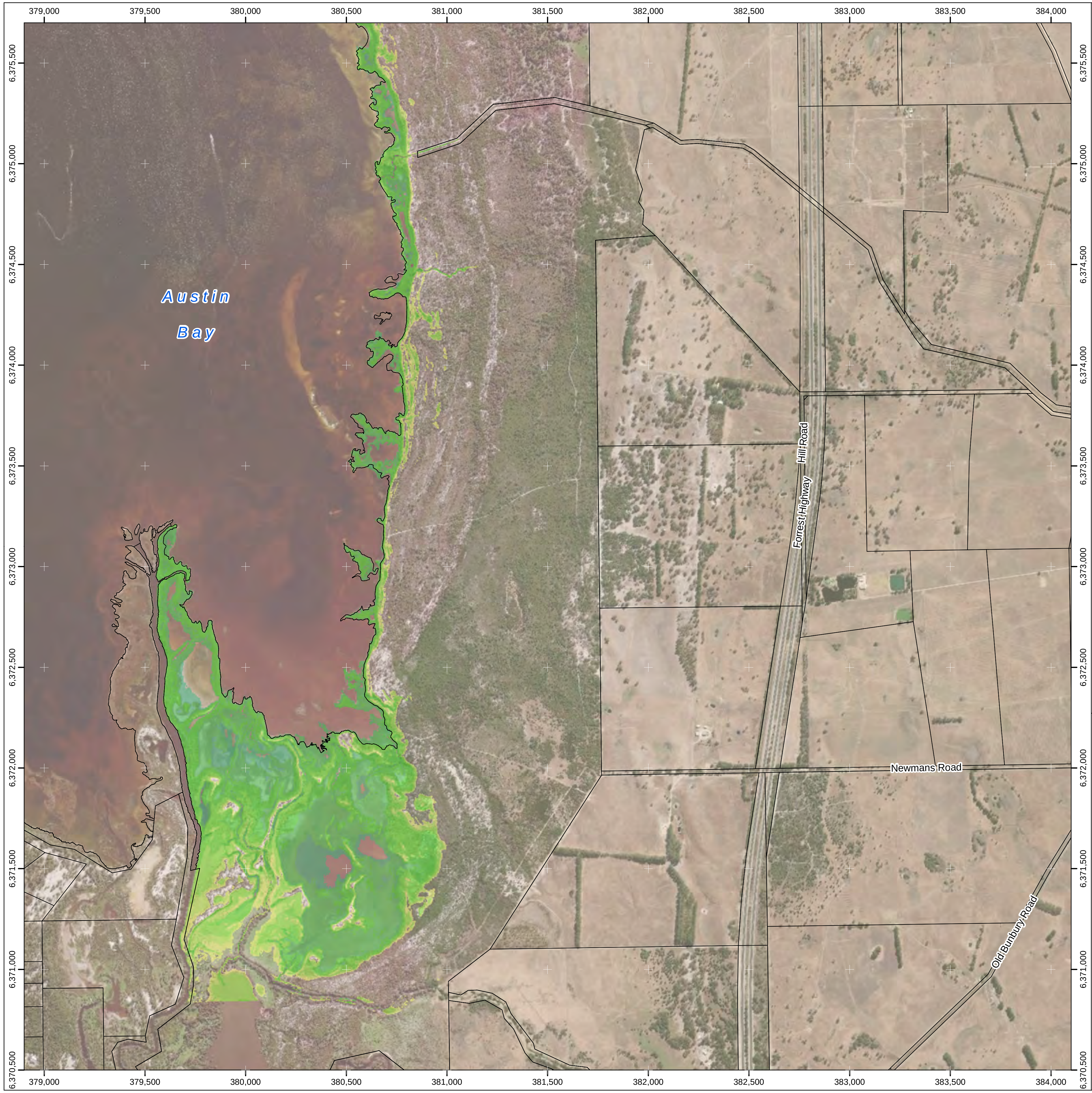
1915 Pinjarra Rd
Pinjarra WA 6208

https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 1E



Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.09m AHD (no Sea Level Rise)

Inundation Depth (m)

- > 1.0
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

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Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

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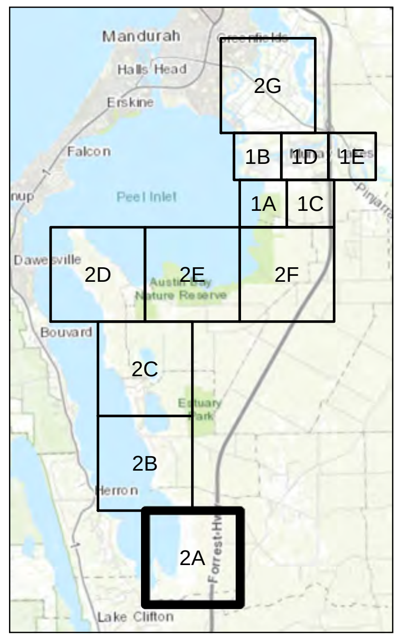
Street name data © OpenStreetMap contributors. Basemap Image: ESRI World Imagery © 2020. Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

N W E S

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray

1915 Pinjarra Rd
Pinjarra WA 6208

https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 2A

Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.09m AHD (no Sea Level Rise)

Inundation Depth (m)

- > 1.0
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.

Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

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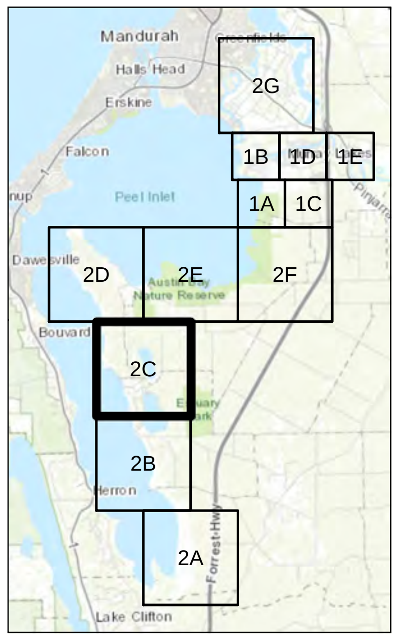
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 2C

Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.09m AHD (no Sea Level Rise)

Inundation Depth (m)

- > 1.0
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

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Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

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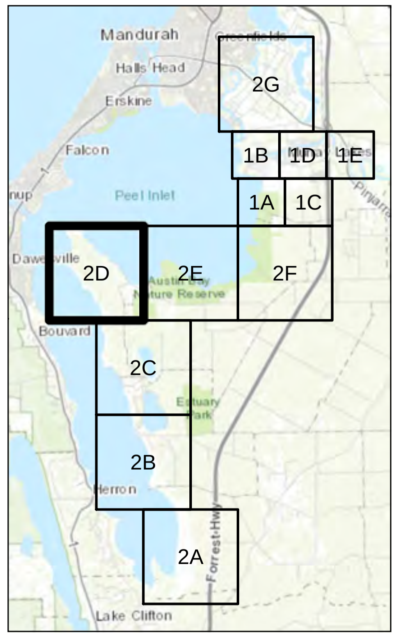
Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

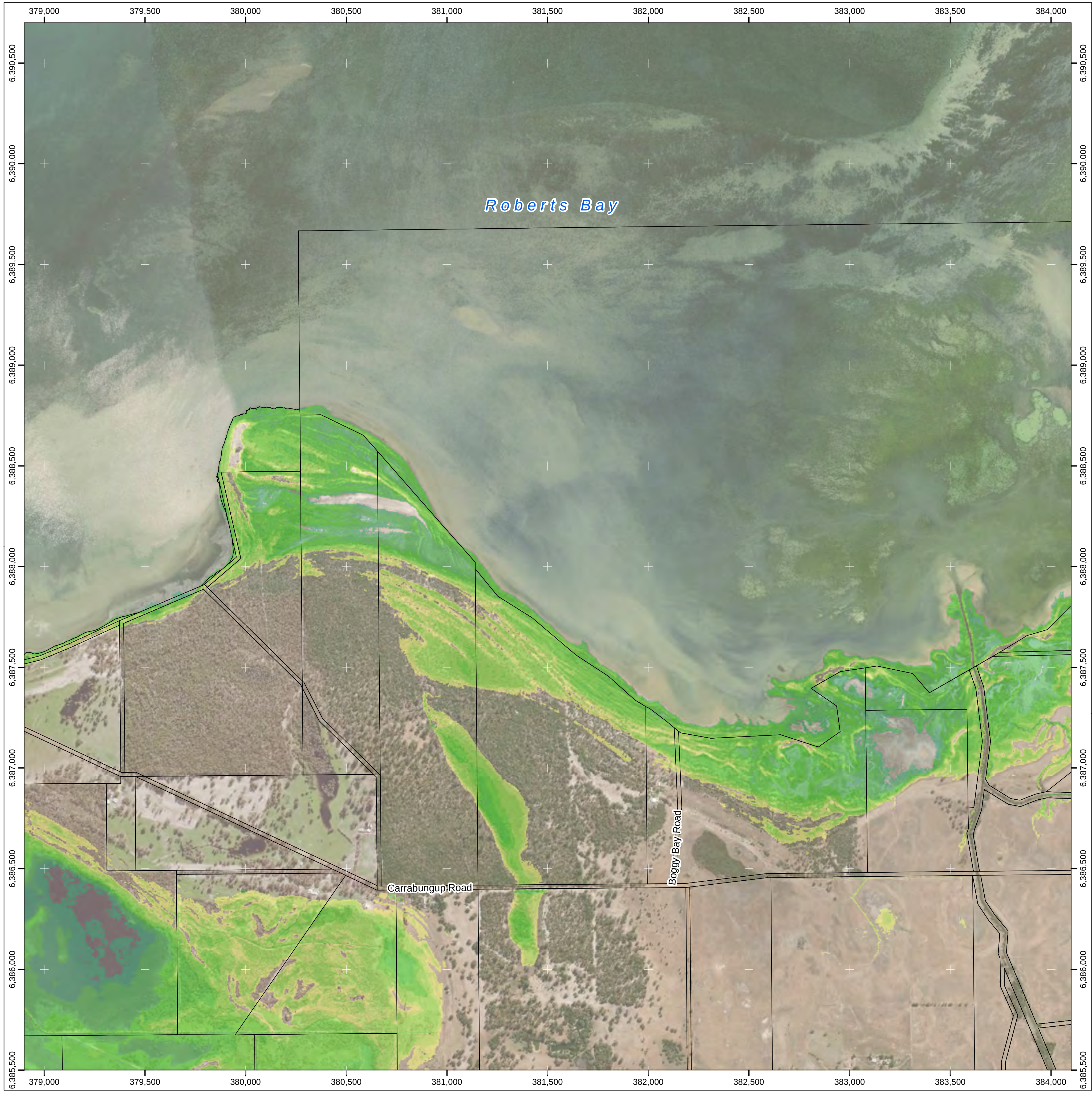
Map Published: 19 Nov. 2020

Mapsheet: 2D

Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.09m AHD (no Sea Level Rise)



Inundation Depth (m)

- > 1.0
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

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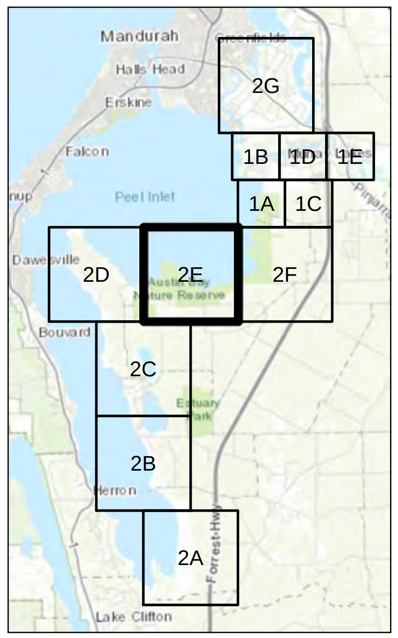
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

N W E S

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).

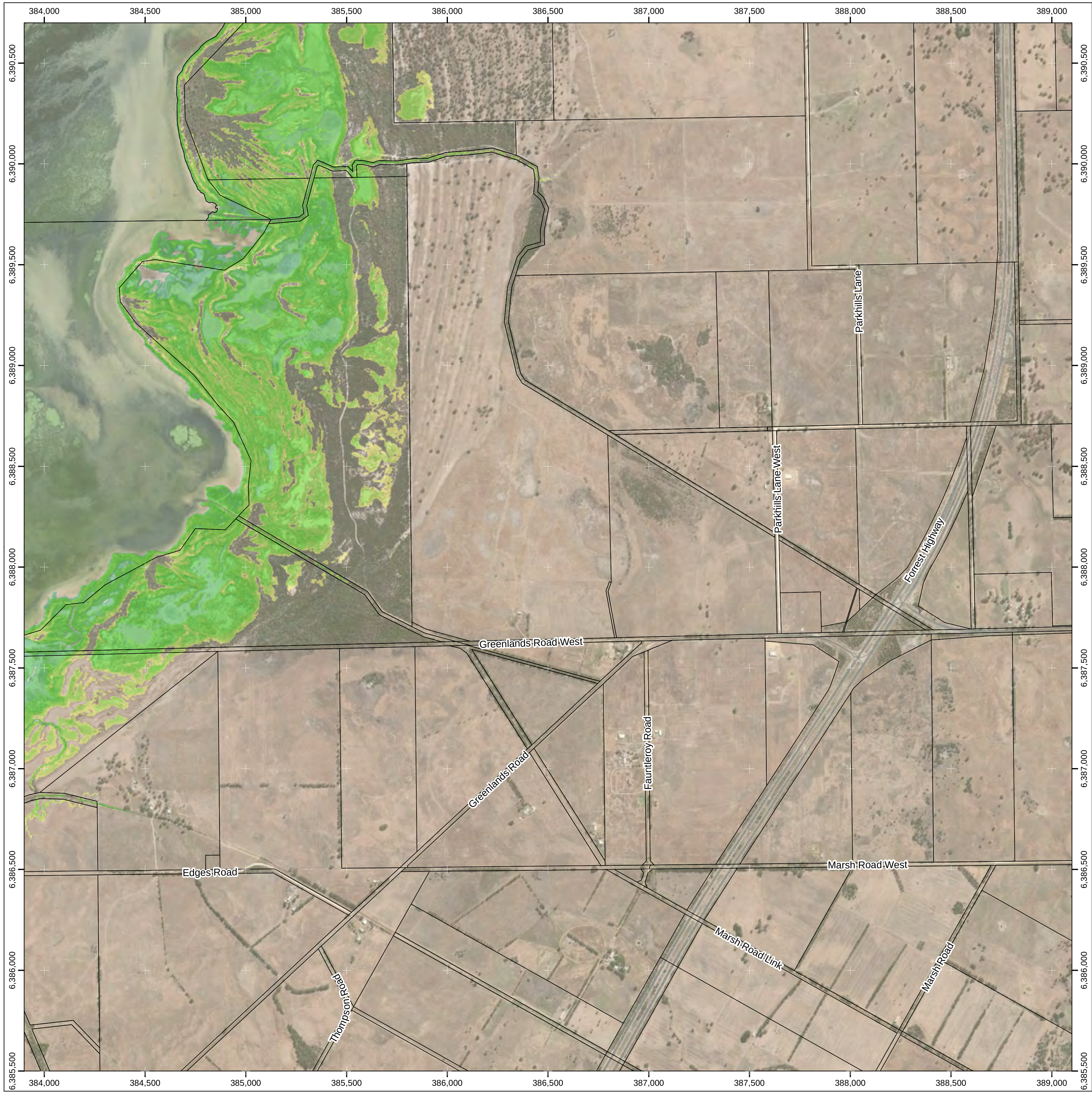


Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 2E



Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.09m AHD (no Sea Level Rise)

Inundation Depth (m)

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- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

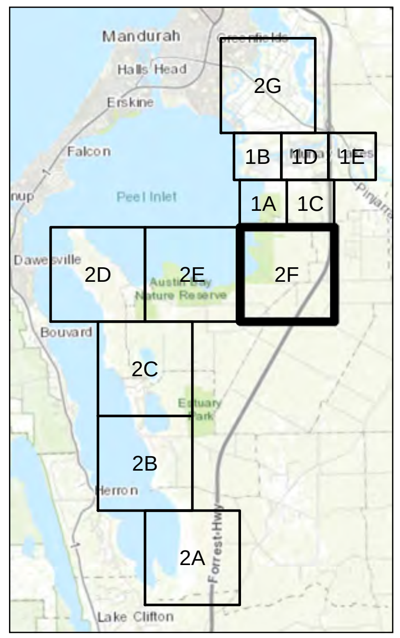
Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray

1915 Pinjarra Rd
Pinjarra WA 6208

https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 2F

Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.09m AHD (no Sea Level Rise)

Inundation Depth (m)

- > 1.0
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

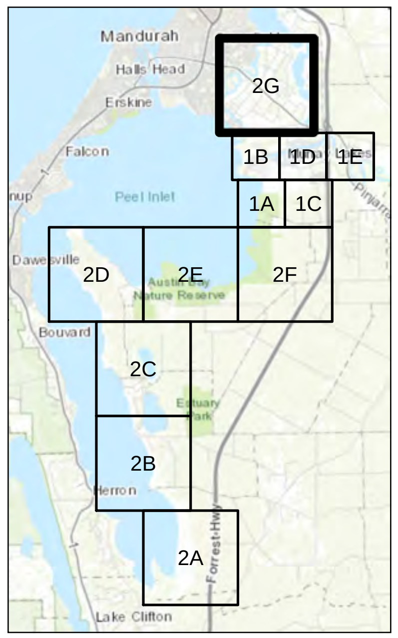
Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

1:20,000
Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 2G

C.4.2 Coastal Inundation Hazard – 100yr ARI Scenario, Planning Year 2070 (Includes 0.4m Sea Level Rise)

Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm
in Planning Year 2070

Inundation Depth Based on Peak Water level of 1.49m AHD (includes 0.4m Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

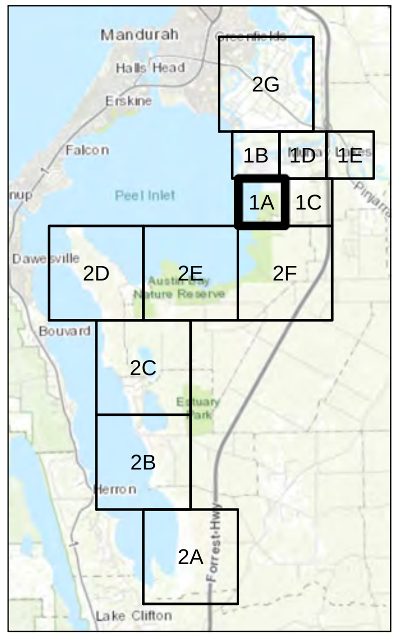
Spatial Reference: GDA 1994 MGA Zone 50

N W E S

0 100 200 300 400 500 m

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 1A

Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2070

Inundation Depth Based on Peak Water level of 1.49m AHD (includes 0.4m Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

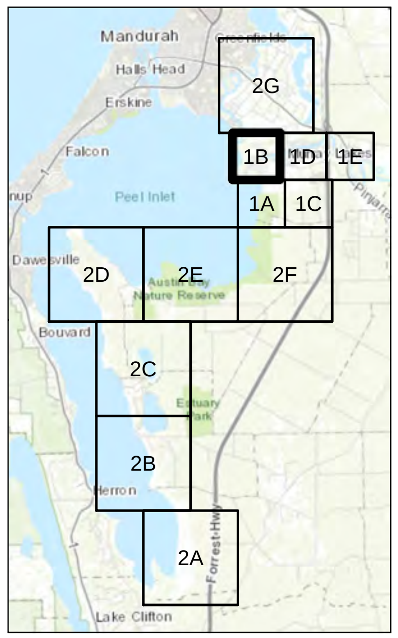
Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 1B

Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2070

Inundation Depth Based on Peak Water level of 1.49m AHD (includes 0.4m Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

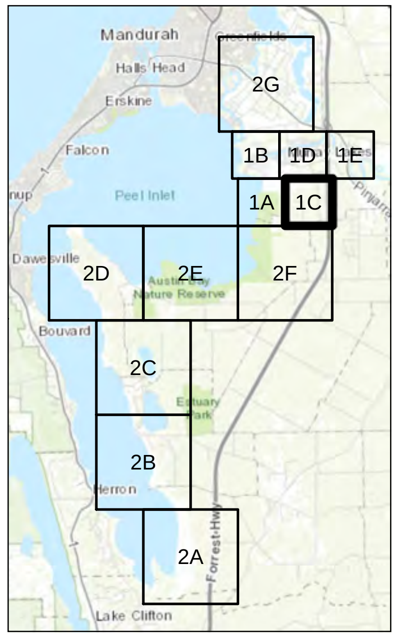
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

N W E S

0 100 200 300 400 500 m

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 1C

Shire of Murray Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2070

Inundation Depth Based on Peak Water level of 1.49m AHD (includes 0.4m Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

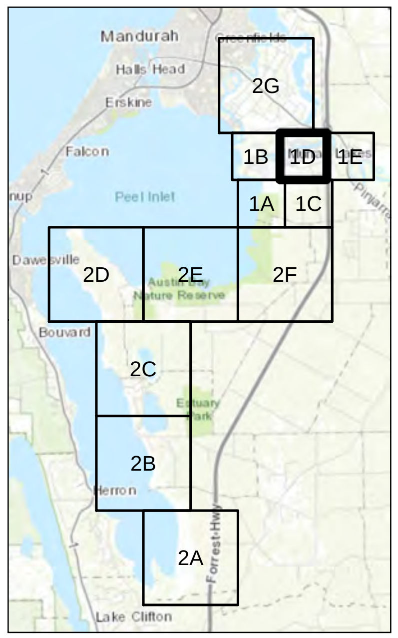
Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 100 200 300 400 500 m

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 1D

Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2070

Inundation Depth Based on Peak Water level of 1.49m AHD (includes 0.4m Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.

Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

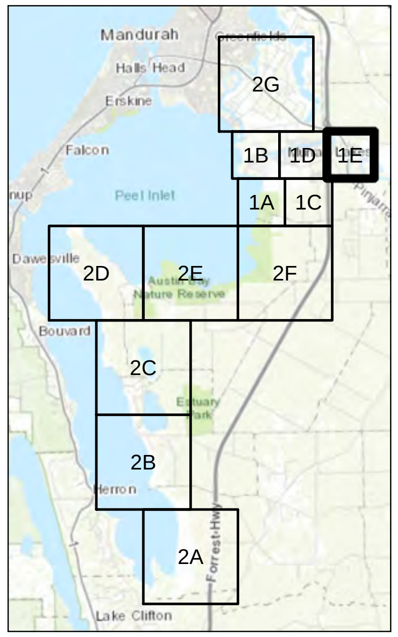
Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 100 200 300 400 500 m

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).

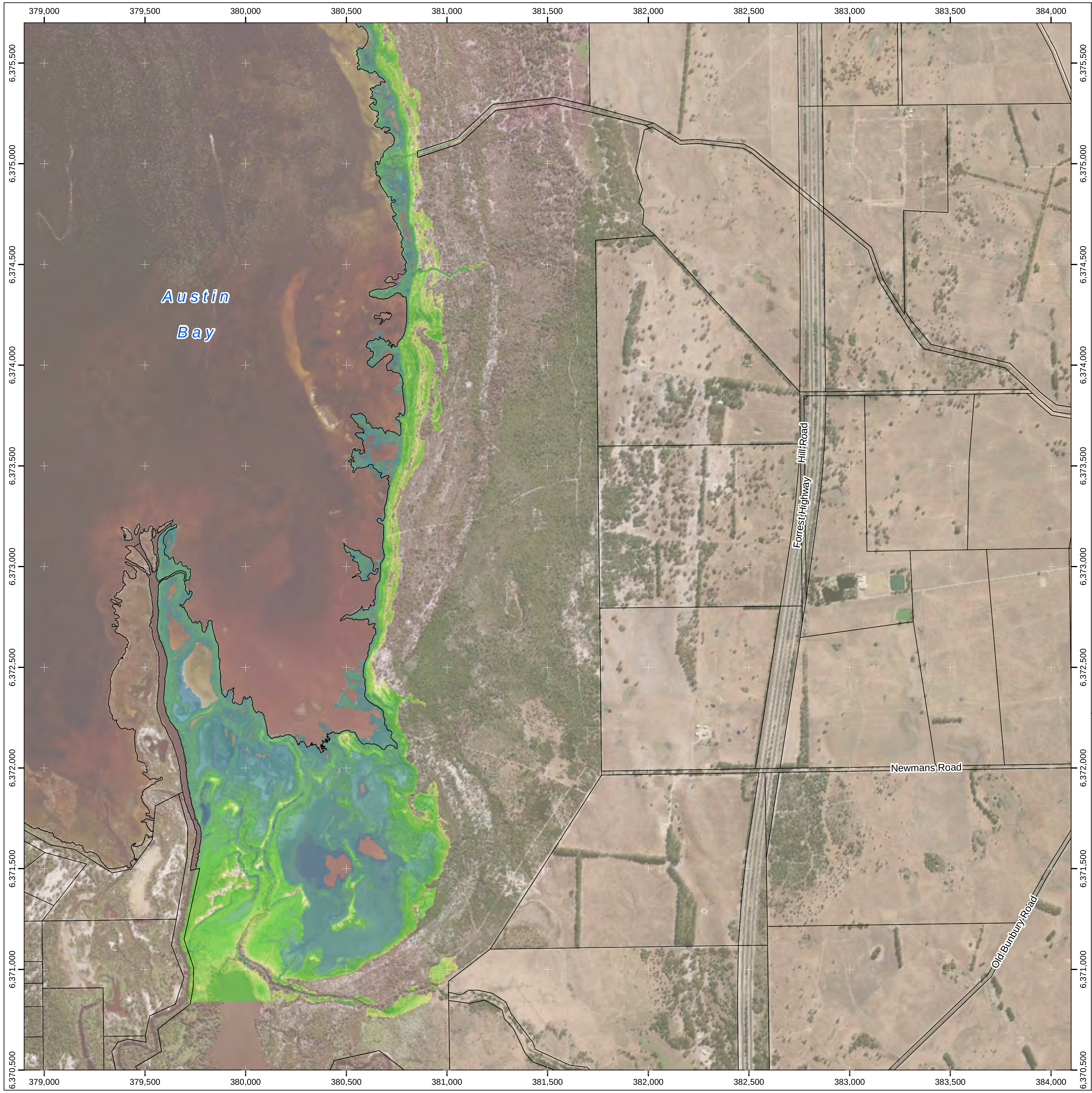


Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 1E



Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2070

Inundation Depth Based on Peak Water level of 1.49m AHD (includes 0.4m Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

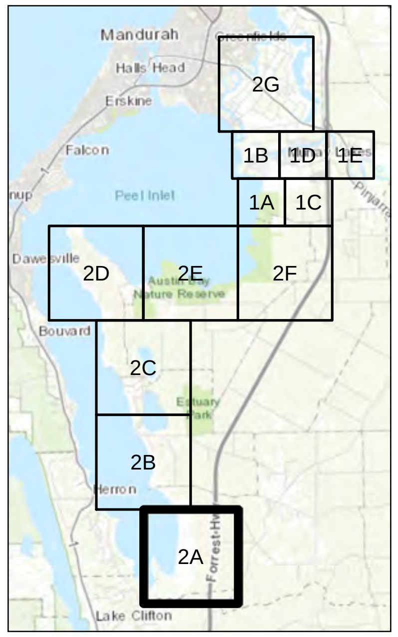
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

N W E S

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 2A

Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2070

Inundation Depth Based on Peak Water level of 1.49m AHD (includes 0.4m Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

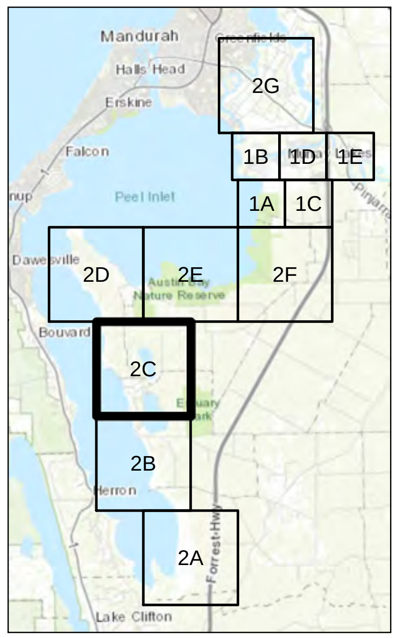
Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

N W E S

0 200 400 600 800 1,000 m

1:20,000
Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 2C

Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm
in Planning Year 2070

Inundation Depth Based on Peak Water level of 1.49m AHD (includes 0.4m Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.

Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

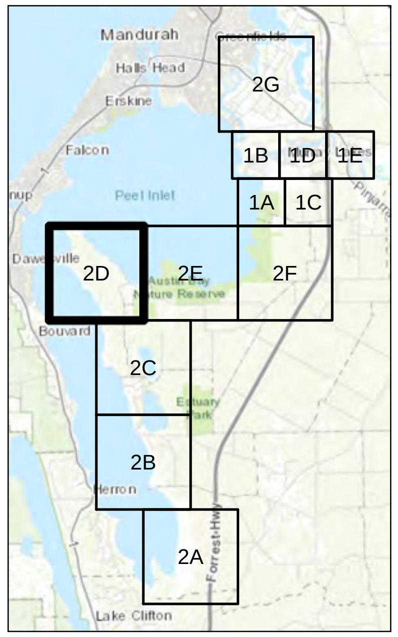
Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray

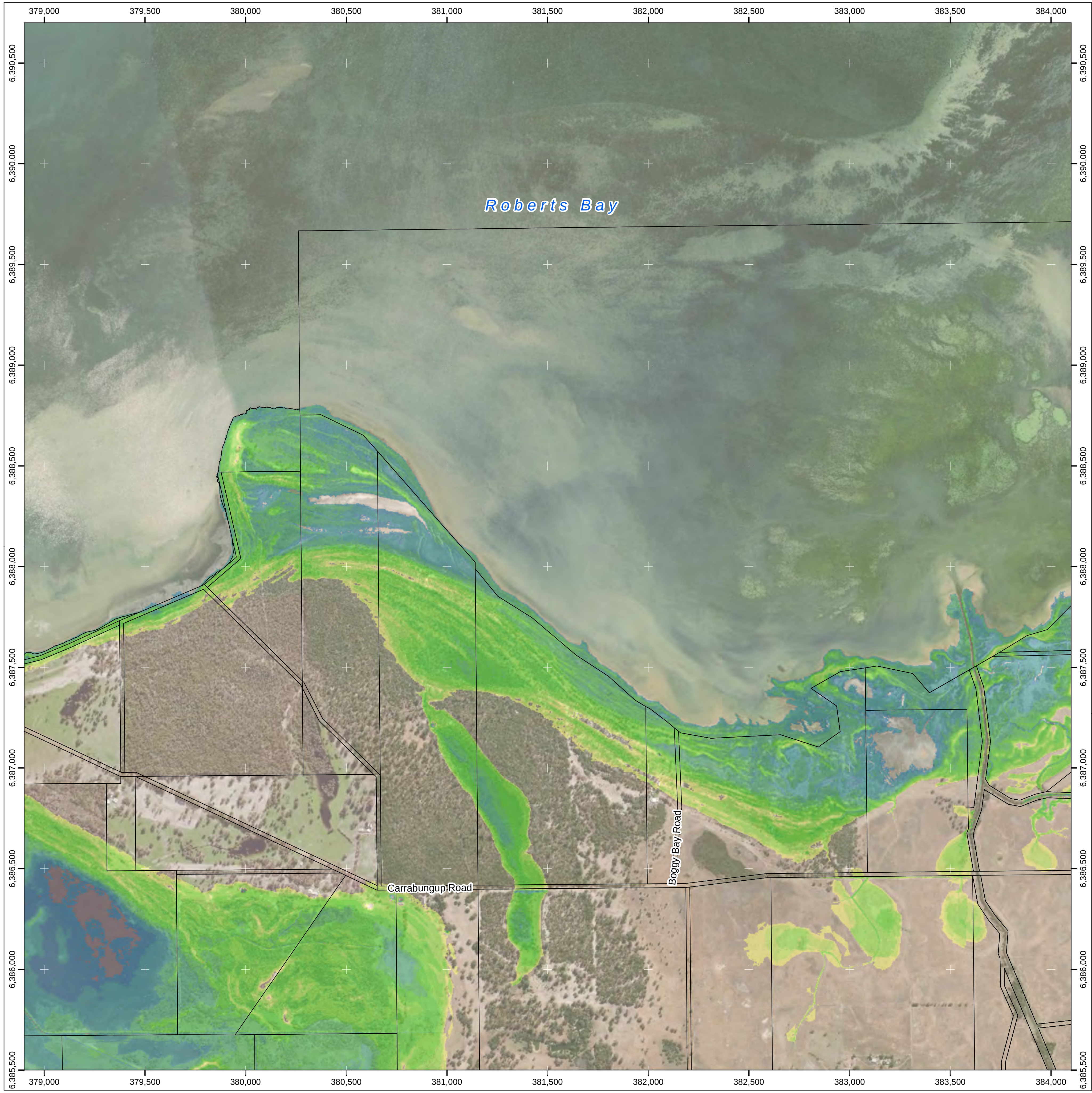
1915 Pinjarra Rd
Pinjarra WA 6208

https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 2D



Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm
in Planning Year 2070

Inundation Depth Based on Peak Water level of 1.49m AHD (includes 0.4m Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.

Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

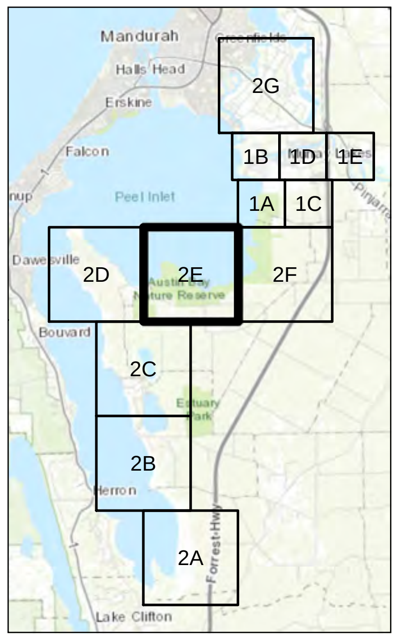
Spatial Reference: GDA 1994 MGA Zone 50

N W E S

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray

1915 Pinjarra Rd
Pinjarra WA 6208

https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 2E

Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2070

Inundation Depth Based on Peak Water level of 1.49m AHD (includes 0.4m Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

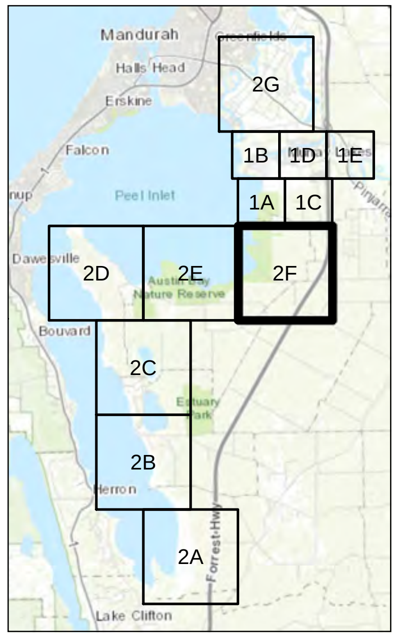
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).

N W E S



Shire of Murray

1915 Pinjarra Rd
Pinjarra WA 6208

https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 2F

Shire of Murray
Coastal Hazard Flood Mapping

100yr ARI Design Storm in Planning Year 2070

Inundation Depth Based on Peak Water level of 1.49m AHD (includes 0.4m Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

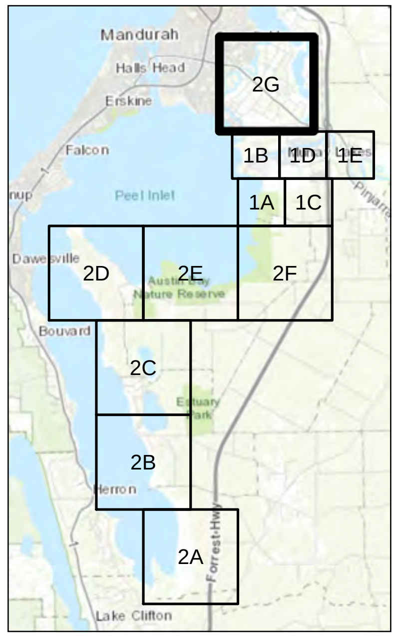
Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 2G

C.4.3 Coastal Inundation Hazard – 500yr ARI Scenario, Planning Year 2020 (No Sea Level Rise)

Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm
in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.44m AHD (No Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

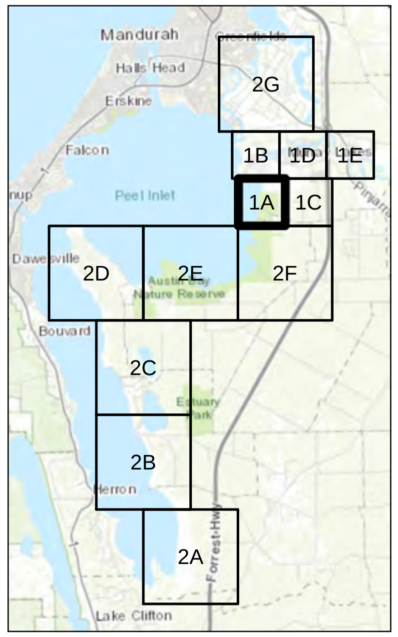
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

N W E S

0 100 200 300 400 500 m

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 1A

Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm
in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.44m AHD (No Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

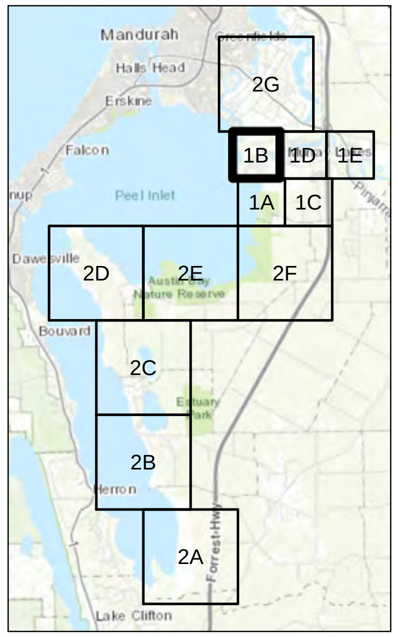
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

N W E S

0 100 200 300 400 500 m

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 1B

Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm
in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.44m AHD (No Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

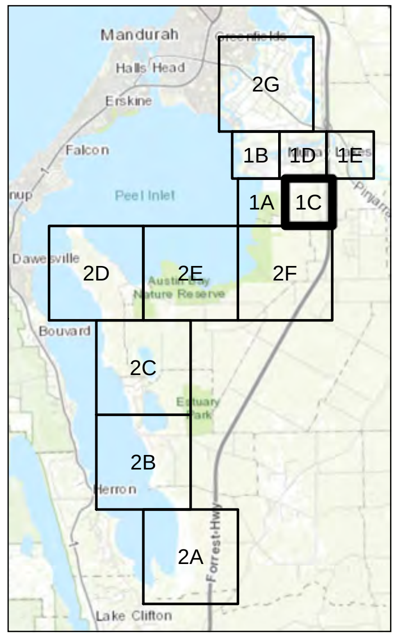
Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 100 200 300 400 500 m

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray

1915 Pinjarra Rd
Pinjarra WA 6208

https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 1C

Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.44m AHD (No Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

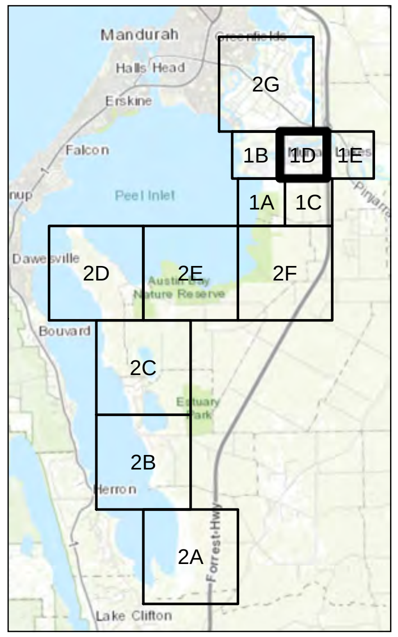
Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 100 200 300 400 500 m

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 1D

Shire of Murray Coastal Hazard Flood Mapping

500yr ARI Design Storm in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.44m AHD (No Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

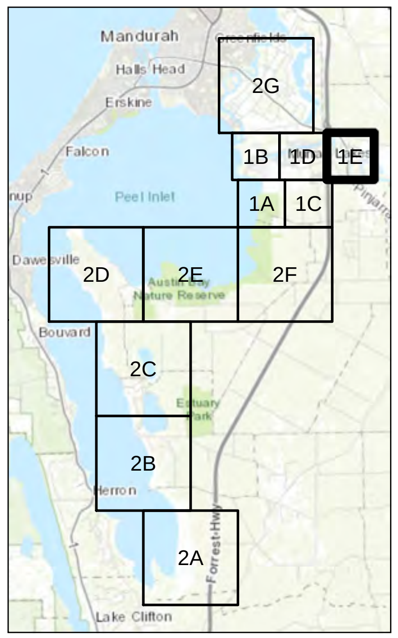
Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

Spatial Reference: GDA 1994 MGA Zone 50

0 100 200 300 400 500 m

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).

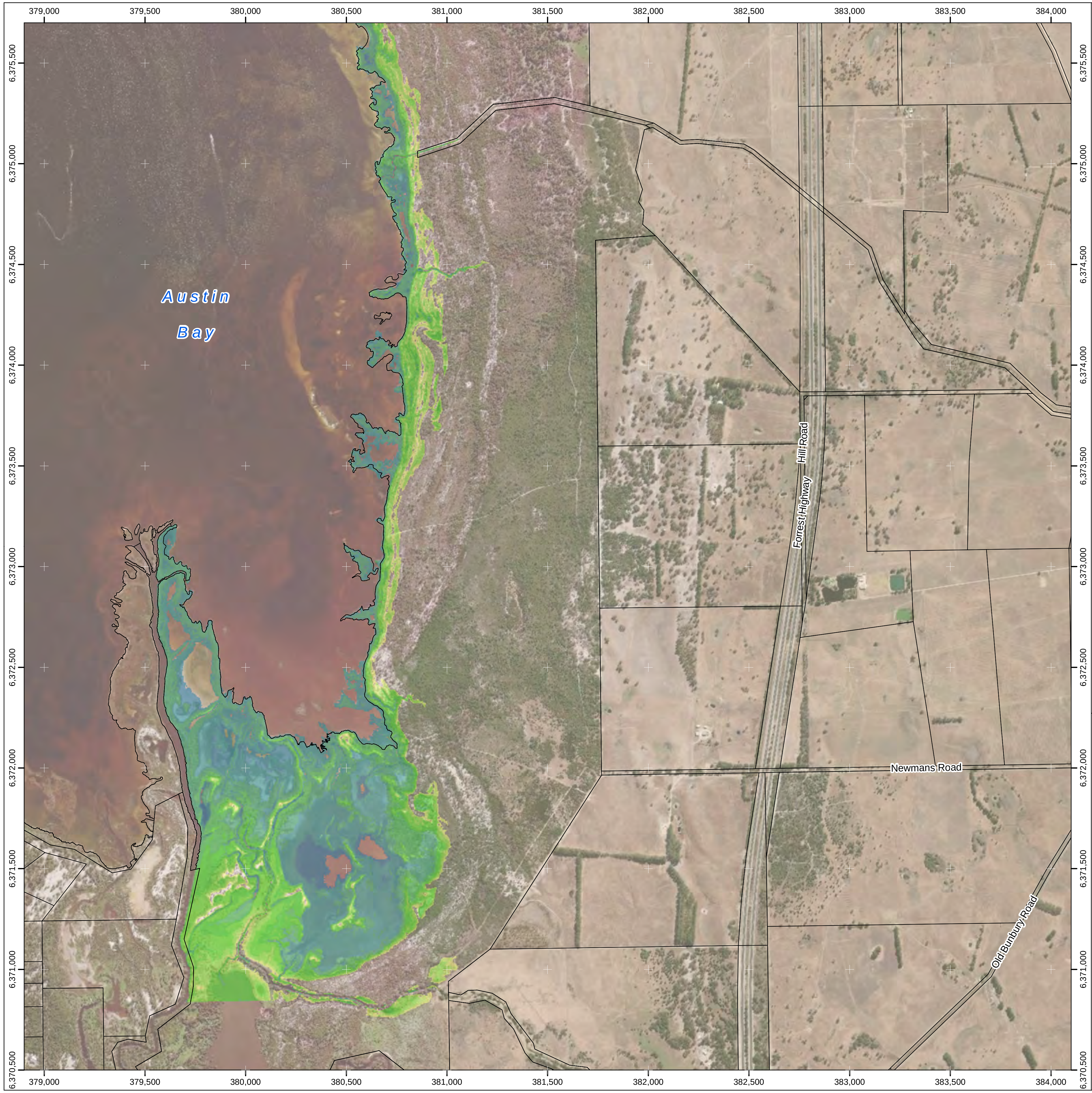


Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 1E



Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.44m AHD (No Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

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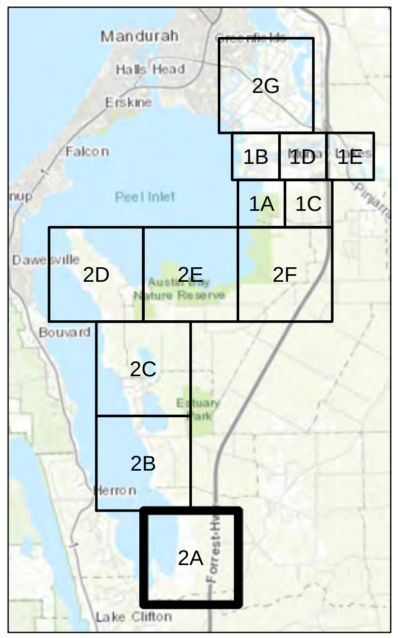
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 2A

Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.44m AHD (No Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

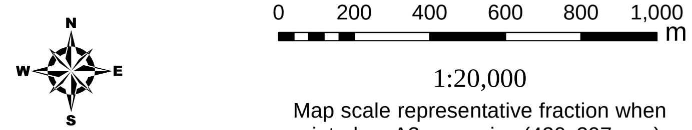
Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.

Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50



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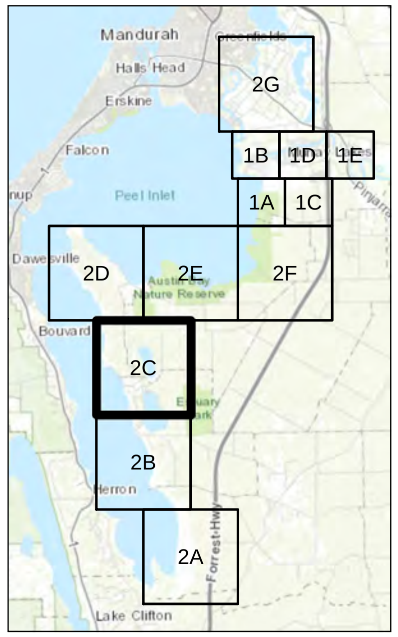
Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 2C

Shire of Murray Coastal Hazard Flood Mapping

500yr ARI Design Storm in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.44m AHD (No Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.

Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

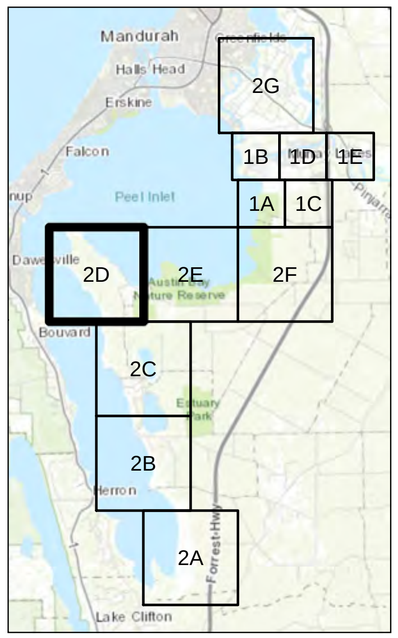
Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray

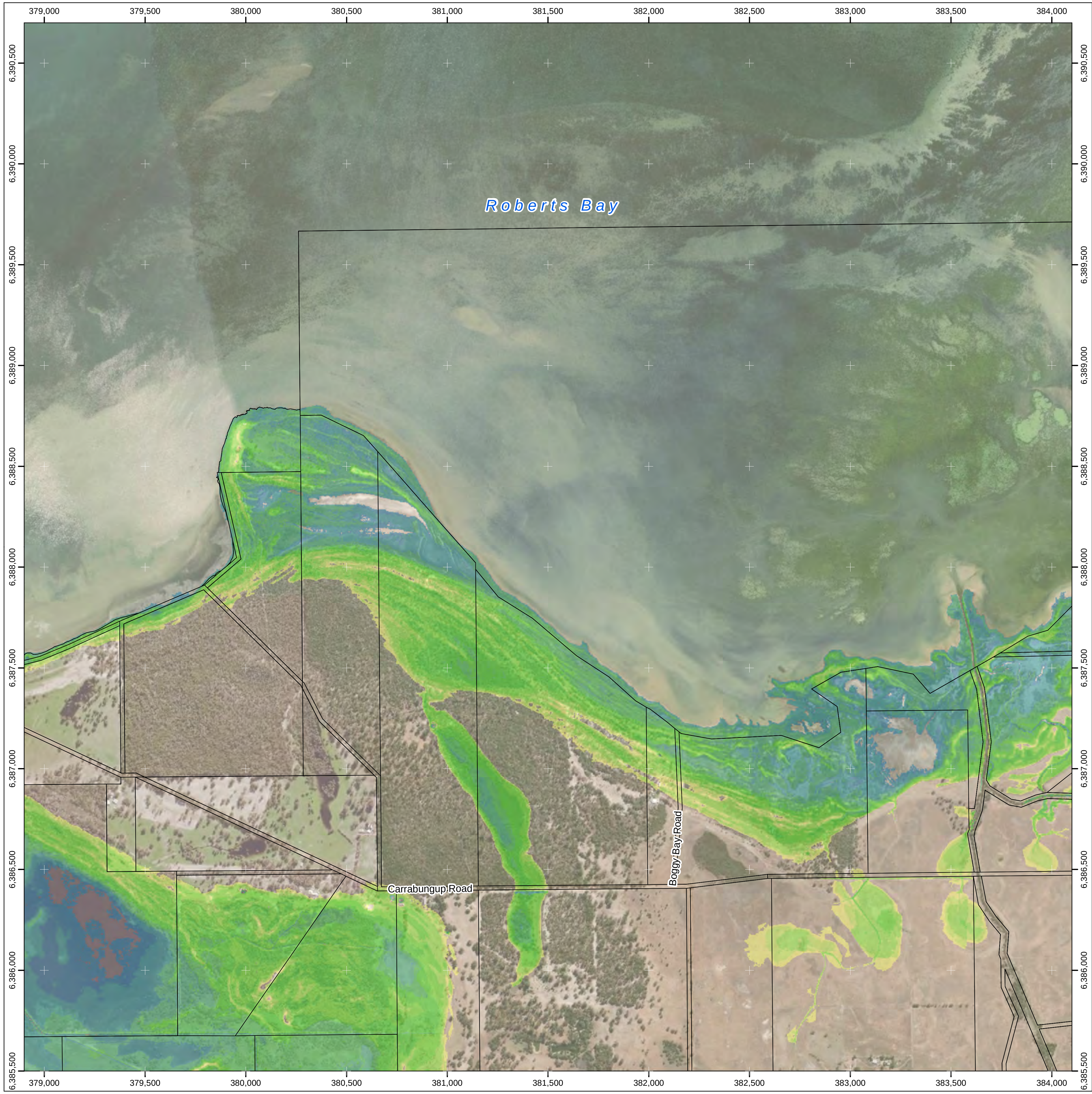
1915 Pinjarra Rd
Pinjarra WA 6208

https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 2D



Shire of Murray Coastal Hazard Flood Mapping

500yr ARI Design Storm in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.44m AHD (No Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

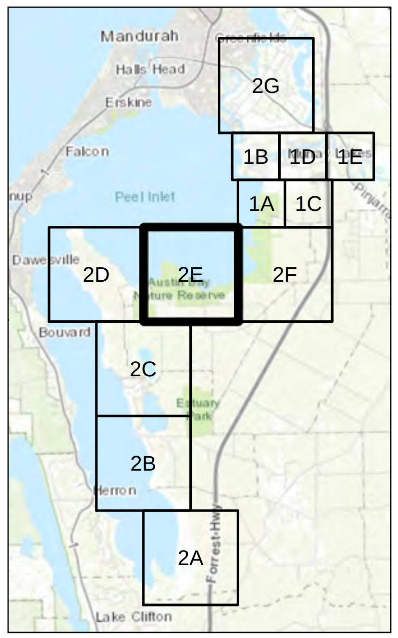
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

N W E S

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 2E

Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm
in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.44m AHD (No Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

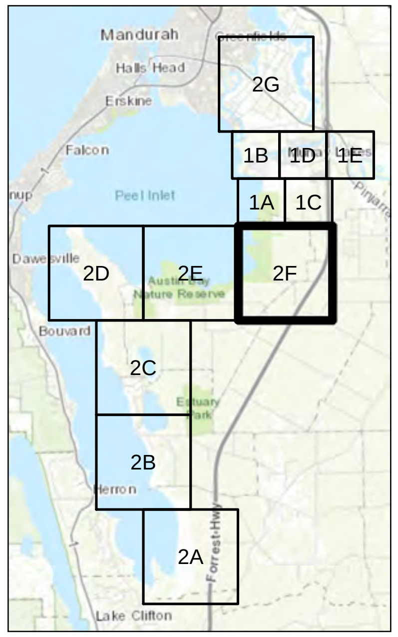
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

N W E S

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray

1915 Pinjarra Rd
Pinjarra WA 6208

https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 2F

Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm in Planning Year 2020

Inundation Depth Based on Peak Water level of 1.44m AHD (No Sea Level Rise)

Inundation Depth (m)

- > 1.4
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- 0 - 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.

Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

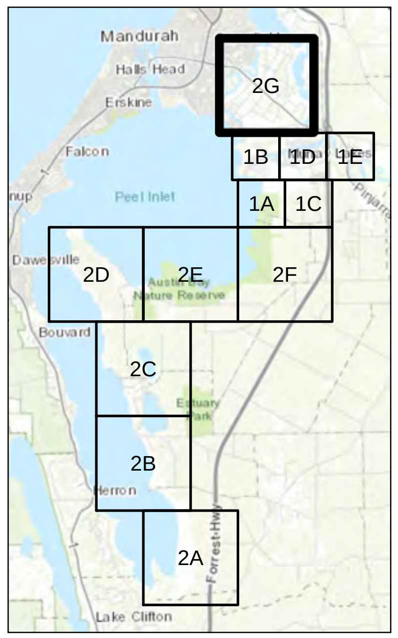
Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



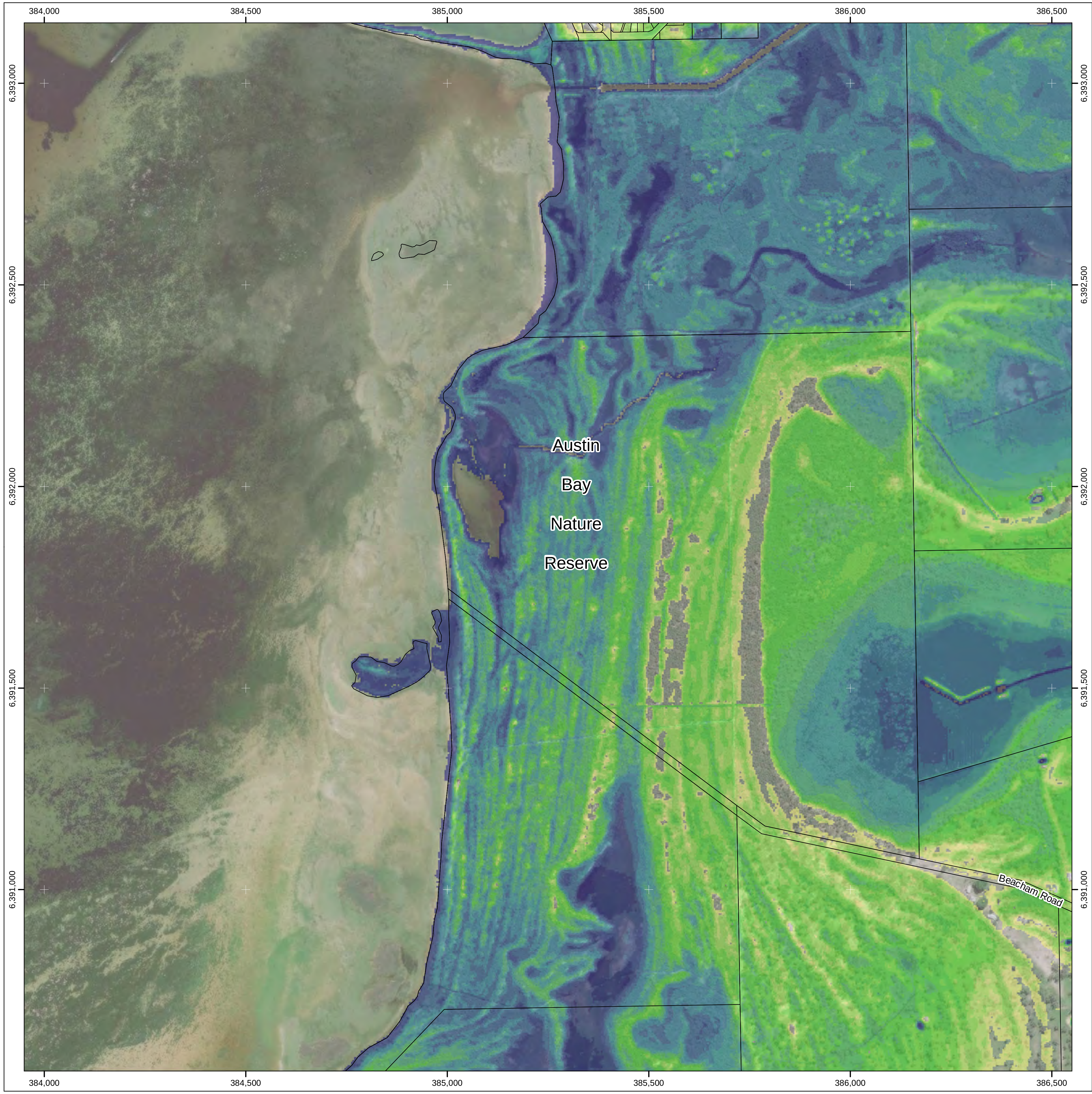
Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 19 Nov. 2020

Mapsheet: 2G

C.4.4 Coastal Inundation Hazard – 500yr ARI Scenario, Planning Year 2120 (Includes 0.9m Sea Level Rise)



Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm in Planning year 2120

Inundation Depth Based on Peak Water level of 2.34m AHD (includes 0.9m Sea Level Rise)

Inundation Depth (m)

- > 2.0
- 1.81 - 2.0
- 1.61 - 1.8
- 1.41 - 1.6
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1.0
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- < 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.

Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

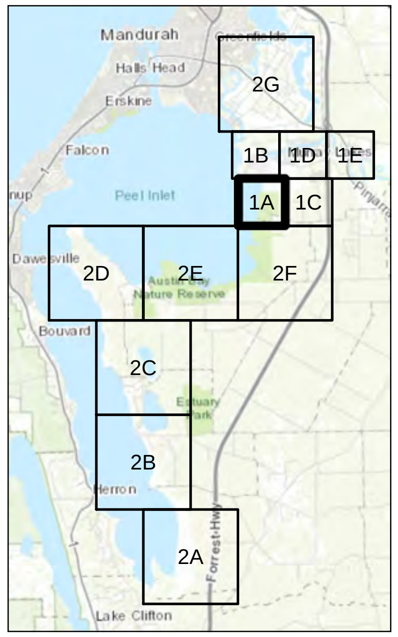
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

N W E S

0 100 200 300 400 500 m

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



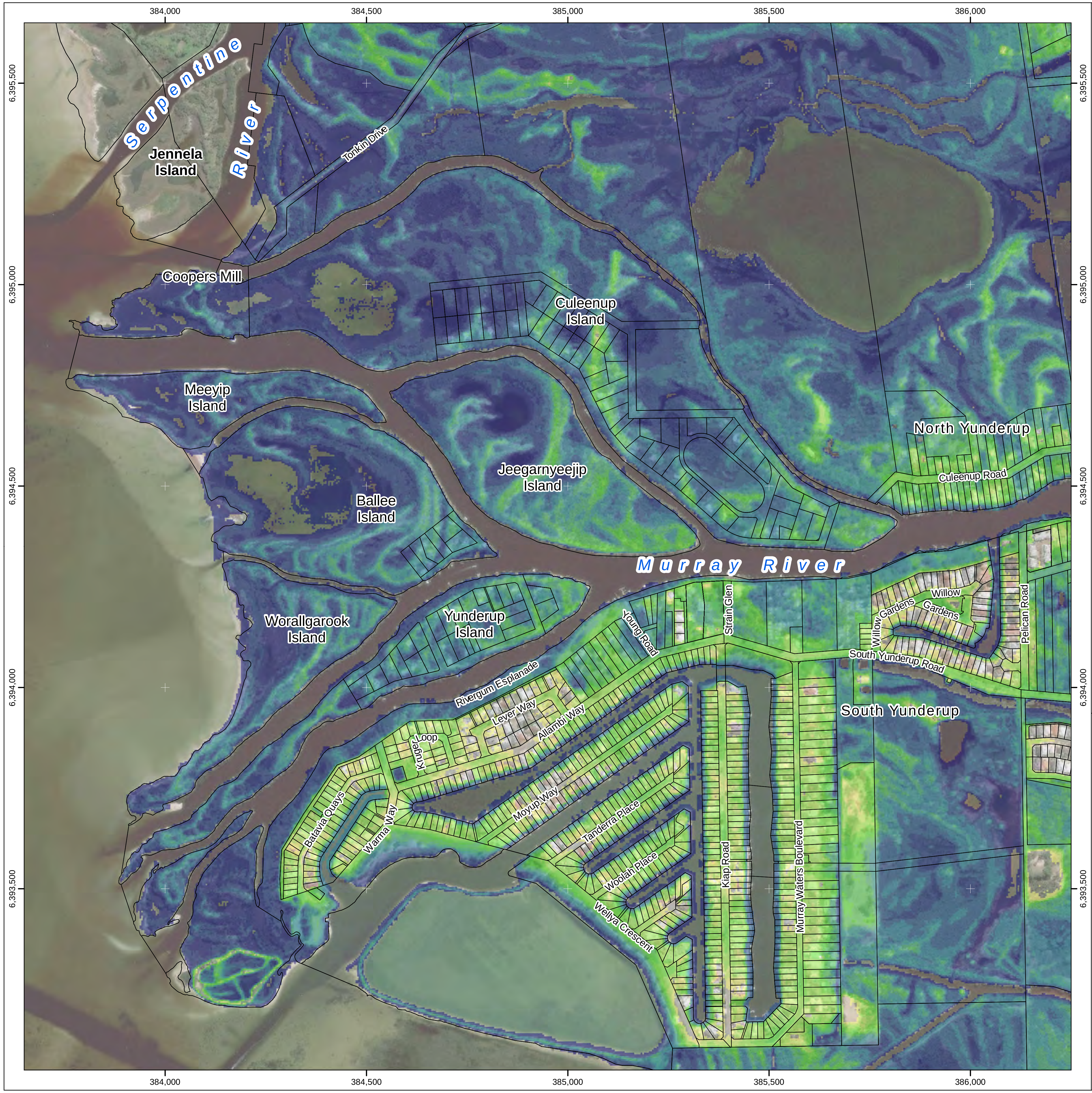
Shire of Murray

1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 16 Nov. 2020

Mapsheet: 1A



Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm in Planning year 2120

Inundation Depth Based on Peak Water level of 2.34m AHD (includes 0.9m Sea Level Rise)

Inundation Depth (m)

- > 2.0
- 1.81 - 2.0
- 1.61 - 1.8
- 1.41 - 1.6
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1.0
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- < 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

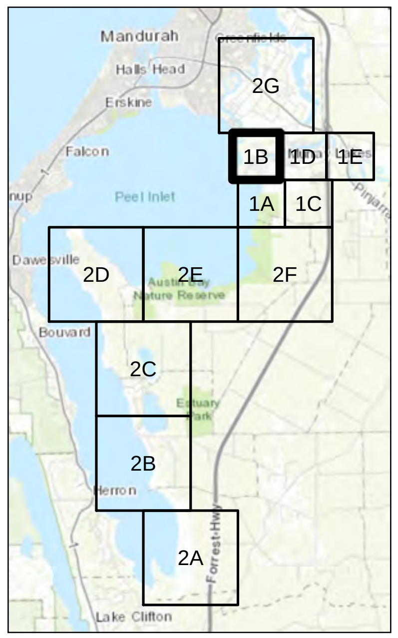
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 100 200 300 400 500 m

N W E S

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 16 Nov. 2020

Mapsheet: 1B

Shire of Murray Coastal Hazard Flood Mapping

500yr ARI Design Storm in Planning year 2120

Inundation Depth Based on Peak Water level of 2.34m AHD (includes 0.9m Sea Level Rise)

Inundation Depth (m)

- > 2.0
- 1.81 - 2.0
- 1.61 - 1.8
- 1.41 - 1.6
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1.0
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- < 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

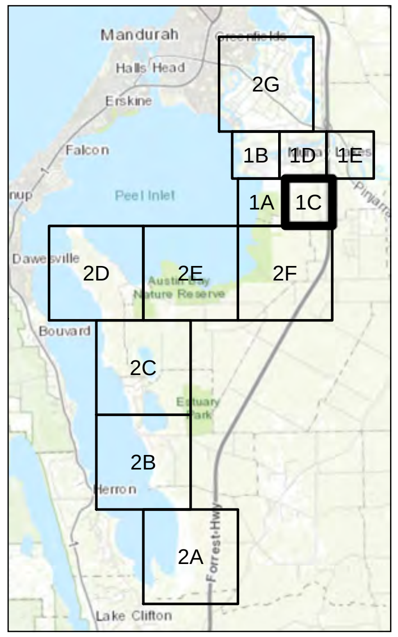
Street name data © OpenStreetMap contributors. Basemap Image: ESRI World Imagery © 2020. Spatial Reference: GDA 1994 MGA Zone 50

0 100 200 300 400 500 m

N W E S

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray

1915 Pinjarra Rd
Pinjarra WA 6208

https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 16 Nov. 2020

Mapsheet: 1C

Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm in Planning year 2120

Inundation Depth Based on Peak Water level of 2.34m AHD (includes 0.9m Sea Level Rise)

Inundation Depth (m)

- > 2.0
- 1.81 - 2.0
- 1.61 - 1.8
- 1.41 - 1.6
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1.0
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- < 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

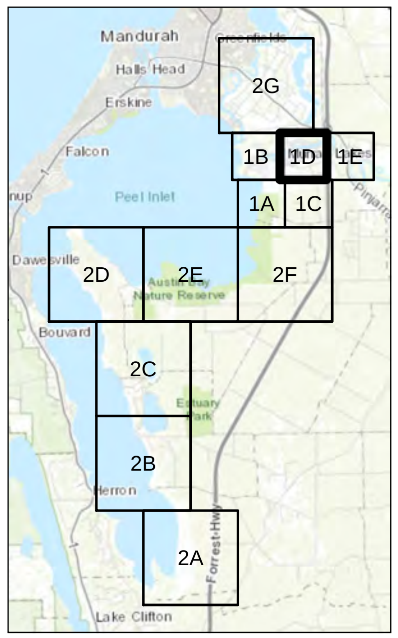
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 100 200 300 400 500 m

N W E S

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 16 Nov. 2020

Mapsheet: 1D

Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm
in Planning year 2120

Inundation Depth Based on Peak Water level of 2.34m AHD (includes 0.9m Sea Level Rise)

Inundation Depth (m)

- > 2.0
- 1.81 - 2.0
- 1.61 - 1.8
- 1.41 - 1.6
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1.0
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- < 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

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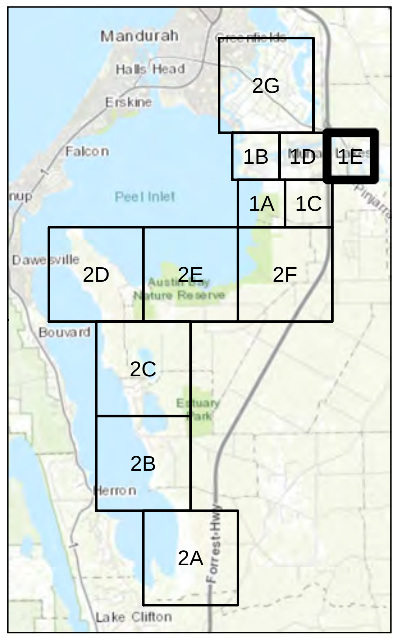
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 100 200 300 400 500 m

1:10,000

Map scale representative fraction when printed on A3 page size (420x297 mm).

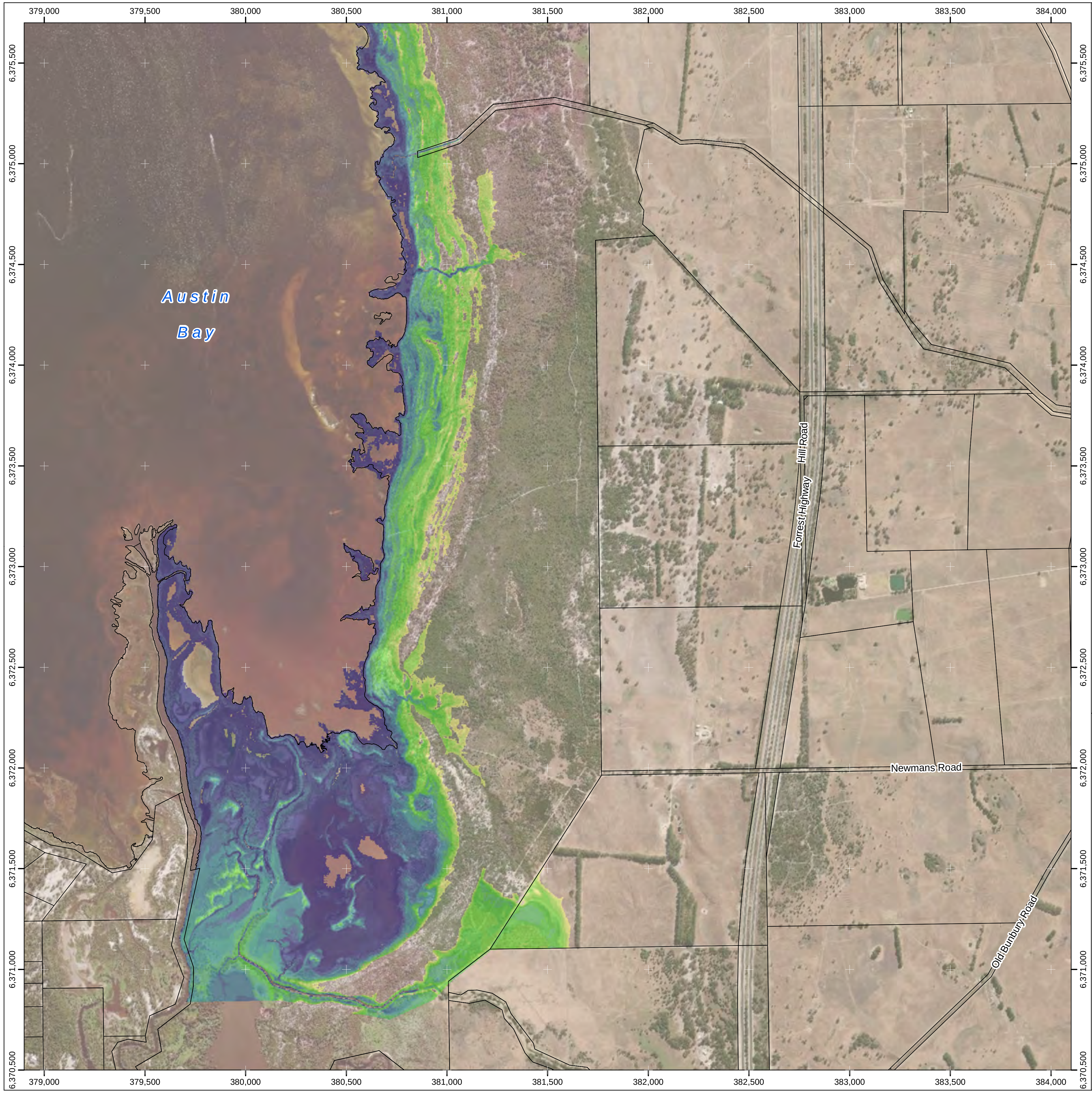


Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 16 Nov. 2020

Mapsheet: 1E



Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm in Planning year 2120

Inundation Depth Based on Peak Water level of 2.34m AHD (includes 0.9m Sea Level Rise)

Inundation Depth (m)

- > 2.0
- 1.81 - 2.0
- 1.61 - 1.8
- 1.41 - 1.6
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1.0
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- < 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

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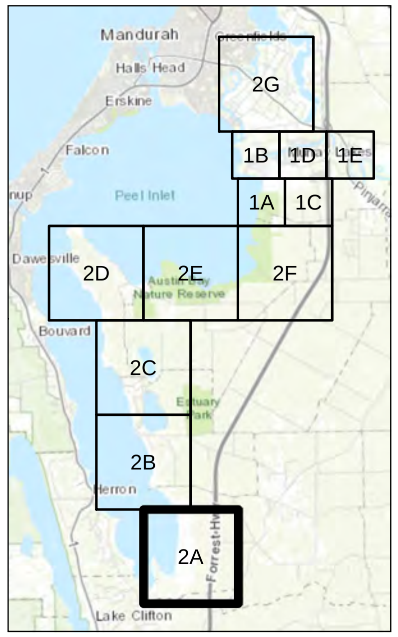
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).

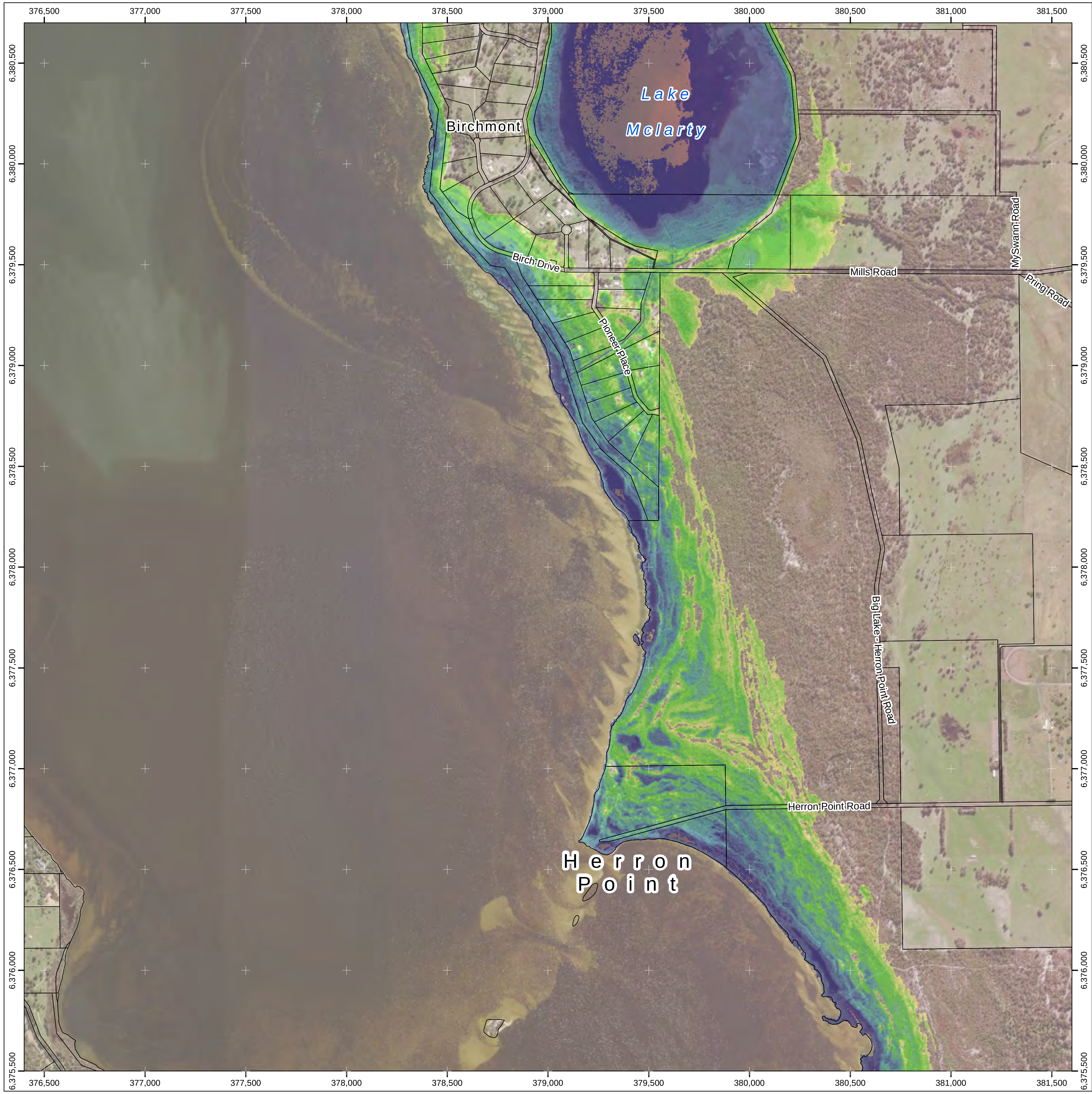


Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 16 Nov. 2020

Mapsheet: 2A



Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm in Planning year 2120

Inundation Depth Based on Peak Water level of 2.34m AHD (includes 0.9m Sea Level Rise)

Inundation Depth (m)

- > 2.0
- 1.81 - 2.0
- 1.61 - 1.8
- 1.41 - 1.6
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1.0
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- < 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

Cadastral data supplied by Landgate. This product is for information purposes only and is not guaranteed. The information may be out of date and should not be relied upon without further verification from the original documents. Where the information is being used for legal purposes then the original documents must be searched for all legal requirements.

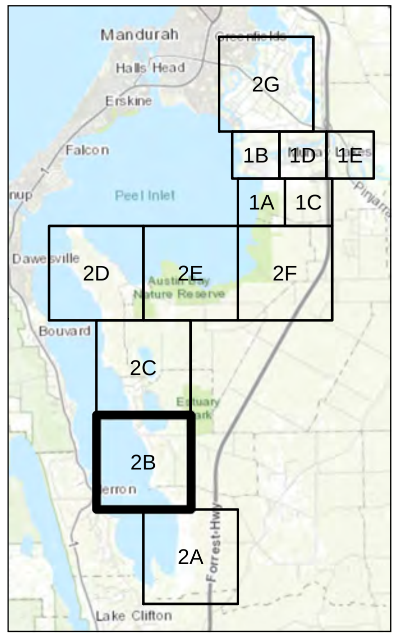
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

N W E S

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray

1915 Pinjarra Rd
Pinjarra WA 6208

https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 16 Nov. 2020

Mapsheet: 2B

Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm in Planning year 2120

Inundation Depth Based on Peak Water level of 2.34m AHD (includes 0.9m Sea Level Rise)

Inundation Depth (m)

- > 2.0
- 1.81 - 2.0
- 1.61 - 1.8
- 1.41 - 1.6
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1.0
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- < 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

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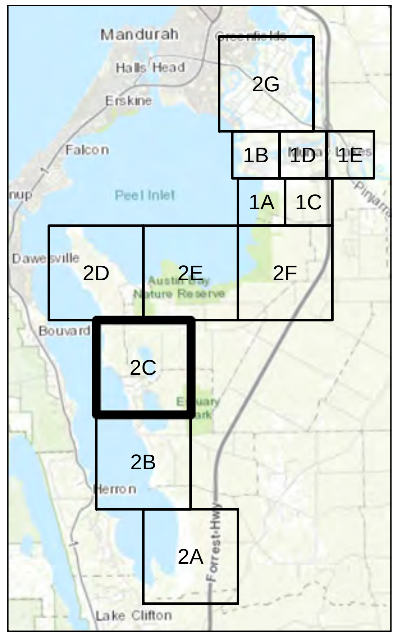
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

N W E S

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 16 Nov. 2020

Mapsheet: 2C

Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm in Planning year 2120

Inundation Depth Based on Peak Water level of 2.34m AHD (includes 0.9m Sea Level Rise)

Inundation Depth (m)

- > 2.0
- 1.81 - 2.0
- 1.61 - 1.8
- 1.41 - 1.6
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1.0
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- < 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.

Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

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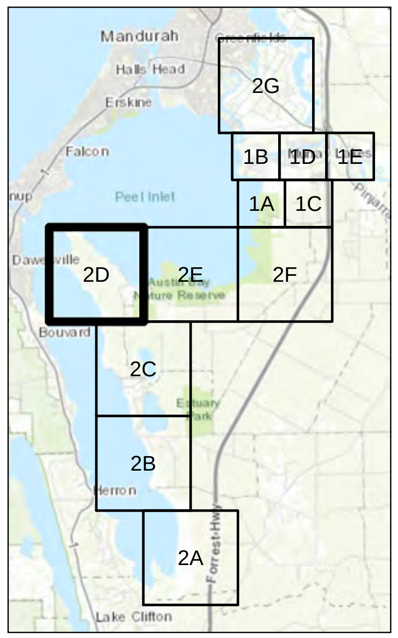
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

N W E S

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray

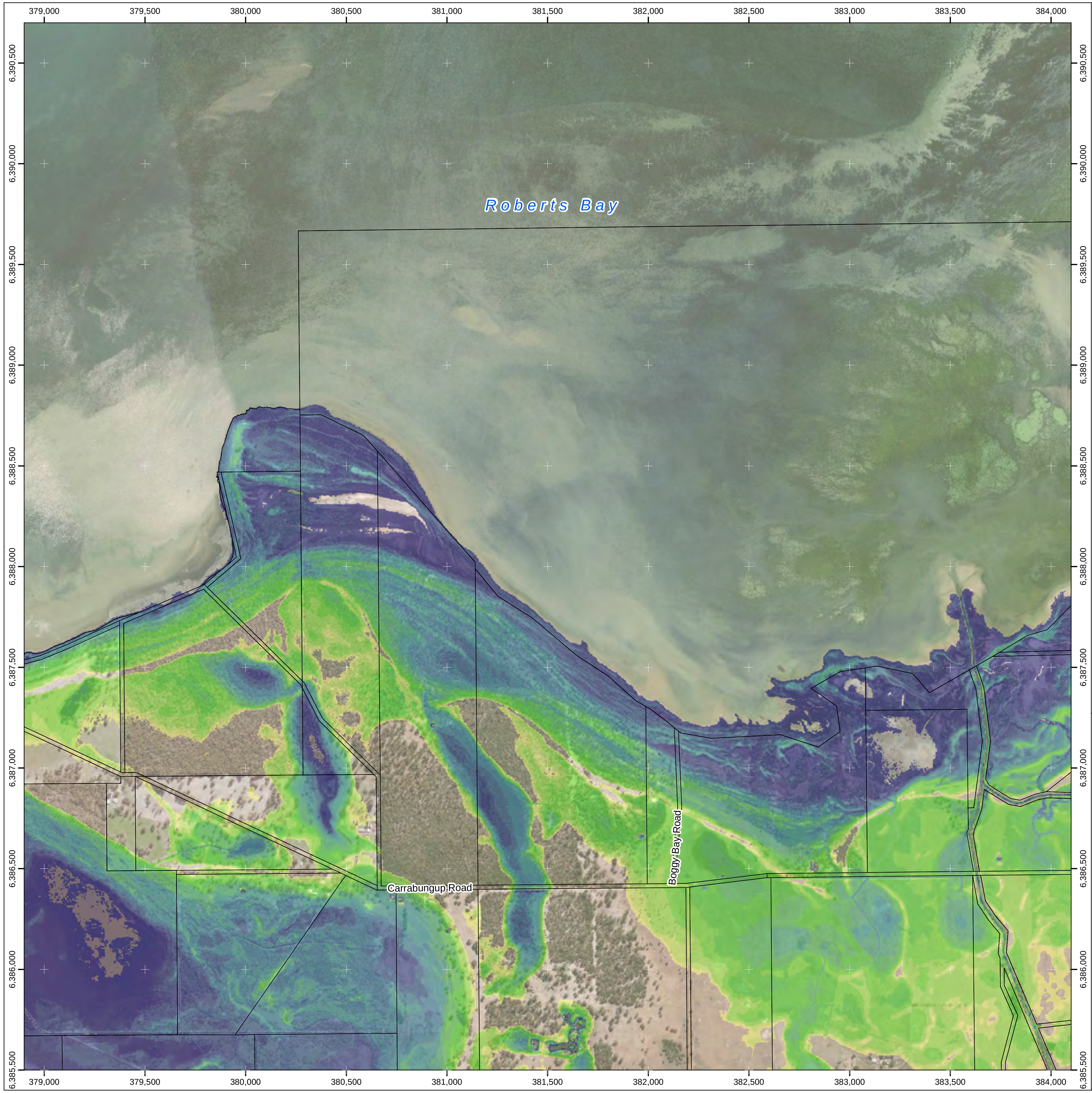
1915 Pinjarra Rd
Pinjarra WA 6208

https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 16 Nov. 2020

Mapsheet: 2D



Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm
in Planning year 2120

Inundation Depth Based on Peak Water level of 2.34m AHD (includes 0.9m Sea Level Rise)

Inundation Depth (m)

- > 2.0
- 1.81 - 2.0
- 1.61 - 1.8
- 1.41 - 1.6
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1.0
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- < 0.1

Source Data

Inundation areas defined from LiDAR datasets collected in 2008 (DWER) and 2016 (Landgate) through the Shire of Murray.
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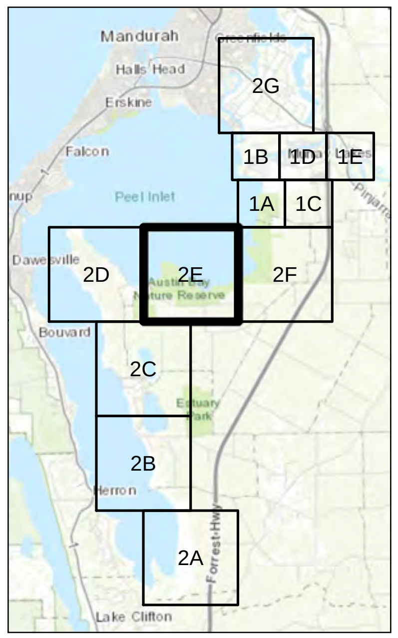
Street name data © OpenStreetMap contributors.
Basemap Image: ESRI World Imagery © 2020.
Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).

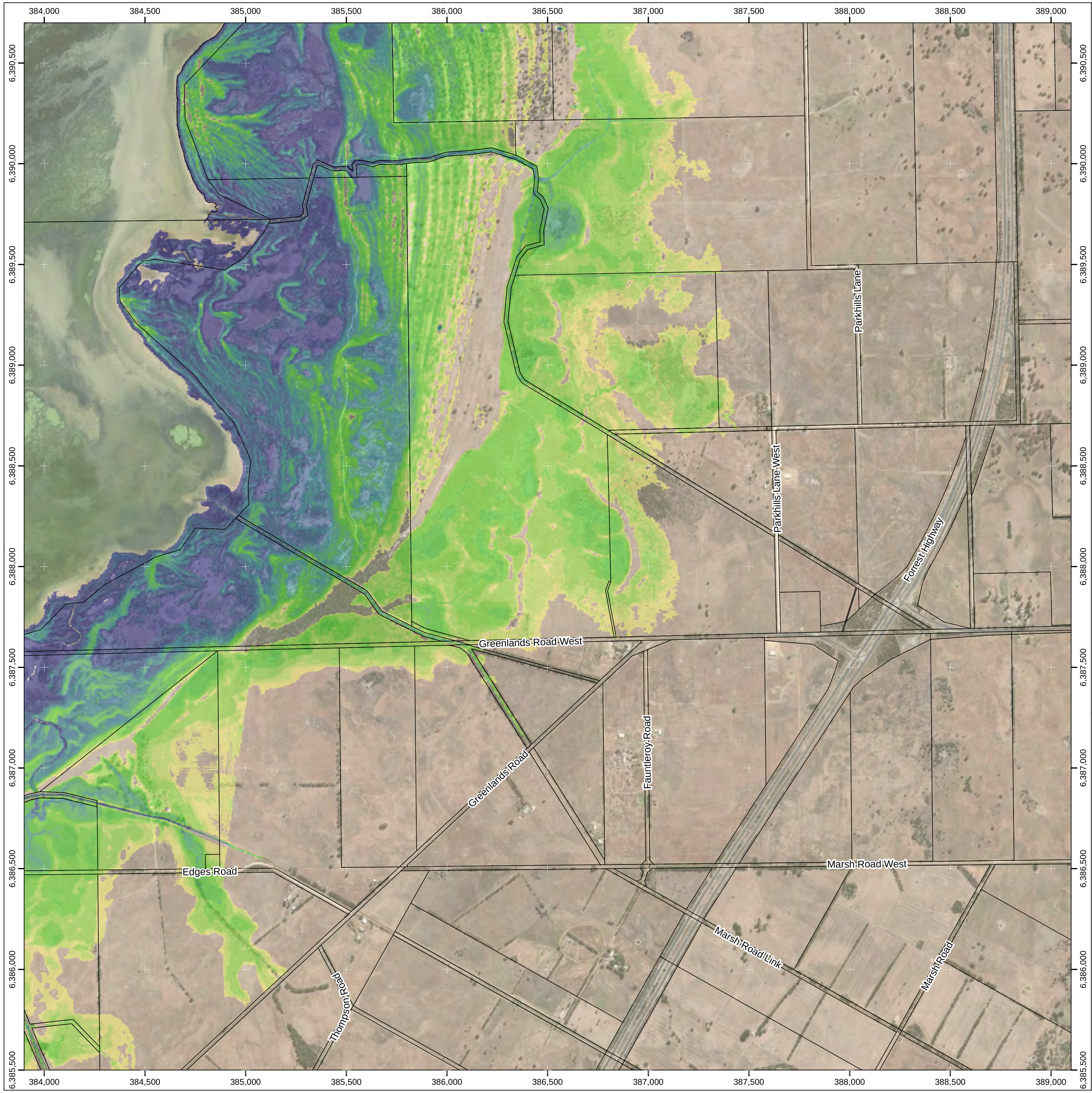


Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 16 Nov. 2020

Mapsheet: 2E



Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm
in Planning year 2120

Inundation Depth Based on Peak Water level of 2.34m AHD (includes 0.9m Sea Level Rise)

Inundation Depth (m)

- > 2.0
- 1.81 - 2.0
- 1.61 - 1.8
- 1.41 - 1.6
- 1.21 - 1.4
- 1.01 - 1.2
- 0.81 - 1.0
- 0.61 - 0.8
- 0.41 - 0.6
- 0.21 - 0.4
- 0.11 - 0.2
- < 0.1

Source Data

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Levels across Austin Lakes development based on construction drawings (2009) with minimum 2.9m AHD level across site.

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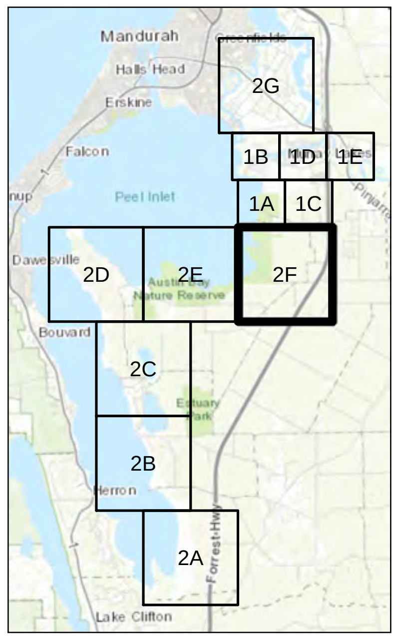
Street name data © OpenStreetMap contributors. Basemap Image: ESRI World Imagery © 2020. Spatial Reference: GDA 1994 MGA Zone 50

N W E S

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).

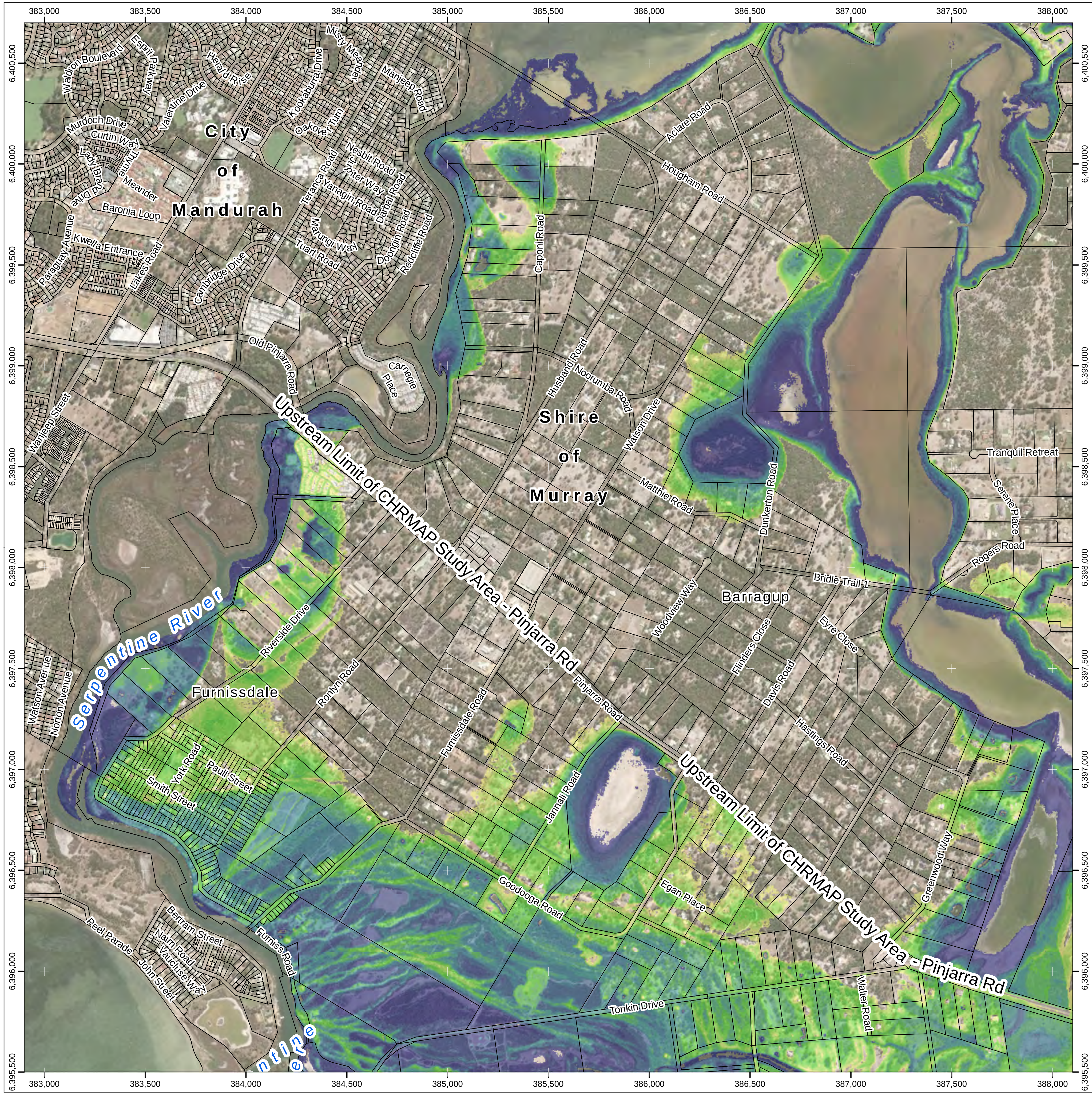


Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 16 Nov. 2020

Mapsheet: 2F



Shire of Murray
Coastal Hazard Flood Mapping

500yr ARI Design Storm in Planning year 2120

Inundation Depth Based on Peak Water level of 2.34m AHD (includes 0.9m Sea Level Rise)

Inundation Depth (m)

- > 2.0
- 1.81 - 2.0
- 1.61 - 1.8
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- 0.11 - 0.2
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Source Data

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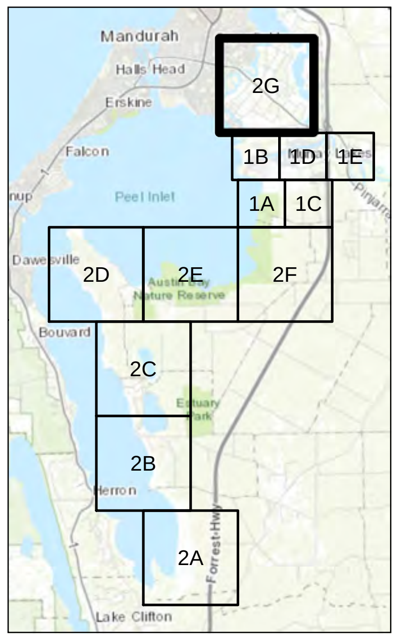
Street name data © OpenStreetMap contributors. Basemap Image: ESRI World Imagery © 2020. Spatial Reference: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 m

1:20,000

Map scale representative fraction when printed on A3 page size (420x297 mm).



Shire of Murray
1915 Pinjarra Rd
Pinjarra WA 6208
https://www.murray.wa.gov.au/

Mapping prepared by Baird.

Map Published: 16 Nov. 2020

Mapsheet: 2G