MODERATE Inundation Risk
at coast

Shire of Dandaragan

Focus

Adaptation Priority

Management at Foreshore

Actions

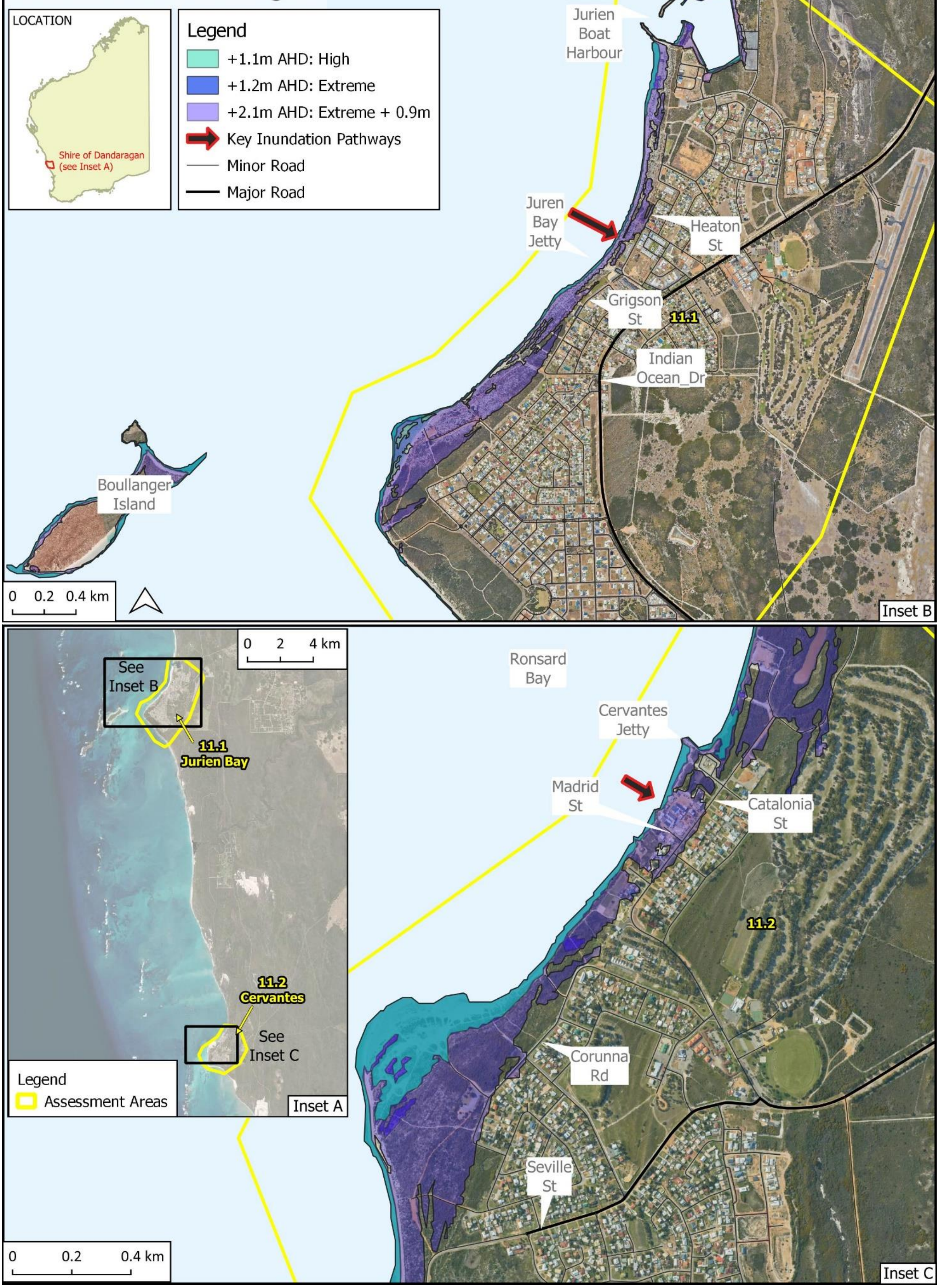
Management at Foreshore

Targeted Mitigation

WL Review (CHRMAP)

Seashore Engineering

11. Shire of Dandaragan



11. DANDARAGAN

Site overview:
The authors wish to acknowledge the Yued people as the native title holders of the lands and waters in and around the Shire of Dandaragan. The Shire of Dandaragan is located approximately 200km north of Perth and has a population of over 3,000 people. The major townsites of Jurien Bay and Cervantes have estimated populations of 1,500 and 545 respectively. Mining is the largest industry sector to the local economy, however the agricultural, farming and fishing sectors are major employers in the region. Tourism and hospitality have shown the fastest employment growth rates with seasonal influx of visitors during holiday periods increasing the population to approximately 4,500-5,000.

Areas at risk from inundation:
Exposure to inundation impacts in the Dandaragan LGA has been considered for two areas with land areas above Highest Astronomical Tide[1] (HAT) potentially inundated under high (~25yr ARI), extreme (~100yr ARI), and extreme +0.9m (~100yr ARI +0.9m) water levels estimated as:

REGION	WL ARI	1.1m AHD High	1.2m AHD Extreme	2.1m AHD Extreme + 0.9m
11.1 Jurien Bay		0.1km^2	0.1km^2	0.8km^2
11.2 Cervantes		0.1km^2	0.2km^2	0.8km^2

There is not presently an inundation problem *per se*, although the existing foreshore reserve is potentially inadequate to manage wave setup and run up.

Morphology: Cuspate Foreland; Offshore Reef Protection; Rock Control

11.1 Jurien Bay:
- Island Point in Jurien Bay is a cuspate foreland that has formed in the lee of a chain of submerged reefs and island chains consisting of Escape, Whitlock, and Boulanger Islands.
- Long-term stability of the geomorphic landform at Island Point is dependent upon stability provided by this island chain and the ongoing supply of sand that originates from the lee of these islands as 'sand slugs', which are currently connected to accretion on the northern side of Island Point.

11.2 Cervantes:
- The townsite is located on Thirsty Point, a prominent sand foreland protruding >1km seaward from general shoreline alignment and situated in the lee of shallow offshore reefs.
- An offshore reef chain and Cervantes Islands run parallel to the general shore, providing wave sheltering to Cervantes townsite.
- Historical shoreline plots indicate Cervantes cuspate foreland has evolved substantially since 1943.
- Broad scale geological mapping covering Cervantes townsite indicates coastal limestone may be present along the coast.

Climate: Microtidal; Mid-Latitude Storms; Rare TCs

- The mainly diurnal tides are microtidal with a tidal range of 1.2 m from LAT to HAT
- Mediterranean climate with mild wet winters and hot, dry summers.
- The region lies within the southern half of the extra-tropical ridge and is dominated in summer by eastward travelling high pressure systems which cross the coast every 3 to 10 days.
- During winter, a northward movement of the pressure belts allows the impact of mid-latitude low-pressure systems to increase, through fronts or more direct synoptic winds systems.
- Dandaragan is in Wind Region A1 (AS1170.2), which means that extreme winds are caused by mid-latitude storms.

[1] Areas were calculated at 0.1m increments with HAT for Geraldton taken at 0.7m AHD in this study.

Development Record: Fishing; Tourism

Jurien Bay and Cervantes are located on the traditional lands of the Yued people.

11.1 Jurien Bay:
The township of Jurien Bay was settled by European's in the mid-1850s and a jetty was constructed in 1885–87 due to the success of pastoralism at the time. The townsite was gazetted in 1956 and it serves a regional centre that has experienced substantial population growth in recent decades. Jurien Bay Boat Harbour was completed in 1986, with two groynes also constructed around this time.

11.2 Cervantes:
The township of Cervantes was gazetted in 1963 and is a regional centre that services the State's crayfishing industry. Tourism is also important for the town, located nearby the Pinnacles in Nambung National Park, and the saline Lake Thetis, which contains Stromatolites.

Coastal Inundation History: Rare Storm Events; Surge Dominated

Jurien Bay tide gauge in Shire of Gingin has records for over 30 years since 1991.

- Contribution of surges in the water level record is high relative to a small tidal signal in the Dandaragan region.
- Dependence of water level upon weather conditions suggests most surge is atmospheric in origin, a combination of barometric effect, wind, and wave setup, related to mid-latitude storms.
- Surges may also occur due to more unusual meteorological events, such as Tropical Cyclone Glynis in 1970[2], which can combine with resonant phenomena, such as shelf waves.

The three highest water levels recorded in the Jurien tide gauge record are:

EX TC Mangga, May 2020 – 2.06m CD (1.14m AHD)

- Still water levels mapped at the 1.1m AHD level for this study show inundation of the beach area in Cervantes adjacent to Biscay Street and Catalonia Street around the Lobster Shack.
- It is therefore likely that wetting was experienced during Ex TC Mangga in these areas due to additional impacts of wave run up, but locally relevant descriptions are not available.

EX TC, May 2003 – 1.89m CD (1.01m AHD)

- Likely minor inundation of beach areas with wave run up impacts around Cervantes Jetty

Mid Latitude Depression, July 1995 – 1.77m CD (0.89m AHD)

Hazard: Existing Coastal Inundation Hazard Assessment Summary

NACC

- In 2014, the Shire partnered with the NACC and WA Department of Transport to undertake preliminary assessment of coastal hazards that included the Cervantes and Jurien Bay townsites.
- Findings of the assessment included that adaptation planning for coastal inundation is a priority at Jurien Bay and Cervantes. This is mainly due to the low-lying nature of, and proximity of assets to, the shoreline at these locations.

CHRMAP

- The Shire of Dandaragan CHRMAP considered impacts of erosion to coastal assets within the areas of interest (Jurien Bay & Cervantes). It identified the area is low-lying and likely prone to future coastal inundation, recommending evaluation in subsequent revision of the CHRMAP.

Hazard: Existing Controls

Existing controls for coastal inundation in the Shire of Dandaragan are limited to planning requirements for development approval. For Jurien and Cervantes, foreshore reserves have been defined, with a special use area at Cervantes for the Lobster Shack.

[2] TC Glynis was not recorded in the Jurien Record which began in 1991. However, the Geraldton tide gauge recorded a peak level of 1.17m AHD during this even so anecdotally, it is likely that the Cervantes area in particular would have experienced inundation impacts around Cervantes Jetty and seaward of Catalonia Street.

Assets: Exposure of Coastal Assets to Inundation Impacts

Inundation Level (m AHD)	11.1 Jurien Bay			11.2 Cervantes		
	Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/ Arterial (km)
1.0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.1	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.2	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.3	0	0 / 0	0 / 0	4	0 / 0	0 / 0
1.4	0	0 / 0	0 / 0	4	0 / 0	0 / 0
1.5	0	0 / 0	0 / 0	4	0 / 0	0 / 0
1.6	0	0 / 0	0 / 0	7	0 / 0	0 / 0
1.7	0	0 / 0	0 / 0	10	0 / 0	0 / 0
1.8	0	0 / 0	0 / 0	10	0 / 0	0 / 0
1.9	0	0 / 0	0 / 0	13	0 / 0	0 / 0
2.0	0	0 / 0	0 / 0	20	0 / 0	0 / 0
2.1	1	0 / 0	0 / 0	21	0 / 0	0 / 0

High (~25yr ARI)
Extreme (~100yr ARI)
Extreme +0.9m

- AEIP analysis does not identify any coastal assets exposed to inundation impacts in Jurien Bay
- No coastal assets are exposed below 1.2m AHD (~100yr ARI) in Cervantes
- Residential buildings become exposed to potential impacts in Cervantes area from 1.3m AHD, with gradually increasing exposure up to 2.4m AHD, above which there are significant further assets.
- No commerical buildings, industrial buildings or roads are exposed in either area.

Damage: Inundation Risk Ratings & Damage Assessment

Average Annual Damage		AEIP			
	WL	1.1m AHD	1.2m AHD	2.1m AHD	All WL
Area	ARI	High	Extreme	Extreme+ 0.9m	
11.1: Jurien Bay		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
11.2: Cervantes		$ 0K/yr	$ 0K/yr	$ 127K/yr	$ 129K/yr
Total Damage		**$ 0K/yr**	**$ 0K/yr**	**$ 127K/yr**	**$ 129K/yr**

- Damage assessment for Cervantes includes a nominal 0.5m wave runup allowance due to the absence of a meaningful foreshore reserve to mitigate wave impacts during a storm event.
- Most of the damage at Cervantes is associated with beachfront property.
- No damage was calculated at Jurien Bay, with residential properties set above the water levels considered in the assessment.

Planning Framework

The Shire of Dandaragan Local Planning Strategy and Local Planning Scheme No. 7 require consideration of coastal hazards as part of development approval. A special control area for coastal hazards (SC36) is identified in the scheme.
Evaluation of Dandaragan planning framework against the Inundation Management Health Check criteria gave:

HC1	• Inundation hazard assessment has not yet been undertaken, although it is a recommended element for the next revision of Dandaragan CHRMAP. Due to narrow foreshore reserves at Cervantes, this evaluation should consider erosion and waves processes.
HC2	• Inundation scenarios have not been defined.
HC3	• There is no information on inundation hazard.
HC4	• There is no information regarding mitigation of inundation hazard.
HC5	• Pathways for adaptation are not identified.
HC6	• The planning framework does not acknowledge the role of emergency management for coastal hazards.
HC7	• There is no guidance regarding building design for areas prone to inundation.
HC8	• A special control area for coastal hazards has been defined, but this does not presently incorporate inundation hazard.

MODERATE Inundation Risk
at coast

Shire of Gingin

Focus

Adaptation Priority | Management at Foreshore | Targeted Mitigation | Emergency Management

Actions

Management at Foreshore | Targeted Mitigation | WL Review (CHRMAP) | Emergency Plan

Seashore Engineering


12. Shire of Gingin
Inset A
See Inset B
12.1 Lancelin
12.2 Ledge Point
12.3 Seabird
0 2 4 km
Legend
Assessment Areas
Legend
+1.1m AHD: High
+1.2m AHD: Extreme
+2.1m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road
LOCATION
Shire of Gingin (see Inset A)
Inset B
Beacon Bay
Desert St
Hotel Bay
Inundation spreads through townsite at +2.3m AHD
Harold Park
12.1
Lancelin Jetty
Land below +1.2m AHD: Extreme Scenario (Inundation dependent on dune breaching)
Coastal_Dune
Gingin Rd
Lancelin Bay
Cunliffe St
Inundation spreads through townsite at +2.5m AHD
Hopkins St
Edwards Island
0 0.2 0.4 km

12. GINGIN

Site overview:

The authors wish to acknowledge the Yued Noohgar people as the native title holders of the lands and waters in and around the Shire of Gingin. The Shire is located 84km north of Perth and is one of WA's oldest towns and is known for several historic shipwrecks, as a coastal tourist destination, and for its well-established agricultural industry. There are four coastal sites in the Shire: Guilderton, Lancelin, Ledge Point and Seabird with a total resident population of 5,700. The Shire's economy is based on agriculture and horticulture with expanding tourist revenue in coastal areas especially during summer.

Areas at risk from inundation:

Three inundation exposure areas have been considered for Gingin LGA with land areas above Highest Astronomical Tide[1] (HAT) potentially inundated under high (~25yr ARI), extreme (~100yr ARI), and extreme +0.9m (~100yr ARI +0.9m) water levels estimated as:

REGION	WL ARI	1.1m AHD High	1.2m AHD Extreme	2.1m AHD Extreme + 0.9m
12.1 Lancelin		0.2km²	0.2km²	0.3km²
12.2 Ledge Point		0.1km²	0.1km²	0.2km²
12.3 Seabird		0km²	0km²	0km²
12.4 Guilderton		0km²	0km²	0.3km²

Morphology: Sandy Forelands; Reef; Limestone Cliffs

12.1 Lancelin

- Lancelin townsite occupies three sandy forelands formed in the lee of Edwards Reef to the south and Lancelin Island to the north.
- Edward Island is connected to a long shallow nearshore reef (~850m) which provides protection from wave energy to the adjacent shoreline.
- A shallow nearshore reef is between the two islands, extending approximately 500m offshore. Deeper passages are between the shallow reefs and islands, allowing boat access to Lancelin, but locally allowing waves towards the shore.

12.2 Ledge Point

- Ledge Point townsite is located on a sandy foreland formed behind a shore-parallel reef, with both offshore and nearshore reefs sheltering Ledge Point beach.

12.3 Seabird

- The townsite is located on a broad salient.
- Beach rock (Tamala Limestone) is visible along the coast in front of Seabird, with discontinuous offshore reefs giving some shelter from waves.
- Lacks the significant offshore reef structure present further to the north.
- Limestone cliff, of low to medium strength, under the dunes south of Seabird.

Climate: Microtidal; Mid-latitude Depressions; Rare TCs

- Mediterranean climate with mild wet winters and hot, dry summers.
- Shire of Gingin lies within the southern half of the extra-tropical ridge and is dominated in summer by eastward travelling high pressure systems which cross the coast every 3 to 10 days.
- During winter, a northward movement of the pressure belts allows the impact of mid-latitude low-pressure systems to increase, through fronts or more direct synoptic winds systems.
- The influence of tropical systems is rare, although it may be significant.
- The land-sea breeze cycle dominates the prevailing winds of the region, particularly over summer, with moderate easterly winds in the morning and stronger (up to 15 m/s) southerly sea breezes commencing around noon and weakening during the night.
- Gingin is in Wind Region A1 (AS1170.2), which means that extreme winds are caused by mid-latitude storms.

[1] Areas were calculated at 0.1m increments with HAT for the study area taken at 0.5m AHD.

Development Record: Agricultural; Coastal Tourism

Lancelin, Ledge Point and Seabird are located on the traditional lands of the Yued people.

12.1 Lancelin

The townsite of Lancelin is located approximately 100 km north of Perth and has an estimated residential population of around 600. The townsite was used in the late 1940s for camping and as a rock lobster fishery base. The townsite was declared in 1950 and gazetted in 1954. Lancelin is the regional centre for the upper coastal area of the Shire. Rock lobster fishing remains a significant local industry, with the town also having strong seasonal tourism. Lancelin is well known as a windsurfing venue. The jetty located is infrequently dredged with material historically placed in the foreshore or beach north of the townsite or on the beach fronting Grace Darling Park. Recent erosion of the foreshore at Grace Darling Park has been a concern for local residents and the Shire. Some sand nourishment has occurred here using dredge spoil and imported sand.

12.2 Ledge Point

The townsite of Ledge Point is located approximately 70 km north of the Perth Metropolitan area and has an estimated population of around 200. The townsite was gazetted in 1955, mainly for retirees and holiday housing and to service the local fishing and rock lobster industries. The beach and nearshore waters are used for launching and mooring of boats. As part of the town establishment the dunes along DeBurgh Street were modified and flattened to allow for residential development. Two groynes were constructed in the 1970s and 1980s with associated renourishment.

12.3 Seabird

Seabird is located approximately 40 km north of Perth Metropolitan area. It was gazetted in 1968 and currently has a population of around 80. The site has been subject to ongoing coastal erosion, causing loss of a substantial area of primary coastal dunes and a coastal road (Turner Street). Historical erosion management has included beach nourishment and a temporary revetment, which rapidly degraded before a seawall was constructed in 2015 (and extended in 2016) to protect residential properties.

Coastal Inundation History: Rare Storm Events; Tidally modulated

- No documented history of extreme water level events – nearest tide gauge is at Jurien Bay
- Tropical cyclones are rare affecting the Central Coast Region approximately once every five to ten years. These may produce strong winds in any direction due to their intense radial structure, but most commonly pass southwards offshore, and hence produce northeast winds, swinging through to northwest, westerly and southwest winds.
- Storm events that impacted the area which may be in living memory include storms TC Alby (1978), June 1996, May 2003, August 2005, March 2011 (TC Bianca) and May 2020 Ex-TC Mangga.

Hazard: Existing Coastal Inundation Hazard Assessment Summary

Lancelin Townsite Coastal Hazard Assessment (2014)

- In 2014, the Shire partnered with the NACC and WA Department of Transport to undertake preliminary assessment of coastal hazards that included Lancelin townsite. Findings of the assessment included that adaptation planning for coastal inundation is a priority at Lancelin. This is mainly due to the low-lying nature of, and proximity of assets to the shore.

CHRMAP (2017)

- Gingin CHRMAP (Cardno 2017) addresses areas identified at risk from coastal erosion hazards.
- Inundation mapping for Lancelin by Baird (2020) of water levels with 20, 100 and 500yr ARI recurrence for 2020, 2040, 2070, and 2120 time horizons using sea level rise scenarios of 0, 0.1m, 0.35m and 0.9m respectively. However, inundation depth mapped in the Townsite didn't consider a percolation approach or dune stability.

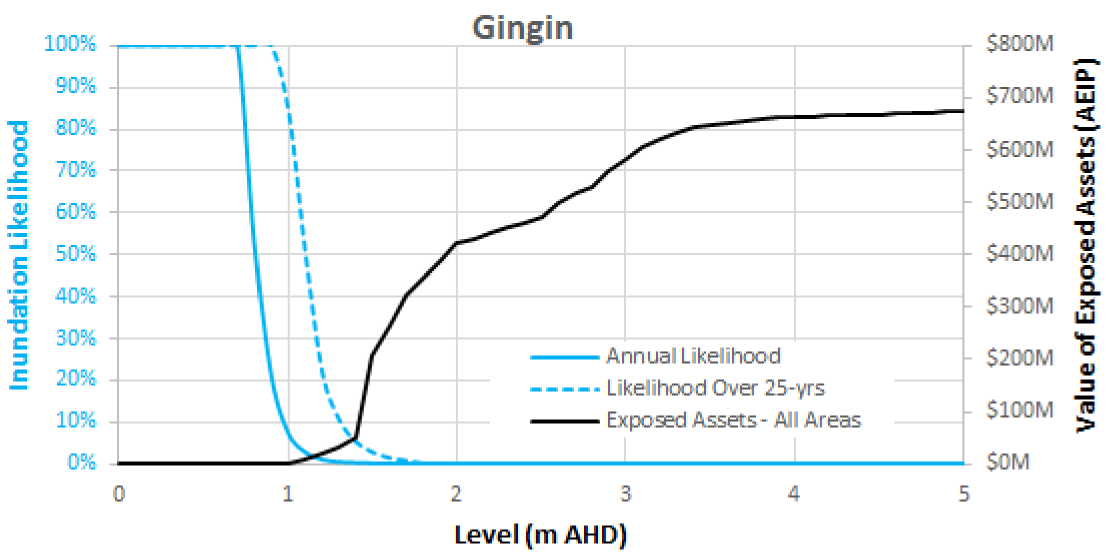
Hazard: Existing Controls

Existing controls for coastal inundation in the Shire of Gingin are limited to planning requirements for development approval. For Lancelin, the existing foreshore reserve provides a substantial control to potential inundation hazard, with areas of the townsite well below the elevation of the coastal dunes.

Assets: Exposure of Coastal Assets to Inundation Impacts

Inundation Level (m AHD)	12.1 Lancelin			12.2 Ledge Point			12.3 Seabird			12.4 Guilderton		
	Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/ Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/ Arterial (km)
1.0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.1	20	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.2	40	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.3	60	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.4	100	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.5	198	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.6	288	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.7	379	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.8	426	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.9	472	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
2.0	519	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
2.1	527	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0

- Inundation of assets within low lying areas landward of the Lancelin dune system (i.e. from +1.1m AHD) is dependent on dune breaching, with lowest level of the dune system presently at approximately +2.3m AHD adjacent to Harold Park. Exposure of buildings listed in the table assumes dune breaching.
- Exposure of buildings in Lancelin is limited to residential buildings for all inundation levels considered with impacts first occuring around 1.1m AHD (high scenario).
- Exposure of residential buildings increases substantially between the extreme scenario (40 residences at 1.2m AHD) and the extreme + 0.9m scenario (527 residences at 2.1m AHD), indicating a high sensitivity to an inundation of around 0.9m.
- This difference could be developed through event scenarios or statistics, inclusion of wave processes, or allowance for sea level rise. This helps to explain a significant difference in hazard identification between this evaluation and Gingin coastal inundation hazard assessment at Lancelin.
- No assets are exposed to inundation at Ledge Point, Seabird and Guilderton townsites.



Damage: Inundation Risk Ratings & Damage Assessment

Average Annual Damage		AEIP			
	WL	1.1m AHD	1.2m AHD	2.1m AHD	All Water Levels
Area	ARI	High	Extreme	Extreme+ 0.9m	
12.1: Lancelin		$ 0K/yr	$ 0K/yr	$ 35K/yr	$ 35K/yr
12.2: Ledge Point		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
12.3: Seabird		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
12.4: Guilderton		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
Total Damage		**$ 0K/yr**	**$ 0K/yr**	**$ 35K/yr**	**$ 35K/yr**

- Inundation likelihood applied low lying coastal assets in damage estimates for Lancelin have assumed dune breaching at a water level of +1.5m AHD, based on dune stability assessment by Baird (2020).
- Guilderton, Ledge Point and Seabird are identified as having no exposure to inundation impacts using AEIP.
- Inundation mapping has been presented for Lancelin only.

Planning Framework

The Shire of Gingin Local Planning Strategy and Local Planning Scheme No. 9 identify the importance of understanding changing coastal conditions when planning for future development. However, there is otherwise limited inclusion of coastal inundation in the Shire's policies, with 'flood prone' areas only identified as those areas susceptible to flooding by the Moore River, adjacent to Guilderton. A special control area for river environs management (SCA1) is identified in Local Planning Scheme No. 9.
Evaluation of Gingin's planning framework against the Inundation Management Health Check criteria gave:

- HC1 • Interactions between coastal inundation and dune erosion were identified in coastal vulnerability studies for Lancelin.
- HC2 • Gingin Local Planning Scheme No. 9 requires consideration of 100-year ARI plus 0.5m freeboard for river flooding at Guilderton, with no stated requirement for coastal inundation. Coastal vulnerability studies evaluated conditions up to 500-year ARI, with 0.9m sea level rise.
- HC3 • Mapping of coastal inundation hazard in the CVS does not have connection to planning documents.
- HC4 • Inundation mitigation measures are not identified in Gingin planning framework.
- HC5 • Pathways for adaptation for changing coastal inundation hazard are not identified.
- HC6 • The planning framework does not acknowledge the role of emergency management for coastal hazards.
- HC7 • Building design recommendations associated with coastal inundation mitigation are not outlined in the planning framework, although requirements to meet ABCB are noted.
- HC8 • A special control area for coastal hazards has not been defined. Lack of an SCA limits capacity to obtain targeted financial recompense to support strategic interventions or adaptation.

MODERATE Inundation Risk
at coast

City of Fremantle

Focus

Management at Foreshore

Adaptation Priority

Targeted Mitigation

Emergency Management

Actions

Targeted Mitigation

WL Review (CHRMAP)

Emergency Management

Seashore Engineering

Note that Rous Head Stage 2 reclamation works have been completed after the DEM was captured.

13. FREMANTLE

Site overview:

The authors wish to acknowledge the Whadjuk people as the native title holders of the lands and waters in and around the City of Fremantle. The City is a port city in Western Australia, located at the mouth of the Swan River in Perth metropolitan area. Its unique character is captured by its heritage architecture, music, arts, culture, festivals, retail stores, markets, cafes and restaurants, which all contribute to its village-style atmosphere for its over 30,000 residents. Fremantle is home to the State's largest working harbour and a large commercial fishing fleet. A freight rail line runs parallel to the coast, alongside Marine Terrace, connecting commercial shipments from the port to greater Perth.

Areas at risk from inundation:

Two exposure areas were considered for the City of Fremantle with land areas above Highest Astronomical Tide[1] (HAT) potentially inundated under high (~25yr ARI), extreme (~100yr ARI), and extreme +0.9m (~100yr ARI +0.9m) water levels estimated as:

REGION	WL ARI	1.2m AHD High	1.4m AHD Extreme	2.3m AHD Extreme + 0.9m
13.1 North Fremantle		0.1km²	0.1km²	0.3km²
13.2 Fremantle		0km²	0.1km²	0.7km²

Morphology: Highly Modified; Structurally Controlled; Estuarine and Open Coast

- North Fremantle is situated on a peninsula, with the Indian Ocean to the west and Swan River to the east.
- Fremantle has a highly modified, structurally controlled coast from South Mole at the mouth of Fremantle Harbour to the groyne controlled South Beach foreshore.
- Geomorphic changes experienced along the Fremantle foreshore over the past 200 years have been influenced by the extensive modifications made to the lower reaches of the Swan-Canning River system and significant urbanization of the foreshore from the mouth of the River to North Fremantle including works associated with development of the harbour.
- Structures such as bridges, jetties, and seawalls have been placed on or adjacent to the foreshore.
- Dredging of river channels and the reclamation of the foreshore using dredge material was very common. These works were carried out for navigation, flood control, development, and construction, and to increase foreshore width.
- The system has been subject to a variety of land uses and been significantly altered from its natural state.
- Damming of the river upstream has interrupted flows, leading to silting up of the river downstream. Other modifications to the rivers and tributaries include training (straightening and deepening) and walling of the foreshore, to avoid erosion and flooding.

Climate: Temperate; microtidal; midlatitude depressions;

- Microtidal, mixed, mainly diurnal tides with range of 1.1m LAT to HAT, which includes a large seasonal mean sea level range. Sea levels are around 0.25m lower on average in summer than in winter.
- Locally generated waves are dominated by storms and the sea breeze.
- Local winter cold fronts and mid-latitude depressions can produce seas where significant wave height is greater than 4m and can exceed 7m, with periods between 6 and 10s.
- Fremantle is in Wind region A1 (AS1170.2), which means that extreme winds are caused by mid-latitude storms.
- Storm surge, from barometric effects and wind setup, can account for 56 – 85% of the water level fluctuations at Fremantle.
- The 100-year storm surge amplitude is 1.0m above the predicted tide and can be amplified by local topography.

[1] Areas were calculated at 0.1m increments with HAT for Fremantle taken at 0.6m AHD in this study.

Development Record: Port & Tourism Centre

- Fremantle is located on the traditional lands of the Whadjuk people.
- The accepted Noongar word for Fremantle (both sides of the river) is Waylyup meaning 'lungs' (which was recorded in 1833 as told by Yagan, a Noongar leader).
- Walyalup/Fremantle is the country on both banks of the Derbal Yerrigan (Swan River).
- Fremantle has several significant sites and features in traditional stories. The story of how the land once extended past Rottnest but had been inundated by the sea is one of the oldest oral traditions in human history. The mouth of the Swan River is the place where the Wagyl fought the crocodile spirit and used the crocodile's tail to separate the freshwater from saltwater.
- Construction of the original Fremantle Traffic Bridge commenced in 1863 and was completed in 1867. This required a large earth embankment at the south end of the bridge. Due to instability of the original bridge, a low-level bridge was later built alongside and downstream, opened in 1898.
- Construction of the first railway bridge at Fremantle commenced in 1880, built 600 m downstream of Fremantle Traffic Bridge
- Significant development of Fremantle Harbour occurred from 1897 onwards. Moles were built in 1897 to create the harbour at the mouth of the river, with removal of a rock bar and dredging of Fremantle Harbour navigation basin. Construction of port wharves began in the early 1900's.
- Opening of the harbour increased the tidal range in the upper reaches of the river.
- Flooding in 1926 caused the collapse of the original Fremantle Traffic Bridge. The existing Fremantle Traffic Bridge (now forming part of Queen Victoria Street) was opened in 1939, and the original bridge was demolished in 1947.
- Rock armouring was used as an erosion control method to protect the foreshore from boat wakes and strong waves.
- The original timber railway bridges were replaced by the present Railway Bridge, built in 1964.
- The new Railway Bridge was relocated upstream of the earlier timber bridges, adjacent to Fremantle Traffic Bridge
- Removal of the original railway bridges increased tidal effects in the upper estuary.
- Navigation dredging, and channel and reclamation works were conducted along the river in the vicinity of Fremantle Port in the 1960s. These have had significant influence on shore morphology to the west of Fremantle Traffic Bridge and to the north at Prawn Bay and Crab Bay.
- Harbour works outside the river commenced in the 19th century with construction of Fremantle South Jetty in 1857, replacement with Fremantle Long Jetty in 1873, and subsequent breakwater construction in 1914. A partly enclosed area of land was developed for the fishing fleet in the 1960s, with extensive dredging and reclamation. Success and Challenger Harbours were built in the 1980s.
- Esplanade Park was constructed from reclamation in the early 1900's, partially as coastal protection to buildings on Marine Terrace that had experienced damage from winter storms.
- The North Fremantle coastline including Port Beach is also artificial, largely shaped by early construction work associated with development of the Port. In recent years coastal erosion of Port Beach has led to construction of revetments and an extensive sand nourishment campaign.

Coastal Inundation History: Mid-Latitude Depressions & ex Tropical Cyclones

Fremantle has a water level record extending over 120 years since 1897. HAT for Fremantle is 1.4m CD (0.64m AHD).
Three of the top 5 water level events in Fremantle's record occurred since 2020 with impacts including overtopping of walling in Fremantle Fishing Boat Harbour and Success Harbour, and repeated flooding of Johannah Street foreshore in North Fremantle:

Extra Tropical Storm – May 2003: 1.95m CD (1.18m AHD)

- Sustained strong winds over two days supported by low pressure system being located at more northerly latitudes than most mid latitude depressions, with the track stalling offshore on 15 May. Storm passed south of Cape Leeuwin with an intensity of 986hPa.
- Exceptional water levels at Fremantle were due to coincident timing of high tide and a significant surge peak generated by sustained westerly winds, measured as +0.72m at Fremantle.

Extra Tropical Storm/Meteotsunami 2012: 2.12 CD (1.35m AHD)

- Highest water level recorded at Fremantle tide gauge, over 120 years.
- Tropical low tracked SW parallel to WA coast passing south of Perth.
- The extreme nature of the water level was due to coincidence of a high tide, storm surge, meteotsunami, seiche and unusually high mean sea level linked to a la Niña climate phase. At Fremantle the tidal residual was estimated as 1.14m, with 0.61m attributed to meteotsunami (rapidly fluctuating).
- Meteotsunami was most likely caused by rapid increase in wind speed and directional shift from shore-parallel (north) to onshore (west) over 1-2 hours, as the cold front crossed the coast.

Ex TC Mangga 2020: 1.89m CD (1.25m AHD)

- Western and southern WA experienced a once in a decade weather event when ex-tropical cyclone Mangga combined with an upper-level trough and strong cold front, followed by a deep low through the State's southwest.
- Storm generated water levels more than 0.5m above predicted tides at all stations along the coast.
- Peak water level partly moderated by occurrence during relatively low tides around 2am. If peak surge had occurred around the predicted spring tidal peak near 10am, total water level would likely have exceeded a 100yr ARI.
- Water levels for Fremantle were inferred from Hillarys Harbour tide gauge due to failure of Fremantle tide gauge during this event.
- Johannah Street area was inundated.

Hazard: Existing Coastal Inundation Hazard Assessment Summary

CZM & Damara WA (2013)

- Cockburn Sound Coastal Alliance Coastal Vulnerability Study. Erosion and Inundation Hazard Assessment Report.
- The investigation identified inundation (flooding) and erosion hazards for the study area for present day, 2070 and 2110 The assessment focused on potential impacts to the coast from coastal processes, influenced by climate change and associated sea level rise.

BMT Oceanica (2014)

- Cockburn Sound Coastal Vulnerability Values and Risk Assessment Study.
- BMT (2014) evaluation based on extreme event analysis conducted by CZM and Damara (2013) with vulnerability assessment considering low, medium, high, and extreme inundation scenarios along Fremantle coast for present day (2014), 2070 and 2110.

GHD (2016)

- Cockburn Sound Coastal Vulnerability & Flexible Adaptation Pathways Project – Stage 3 Report Coastal Adaptation Plan.
- Used 2013 inundation mapping to identify adaptation pathways for the Fremantle area. Analysis based on bath-tub assessment with no consideration of percolation or inundation pathways.

Hazard: Existing Controls

Existing controls to inundation hazard are largely associated with the minimum fill level used during reclamation works, mostly through the 1960s. Low-lying areas are assumed to be drained through the stormwater pipe network. Gravity drainage at Johannah Street is below extreme sea levels, and the pipework has occasionally provided a pathway for ingress of seawater.

Assets: Exposure of Coastal Assets to Inundation Impacts

Inundation Level (m AHD)	13.1 North Fremantle			13.2 Fremantle		
	Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/ Arterial (km)
1.0	0	0 / 0	1 / 0	0	0 / 0	1 / 0
1.1	0	0 / 0	1 / 0	0	0 / 0	1 / 0
1.2	7	0 / 0	1 / 0	0	0 / 0	1 / 0
1.3	12	0 / 0	1 / 0	0	0 / 0	1 / 0
1.4	13	0 / 0	1 / 0	0	1 / 0	1 / 0
1.5	15	0 / 0	1 / 0	0	1 / 0	1 / 0
1.6	17	0 / 0	1 / 0	0	5 / 0	1 / 0
1.7	17	0 / 0	1 / 0	0	10 / 0	1 / 0
1.8	19	0 / 0	1 / 0	20	39 / 0	1 / 1
1.9	20	0 / 0	1 / 0	27	53 / 0	1 / 2
2.0	23	0 / 0	1 / 0	44	62 / 0	1 / 2
2.1	28	0 / 0	1 / 0	57	77 / 0	1 / 2
2.2	34	0 / 0	1 / 0	72	89 / 0	1 / 2
2.3	48	0 / 0	1 / 0	98	103 / 0	1 / 3

Other Assets Exposed:

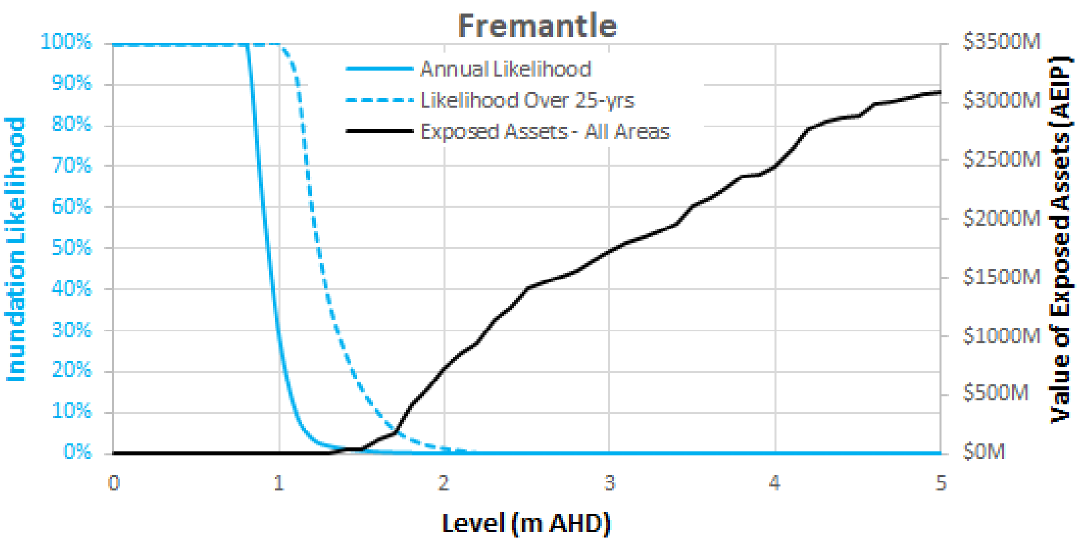
13.1 North Fremantle
High: 1km railway track
Extreme: 1km railway track
Extreme +0.9m: 1km railway track

13.2 Fremantle
High: 1km railway track
Extreme: 1km railway track
Extreme +0.9m: 3km railway track

High (~25yr ARI)
Extreme (~100yr ARI)
Extreme +0.9m

- Coastal inundation for North Fremantle mainly occurs through an overbank flow pathway at Prawn Bay, via Johannah Street, starting around 1.1m AHD, progressively extending across Gil Fraser Oval. Other overbank flows can occur for Rous Head around 1.8m AHD and through Northbank and Pier 21 around 2.2m AHD.
- Exposure of buildings in North Fremantle is limited to residential buildings for all inundation levels considered with impacts first occuring around 1.2m AHD, increasing steadily up to 2.3m AHD with inundation impacts around Johannah Street area, extending to Northbank and Pier 21 areas.
- For Fremantle, inundation exposure occurs around the Fishing Boat Harbour area from around 1.8m AHD, extending across Mews Road to the reclaimed foreshore area of Esplanade Park and the heritage area around Cliff Street including buildings used by the University of Notre Dame.
- For Fremantle, most exposure is related to commerical buildings impacted above 1.4m AHD, increasing from one building to 103 buildings impacted for a level of 2.3m AHD.
- Each area has 1km of major road impacted under all inundation scenarios with a futher 3km of arterial road exposed in the Fremantle area by an inundation level of 2.3m AHD. Residential buildings in the Fremantle area begin to be exposed to inundation impacts around 1.8m AHD when the area landward of Esplanade Park is inundated, including the low lying areas around the 'old' historic precinct around the University of Notre Dame.

Assets identified with AEIP occur from 1.4m AHD, with a progressive increase in assets to 2.4m AHD, above which the topography steepens. Comparison with estimated inundation likelihood indicates limited interaction, with roughly 5% likelihood of coastal inundation impacts within a 25 year period. Notably, this does not include effects of waves, which can extend to higher levels. Substantial increase in the potential area of inundation around 1.8m AHD, affecting Esplanade Park indicates high senstivity to an inundation difference of around 0.5m. This difference could be developed through event scenarios or statistics, inclusion of wave processes, or allowance for sea level rise. This explains a difference in hazard identification between this evaluation and CSCA coastal vulnerability assessment, which included allowance for projected sea level rise.



Damage: Inundation Risk Ratings & Damage Assessment

Average Annual Damage		AEIP			
	WL	1.2m AHD	1.4m AHD	2.3m AHD	All Water Levels
Area	ARI	High	Extreme	Extreme+ 0.9m	
13.1: North Fremantle		$ 0K/yr	$ 7K/yr	$ 23K/yr	$ 23K/yr
13.2: Fremantle		$ 0K/yr	$ 0K/yr	$ 82K/yr	$ 82K/yr
Total Damage		**$ 0K/yr**	**$ 7K/yr**	**$ 106K/yr**	**$ 106K/yr**

- Greater damage in the Fremantle segment due to high value infrastructure exposed to residual risk, commencing above +1.5m AHD. This segment has high sensitively to damage, due to increasing exposure of significant exposure of high value assets with sea level rise.
- Damage for North Fremantle associated with relatively localised flooding of residential buildings near Johannah Street, starting above +1.2m AHD. These buildings are amongst the lowest property levels identified in the state.

Planning Framework

The City of Fremantle falls within the area covered by the Metropolitan Regional Scheme, which stipulates an objective for coastal and foreshore reserves to accommodate coastal hazards. The MRS defines existing property boundaries, with further consideration of coastal hazards applicable for sub-division conditions under SPP 2.6.

The City of Fremantle Local Planning Scheme 4 does not refer to coastal hazards, including inundation or erosion.

Coastal adaptation plans (CAP) were developed following Cockburn Sound Coastal Alliance coastal vulnerability study. These include plans for adaptation to coastal inundation hazard and recommend development of Special Control Areas to manage non-conforming uses in land with coastal vulnerability. City of Fremantle also has a climate change adaptation plan with some listed actions relating to inundation. However, to date, CAP recommendations have not yet been incorporated into the City of Fremantle planning framework.

Evaluation of Fremantle's planning framework against the Inundation Management Health Check criteria gave:

HC1	• Interactions between coastal inundation and waves were identified in coastal vulnerability studies.
HC2	• Fremantle Local Planning Scheme 4 does not address coastal inundation. Coastal vulnerability studies evaluated conditions up to 500-year ARI, with 0.9m sea level rise.
HC3	• Mapping of coastal inundation hazard in the CVS does not have connection to planning documents.
HC4	• Inundation mitigation measures are not identified in Fremantle planning framework. Proposed activities in the coastal adaptation plan include installing one way stormwater valves and building flood levees.
HC5	• Pathways for adaptation to inundation in the CAP are focused on strategic works, tied to tolerable risk thresholds.
HC6	• The planning framework does not acknowledge the role of emergency management for coastal hazards.
HC7	• The planning framework does not acknowledge flood proofing. The CAP identifies opportunities to mitigate inundation hazard through building design via a local planning policy, but these are not related to ABCB guidance.
HC8	• A special control area for coastal hazards is yet to be defined, with development of an SCA recommended in the CAP and the requirement for supporting work to establish an SCA identified in the draft Local Planning Scheme. Lack of an SCA limits capacity to obtain targeted financial recompense to support strategic interventions or adaptation.

LIMITED Inundation Risk
at coast

City of Rockingham

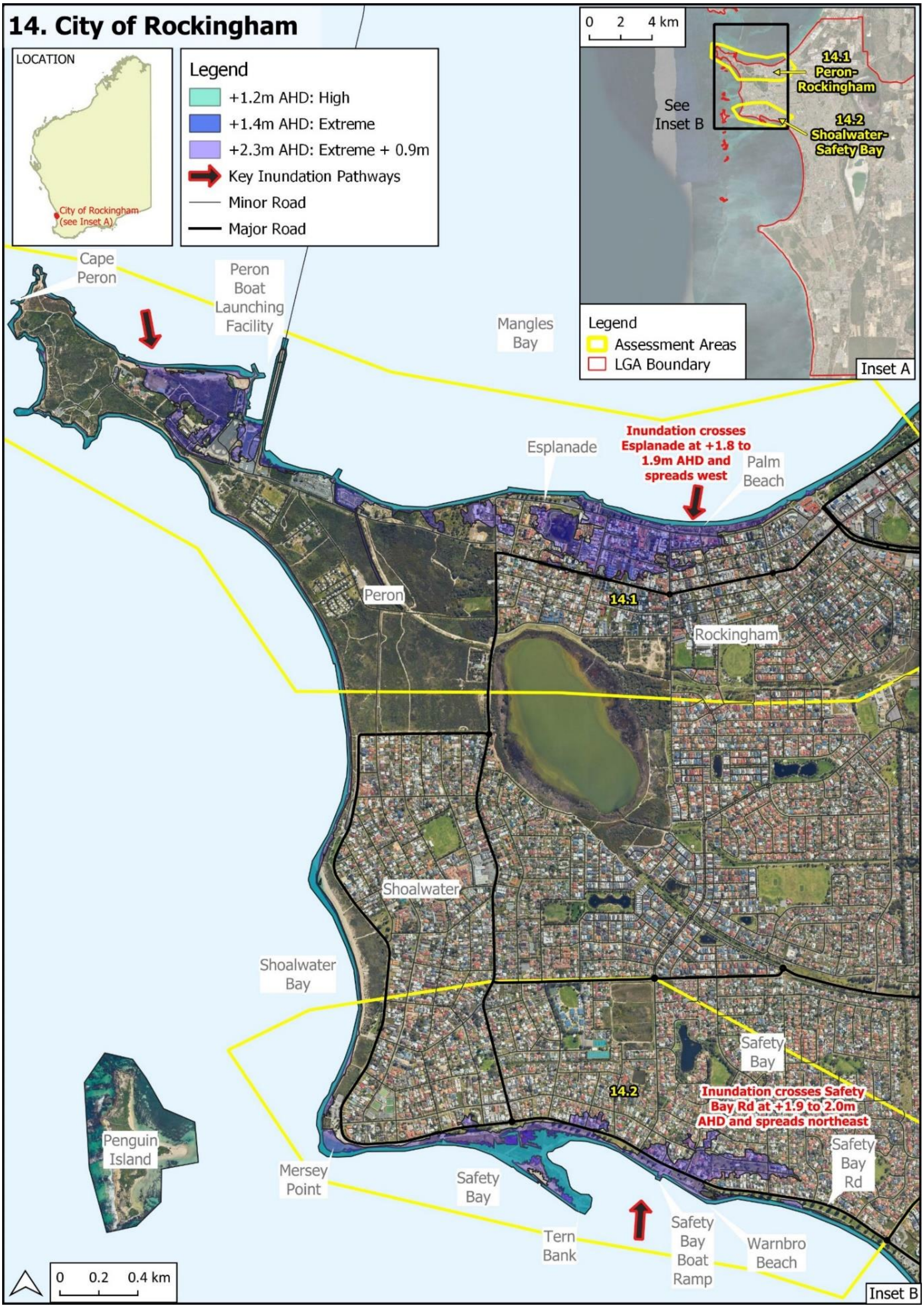
Focus

- Adaptation Priority
- Management at Foreshore
- Targeted Mitigation
- Emergency Management

Actions

- Management at Foreshore
- Targeted Mitigation
- Emergency Plan

Seashore Engineering


14. City of Rockingham
LOCATION
City of Rockingham
(see Inset A)
Legend
+1.2m AHD: High
+1.4m AHD: Extreme
+2.3m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road
0 2 4 km
See Inset B
14.1 Peron-Rockingham
14.2 Shoalwater-Safety Bay
Legend
Assessment Areas
LGA Boundary
Inset A
Cape Peron
Peron Boat Launching Facility
Mangles Bay
Esplanade
Inundation crosses Esplanade at +1.8 to 1.9m AHD and spreads west
Palm Beach
Peron
14.1
Rockingham
Shoalwater
Shoalwater Bay
Safety Bay
14.2
Inundation crosses Safety Bay Rd at +1.9 to 2.0m AHD and spreads northeast
Penguin Island
Mersey Point
Safety Bay
Tern Bank
Safety Bay Boat Ramp
Warnbro Beach
Safety Bay Rd
0 0.2 0.4 km
Inset B

14. ROCKINGHAM

Site Overview:
The authors wish to acknowledge the Binjareb and Whadjuk Nyoongar people as the native title holders of the lands and waters in and around the City of Rockingham. The City is located in Perth's southern suburbs, about 40 kilometres south-west of the Perth CBD. The City encompasses 37 km of coastline, is home to a growing residential population of over 140,000 people, encompasses an industrial hub and is the gateway to the Royal Australian Navy's largest base, HMAS Stirling, on Garden Island. Nearby Penguin Island is a popular tourist destination with ecotourism ventures supported by local populations of fairy penguins, dolphins and seals.

Areas at risk from inundation:
Inundation exposure has been considered across two areas for the City of Rockingham. with land areas above Highest Astronomical Tide[1] (HAT) potentially inundated under high (~25yr ARI), extreme (~100yr ARI), and extreme +0.9m (~100yr ARI +0.9m) water levels estimated as:

REGION	WL ARI	1.2m AHD High	1.4m AHD Extreme	2.3m AHD Extreme + 0.9m
14.1 Peron-Rockingham		0.1km²	0.1km²	0.6km²
14.2 Shoalwater-Safety Bay		0.1km²	0.1km²	0.3km²

Morphology: Sheltered Sandy Beaches & Exposed, Open-Ocean Coast

- Dunes form a wide plain known as Rockingham – Becher Plain. This plain consists of a series of multiple, parallel, linear sand ridges that are stranded former beach ridges.
- The geomorphological complexity of the City's coastline supports a range of unique environments within Cockburn Sound, Warnbro Sound and Shoalwater Islands Marine Park. A chain of islands, offshore ridges and depressions extend from Garden Island in the north to Long Point in the south, providing protection from swell and limiting offshore sediment feeds, resulting in low energy beaches.
- Higher dunes are generally found in the Point Peron area (up to 10 m), Waikiki (up to 20 m), Warnbro (up to 15 m), Port Kennedy (up to 15 m), and Secret Harbour (up to 12 m).
- Low-energy sheltered sandy beaches in Cockburn Sound are generally characterised by long, low sub-tidal terraces in the Mangles Bay area grading to more convex/concave beach structure with the presence of offshore bars and a steeper drop off into deep water around the Rockingham foreshore at the Cruising yacht club with increased penetration of open ocean swell.
- Beaches south of Long Point are high energy as they are not protected by offshore reefs and are exposed to significantly more swell.
- Tern Bank experiences rapid accretion over the winter months, and remains relatively stable over the summer period.

Climate: Microtidal; Water Level Dominated Sheltered Areas;Mid-Latitude Depressions

- Microtidal, with a LAT to HAT range of approximately 1.1m, including a large seasonal mean sea level fluctuation.
- Tides in the region are predominantly diurnal, although semidiurnal components do occur during certain lunar phases.
- Rockingham is in Wind region A1 (AS1170.2), which means that extreme winds are caused by mid-latitude storms.
- In the sheltered areas of Warnbro and Cockburn Sounds, locally generated waves are the prevailing mechanism of coastal change and are significantly influenced by the speed, direction, and duration of wind. In summer months, winds are characterised by a dominant sea breeze, with strong south to southwest winds, which can result in significant longshore movement of sediment towards the north.
- In winter, west and northwest winds dominate due to the movement of low-pressure systems.

[1] Areas were calculated at 0.1m increments with HAT for Rockingham taken at 0.7m AHD in this study.

Development Record: Industry and Commercial; Naval Base Gateway

- The Traditional Owners of the area are the Nyoongar people. The City sits on the boundary of the Whadjuk and Binjareb Nyoongar peoples territories.
- Initial European development of Rockingham occurred in the 1850s through dispersal of farming settlements between Fremantle and Mandurah. The sheltered waters of Cockburn Sound were considered for port operations through the 1870s, but the area failed to develop as a port due to limited depths across Parmelia Bank.
- From the 1920s, Rockingham population increased through the Soldier Settlement Scheme, with increasing residential occupation of the coastal area.
- The City of Rockingham is a rapidly developing residential area, with substantial industrial and commercial areas. Since 1969, it is the closest local government area to the Royal Australian Navy's largest base, HMAS Stirling, on nearby Garden Island.
- The shoreline was heavily modified by construction of the Garden Island causeway, completed in 1973.
- Coastal protection structures including groynes and seawalls have been constructed on the foreshore either side of the causeway over the last 50 years.
- In recent years revetments have been constructed at Mersey Point.
- Excavation of Tern Bank typically occurs annually, dredging of the Bent Street Navigation Channel occurs every 3-5 years, or as required to maintain a navigable depth.

Coastal Inundation History: Rare Storm Events; Tidally Modulated

Rockingham inundation history has been inferred from Fremantle's water level record.

Extra Tropical Storm – May 2003: 1.95m CD (1.31m AHD)

- Sustained strong winds over two days supported by low pressure system being located at more northerly latitudes than most mid latitude depressions, with the track stalling offshore on 15 May. Storm passed south of Cape Leeuwin with an intensity of 986hPa.
- Exceptional water levels in Perth Metropolitan area were due to coincident timing of high tide and a significant surge peak generated by sustained westerly winds, measured as +0.72m at Fremantle.
- Sustained high water level caused erosion along Rockingham foreshore.

Extra Tropical Storm/Meteotsunami 2012: 2.12 CD (1.48m AHD)

- Highest water level recorded at Fremantle tide gauge, over 120 years.
- Tropical low tracked SW parallel to WA coast passing south of Perth.
- The extreme nature of the water level was due to coincidence of a high tide, storm surge, meteotsunami, seiche and unusually high mean sea level linked to a la Niña climate phase. At Fremantle the tidal residual was estimated as 1.14m, with 0.61m attributed to meteotsunami (rapidly fluctuating).
- Meteotsunami was most likely caused by rapid increase in wind speed and directional shift from shore-parallel (north) to onshore (west) over 1-2 hours, as the cold front crossed the coast.

Ex TC Mangga 2020: 1.89m CD (1.25m AHD)

- Western and southern WA experienced a once in a decade weather event when ex-tropical cyclone Mangga combined with an upper-level trough and strong cold front, followed by a deep low through the State's southwest.
- Storm generated water levels more than 0.5m above predicted tides at all stations along the coast.
- Peak water level partly moderated by occurrence during relatively low tides around 2am. If peak surge had occurred around the predicted spring tidal peak near 10am, total water level would likely have exceeded a 100yr ARI.

Hazard: Existing Coastal Inundation Hazard Assessment Summary

CZM & Damara WA (2013)

- Cockburn Sound Coastal Alliance – Coastal Vulnerability Study. Erosion and Inundation Hazard Assessment Report.
- The investigation identified inundation (flooding) and erosion hazards for the study area for present day, 2070 and 2110 The assessment focused on potential impacts to the coast from coastal processes, influenced by climate change and associated sea level rise.

CHRMAP (Cardno 2018)

The spatial extent of coastal inundation caused by storm surge inundation levels were mapped for each planning timeframe using a bathtub modelling approach. Only areas connected to the ocean via a flow path were included in coastal inundation mapping.

- Coastal inundation levels for 1, 10, 50, 100 and 500-year ARI were presented based on available data, an Extreme Value Analysis (EVA) of the measured water level records from three different tide gauges was undertaken (Fremantle Fishing Boat Harbour, Mangles Bay and Mandurah (two locations). This analysis provided estimates of the extreme water levels for the different ARIs at each of the tide gauge locations.
- Allowances for nearshore wave setup and future SLR were added to provide an estimate of the total still water level for each of the ARIs (1, 10, 50, 100 and 500) and planning timeframes (2017, 2030, 2070 and 2110).
- Resulting total still water levels were mapped across the study area using a combination of available survey and LiDAR data.
- The total value of assets potentially impacted by inundation to 2110 was estimated to be around $1.3 billion.
- While the CHRMAP study flagged coastal inundation risks along the length of the City's coastline, it specifically identified 'significant' hazard for low lying areas along the:
  - southern coastline of Cockburn Sound between approximately Wanliss Street and Cape Peron
  - west and south-facing sections of both Shoalwater and Safety Bay
  - Peron and Rockingham
  - Becher Point in Port Kennedy
- A detailed list of vulnerable assets was presented across sectors of the study area. The impact of sea level rise and inundation on drainage infrastructure was assessed with depth and duration of inundation maps for 2110 produced.

Hazard: Existing Controls

Low-lying areas across Rockingham are mostly separated from the ocean by a coastal dune. Active dune management consequently provides an indirect control of coastal inundation hazard, with pedestrian and vehicle access points defining the pathways for inundation.

Along several parts of Rockingham foreshore, buried revetments have been constructed as part of dune restoration works, to limit the potential extent of erosion during a severe storm event.

Assets: Exposure of Coastal Assets to Inundation Impacts

Inundation Level (m AHD)	14.1 Peron-Rockingham			14.2 Shoalwater-Safety Bay		
	Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/ Arterial (km)
1.0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.1	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.2	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.3	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.4	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.5	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.6	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.7	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.8	4	0 / 0	0 / 0	0	0 / 0	0 / 0
1.9	81	0 / 0	0 / 0	3	0 / 0	0 / 1
2.0	99	0 / 0	0 / 0	11	0 / 0	0 / 1
2.1	122	0 / 0	0 / 0	21	0 / 0	0 / 1
2.2	149	0 / 0	0 / 1	36	0 / 0	0 / 1
2.3	185	0 / 0	0 / 1	58	0 / 0	0 / 1

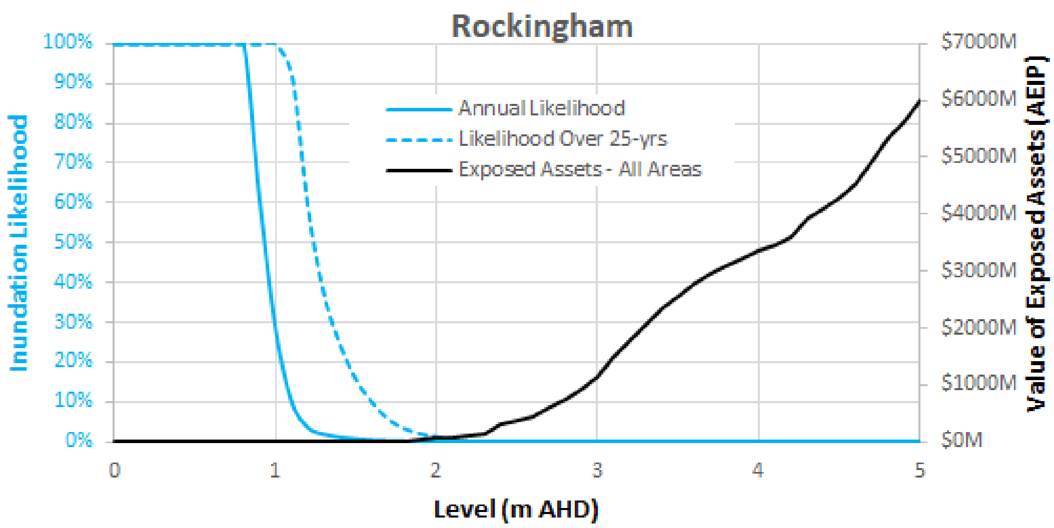
High (~25yr ARI)
Extreme (~100yr ARI)
Extreme +0.9m

Other Assets Exposed:
14.1 Peron-Rockingham
Extreme r+0.9m: 1 wastewater treatment plant

- No assets exposed in either area considered at the high or extreme water levels;
- Initial exposure of residential buildings at 1.8m AHD with primary pathways at Palm Beach and the Point Peron boat launch within area 14.1 and the Safety Bay boat ramp for area 14.2
- No commercial or industrial buildings have been identified as exposed to inundation hazard using the AEIP tool and only 1km or road is predicted to be impacted under an extreme +0.9m water level scenario.

Comparison of exposed assets and estimated inundation likelihood indicates most assets identified via AEIP are above levels likely to be affected by coastal inundation, with less than 1% estimated likelihood of inundation damage over a 25 year time frame. Notably, this does not include effects of waves, which can extend to higher levels.

The marginal separation between inundation likelihood and exposed assets indicates high senstivity to factors that may additionally contribute to inundation hazard, such as wave processes or projected sea level rise. This explains the significant difference in hazard identification between this evaluation and previous evaluations of inundation hazard where sea level rise scenarios were considered.



Damage: Inundation Risk Ratings

Average Annual Damage		AEIP			
	WL	1.2m AHD	1.4m AHD	2.3m AHD	All Water Levels
Area	ARI	High	Extreme	Extreme+ 0.9m	
14.1: Peron-Rockingham		$ 0K/yr	$ 0K/yr	$ 3K/yr	$ 3K/yr
14.2: Shoalwater-Safety Bay		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
Total Damage		**$ 0K/yr**	**$ 0K/yr**	**$ 4K/yr**	**$ 4K/yr**

Relatively small average annual damage in the Peron-Rockingham due to exceptional events, above +1.9m AHD, where inundation crosses Esplanade near Fisher St at +1.9m AHD.

Planning Framework

The City of Rockingham falls within the area covered by the Metropolitan Regional Scheme, which stipulates an objective for coastal and foreshore reserves to accommodate coastal hazards. The MRS defines existing property boundaries, with further consideration of coastal hazards applicable for sub-division conditions under SPP 2.6.
The City of Rockingham Local Planning Scheme No. 2 does not refer to coastal hazards, including inundation or erosion.
The City of Rockingham has developed a CHRMAP, expanding on a coastal adaptation plan (CAP) for Cockburn Sound. These recognise coastal inundation hazard affecting the low-lying areas of Rockingham. It is noted that adaptation plans are largely to be defined through future evaluation, however, preliminary options are focused on erosion hazard, with inundation hazard largely considered to be effectively treated simultaneously.

Evaluation of Rockingham's planning framework against the Inundation Management Health Check criteria gave:

HC1
- Interactions between coastal inundation and waves were identified in coastal vulnerability studies.

HC2
- Rockingham Local Planning Scheme No. 2 does not address coastal inundation. Coastal vulnerability studies evaluated conditions up to 500-year ARI, with 0.9m sea level rise.

HC3
- Mapping of coastal inundation hazard in the CVS does not have connection to planning documents.

HC4
- Inundation mitigation measures are not identified in Rockingham planning framework. Proposed activities in the CHRMAP include installing seawalls and developing emergency management plans.

HC5
- Pathways for adaptation in the CHRMAP are focused on strategic works to manage erosion, and do not include triggers based on inundation hazard.

HC6
- The planning framework does not acknowledge the role of emergency management for coastal hazards, but this is identified as a core activity within the CHRMAP.

HC7
- The planning framework and CHRMAP do not acknowledge flood proofing, or relate to corresponding ABCB guidance.

HC8
- A special control area for coastal hazards has not been defined. Lack of an SCA limits capacity to obtain targeted financial recompense to support strategic interventions or adaptation.

MODERATE Inundation Risk
at coast

City of Mandurah

Focus

Adaptation Priority

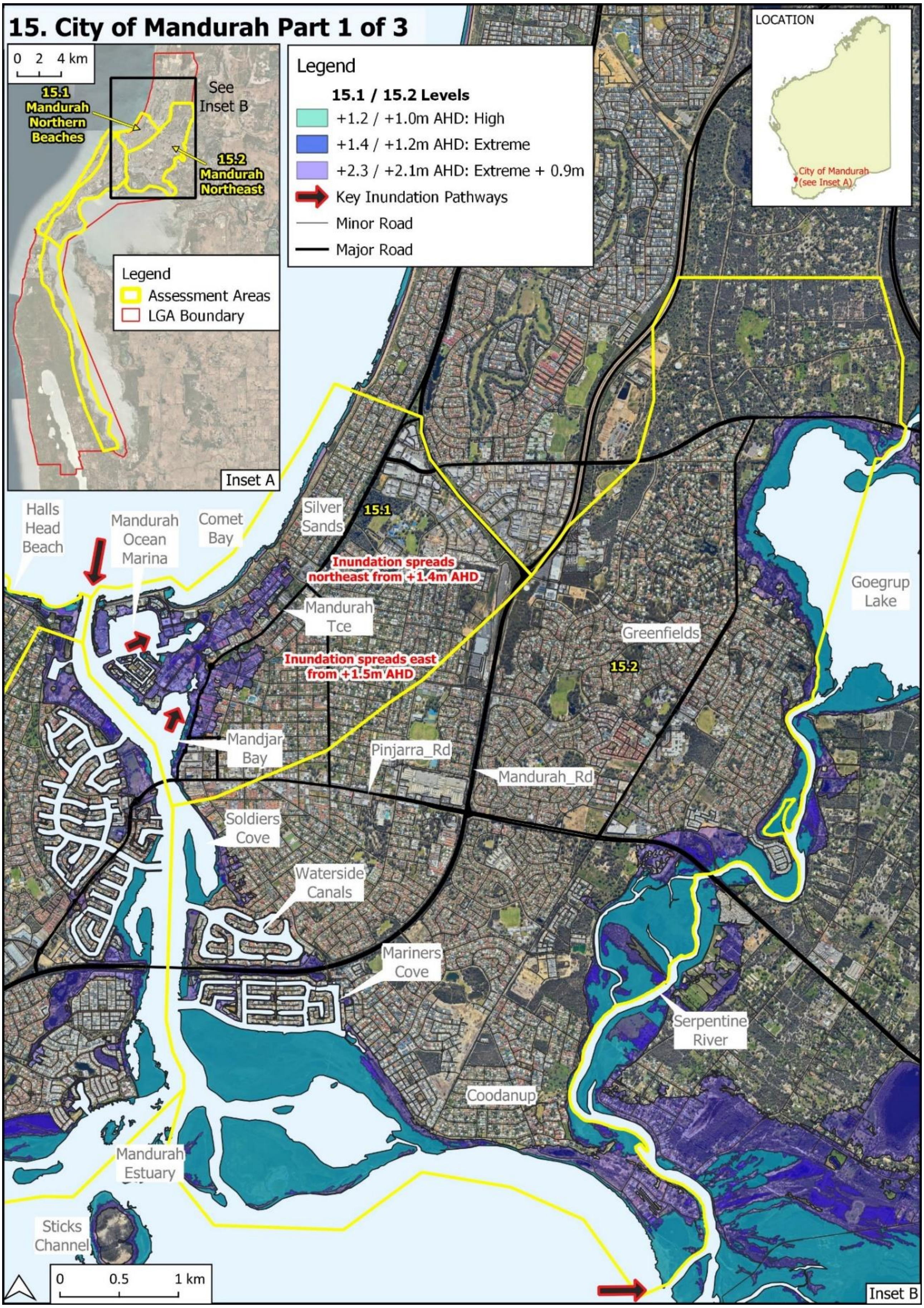
Targeted Mitigation

Actions

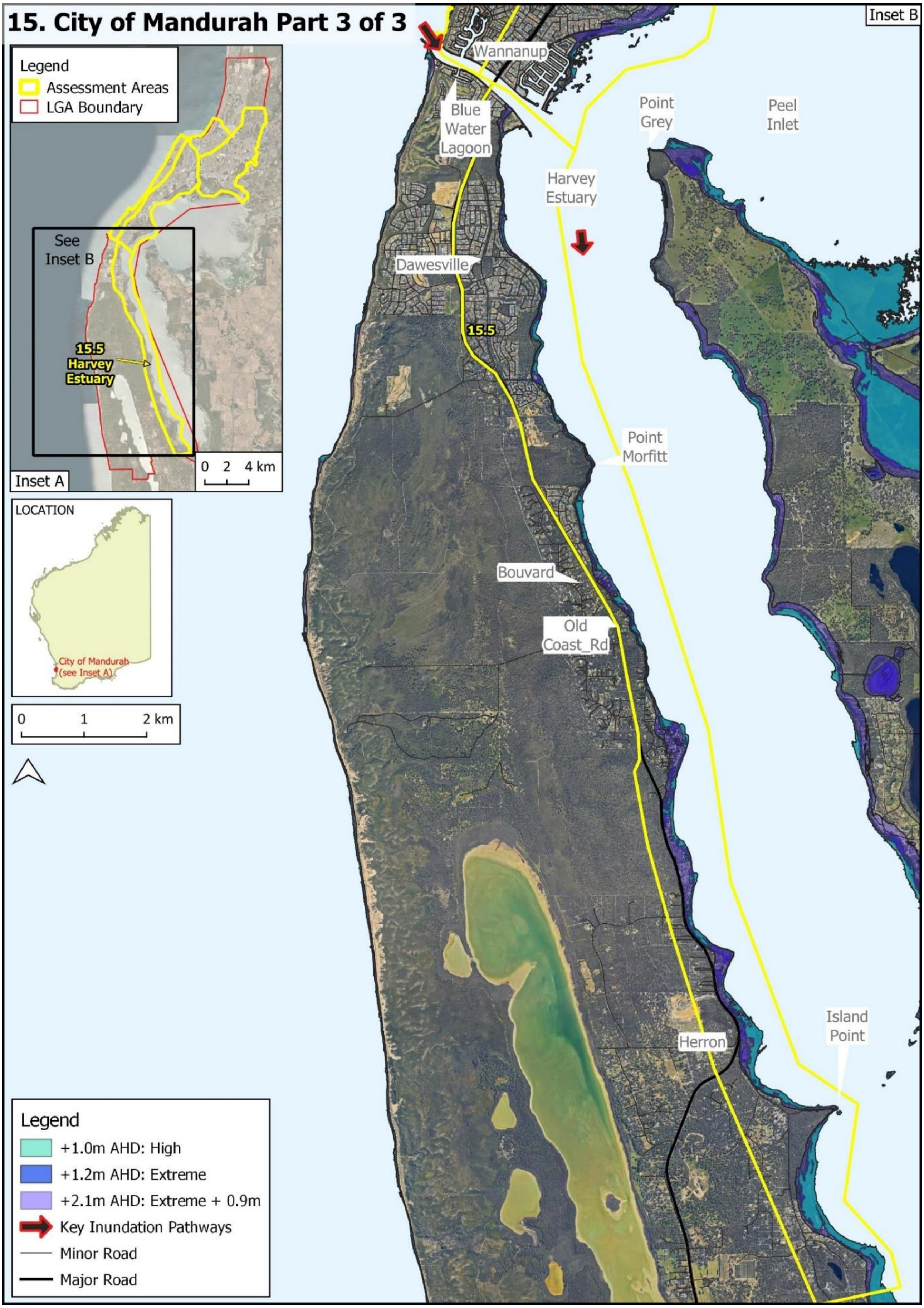
Management at Foreshore

WL Review (CHRMAP)

Seashore Engineering


15. City of Mandurah Part 1 of 3
0 2 4 km
15.1 Mandurah Northern Beaches
See Inset B
15.2 Mandurah Northeast
Legend
Assessment Areas
LGA Boundary
Inset A
Legend
15.1 / 15.2 Levels
+1.2 / +1.0m AHD: High
+1.4 / +1.2m AHD: Extreme
+2.3 / +2.1m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road
LOCATION
City of Mandurah (see Inset A)
Halls Head Beach
Mandurah Ocean Marina
Comet Bay
Silver Sands
15.1
Inundation spreads northeast from +1.4m AHD
Mandurah Tce
Inundation spreads east from +1.5m AHD
Goegrup Lake
Greenfields
15.2
Mandjar Bay
Pinjarra_Rd
Mandurah_Rd
Soldiers Cove
Waterside Canals
Mariners Cove
Serpentine River
Coodanup
Mandurah Estuary
Sticks Channel
0 0.5 1 km
Inset B


15. City of Mandurah Part 2 of 3
0 2 4 km
See Inset B
15.3 Wannanup-Halls Head
15.4 Peel Inlet West
Inset A
Legend
Assessment Areas
LGA Boundary
LOCATION
City of Mandurah (see Inset A)
0 0.5 1 km
Robert Point
Halls Head Beach
Mandurah Ocean Marina
Blue Bay
Mary St Lagoon
Polleys Hole
Port Mandurah
Halls Head
Pinjarra Rd
15.3
Mandurah Rd
Mandurah Quay
Mandurah Estuary
15.4
Erskine
Sticks Channel
Falcon Bay
Cox Bay
Peel Inlet
Falcon
Dawesville Channel
Ward Point
Northport
Port Bouvard Marina
Wannanup
Point Grey
Blue Water Lagoon
Inset B
Legend
15.3 / 15.4 Levels
+1.2 / +1.0m AHD: High
+1.4 / +1.2m AHD: Extreme
+2.3 / +2.1m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road


15. City of Mandurah Part 3 of 3
Legend
Assessment Areas
LGA Boundary
See Inset B
15.5 Harvey Estuary
Inset A
0 2 4 km
LOCATION
City of Mandurah (see Inset A)
0 1 2 km
Inset B
Wannanup
Blue Water Lagoon
Point Grey
Peel Inlet
Harvey Estuary
Dawesville
15.5
Point Morfitt
Bouvard
Old Coast_Rd
Island Point
Herron
Legend
+1.0m AHD: High
+1.2m AHD: Extreme
+2.1m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road

15. MANDURAH

Site overview:

The authors wish to acknowledge the Bindjareb people as the native title holders of the lands and waters in and around the City of Mandurah. The City is in the Peel region of Western Australia, approximately 75 km south of Perth between the Indian Ocean and Peel-Harvey Estuary. The City has expanded exponentially from an agricultural and fishing village to a bustling metropolis. Development and growth has centered on marine environments, particularly the Peel-Harvey estuary. Despite its highly modified nature, the City retains pristine beaches, large areas of high conservation significance and Ramsar listed wetlands. It has a resident population of 93,414[1] and is the second largest city in WA and the second fastest growing regional city in Australia.

Areas at risk from inundation:

Five inundation exposure areas have been considered for the Mandurah LGA with land areas above Highest Astronomical Tide[1] (HAT) potentially inundated under high (~25yr ARI), extreme (~100yr ARI), and extreme +0.9m (~100yr ARI +0.9m) inundation levels have been estimated as:

REGION	WL ARI	1-1.2m AHD High	1.2-1.4m AHD Extreme	2.1-2.3m AHD Extreme + 0.9m
15.1 Mandurah Northern Beaches		0.1km²	0.1km²	0.9km²
15.2 Mandurah Northeast		2.2km²	2.6km²	4km²
15.3 Wannanup-Halls Head		0.1km²	0.2km²	0.4km²
15.4 Peel Inlet West		0.5km²	1km²	2.6km²
15.5 Harvey Estuary		1.1km²	1.7km²	2.9km²

Morphology: Open Ocean; Channel and Estuary

Open Ocean (15.1; 15.3)

- Sandy beaches, perched beaches, channel openings and rocky points.
- Open ocean coast has intermittent protection from offshore chain of rocky submarine reefs, pinnacles, and islands with interspersed passages.
- The reef acts as a barrier to incident wave energy offering protection to areas in the lee of outcrops with higher wave energy at locations coincident with gaps in the reef.
- Localised beach and dune development on the seaward side of the emergent mainland.
- Where offshore reef is absent, the coast is locally comprised of exposed Pleistocene (Tamala) Limestone, generally eroding slowly.

Estuarine (15.4; 15.5; 15.2)

- Peel Inlet and Harvey Estuary are two interlinked coastal lagoons.
- Peel Inlet has a shallow estuarine basin is approximately 10 km in diameter and roughly circular in shape with large areas <0.5 m in depth and a small central basin of approximately 2 m depth. Harvey Estuary is almost 20 km long and 2-3km across, with a series of basins, typically reaching about 1.5m mean depth.
- The Serpentine and Murray rivers discharge into the Inlet from the east. Harvey River discharges into the southern end of Harvey Estuary, although flows have been substantially modified by Harvey Diversion Drain and Harvey Dam.
- Within the system there are many important wetland morphotypes with saltmarshes providing physical stability to the shoreline and inhibiting erosion.
- Overall, geomorphology of the Estuary has been modified through dredging and reclamation, including development of artificial channels and canal estates. The system is connected to the sea by a narrow, naturally occurring channel at the northern end of the Inlet (Mandurah Channel), and a man-made channel connecting to the ocean at the north end of Harvey Estuary (Dawesville Channel).

Channel (present in all areas)

- Mandurah channel is a naturally occurring channel that flows through areas of natural reserve, canal estates and foreshore developments including a new marina at the ocean entrance and a popular city hub of cafés, restaurants, housing, and businesses. This is extensively walled, with entrance training structures and is dredged to provide safe navigation. Sand bypassing is undertaken annually.
- Dawesville Channel was constructed in 1994 to assist in flushing the Peel-Harvey Estuary and help alleviate a chronic algal bloom problem. This channel is walled, with entrance training structures that are used as a sand trap to support annual sand bypassing.
- Both channels have been extensively modified and accommodate residential and commercial development and foreshore reserves.

[1] Areas were calculated at 0.1m increments with HAT for Mandurah taken at 0.7m AHD in this study.

Climate: Microtidal; Wave Dominated

- Microtidal, mixed, mainly diurnal tides with range of 0.81m LAT to HAT, which includes a large seasonal mean sea level range whereby sea levels are around 0.25m lower on average in summer than in winter.
- Mandurah is in Wind Region A1 (AS1170.2), which means that extreme winds are caused by mid-latitude storms.
- Direct rainfall accounts for approximately 15% of the total inflow of water into the system.
- Storms occur mainly between June and November and have an annual frequency of 15 days per year.
- Significant meteorological surges, associated with low barometric pressure and westerly storm events, with depressed water levels during sustained easterly winds or high barometric pressure.
- Minor surges associated with the passage of continental shelf waves, generated from the tropical and sub-tropical zones, including the effects of remote tropical cyclones.

Development Record: Regional City and Services Hub

The Bindjareb people are the original inhabitants and traditional owners of the land in and around Mandurah. They named the locality Mandjoogoordap (now Mandurah) which translates to 'meeting place of the heart'. A colonial townsite for Mandurah was laid out in 1831 but it remained a small fishing village until the late 1950s when its reputation for boating and fishing attracted many retirees. The city has expanded exponentially in recent years and Mandurah coastal region is now amongst the most populous, rapidly developing and highly modified and managed parts of Western Australia's coast.

- It is highly developed close to shore, with a minimal buffer to residential development along the beaches north of Mandurah Ocean Marina.
- Flow patterns between the Peel-Harvey Estuary and the Indian Ocean have been highly modified since the 1870's.
- The first major modification involved training of Mandurah Channel using rock walling near the Mandurah Ocean Entrance and dredging of the entrance sand bar. The training walls have been given a series of minor extensions, with further walling inside the arc of the sandbar to restrict local trapping of littoral drift.
- Development within the channel and its surrounds since the 1980s, including bridges and canal entrance training walls has reduced the capacity of Mandurah Channel as a floodway.
- In 1994, Dawesville Channel was opened, providing a second entrance from the estuary to the Ocean.
- A proliferation of artificial waterbodies has occurred across Mandurah Channel. The two most significant developments in size are Mandurah Ocean Marina and Port Mandurah canal estate. The latter waterbody was connected at two locations to Mandurah Channel, allowing a supplementary route for tidal and flood flows.

Coastal Inundation History: Frequent Moderate Events; Tidally Modulated

Water level recorders were installed through Peel-Harvey Estuary in the 1970s to support agricultural drainage plans and inform mosquito management. A permanent tide gauge collecting digital data was installed in 1990, partly to support investigations for Dawesville Channel. Additional gauges were deployed throughout the estuary to characterize exchanges between the ocean and the estuary basins, to verify the changes caused by the artificial channel, which substantially increased tides in the estuary. The top-3 water level events in known records for Mandurah are:

Tropical Cyclone Alby – 1.65m CD (1.11m AHD)

- TC Alby recorded a +1.65m CD (0.89m AHD) water level at the historical Mandurah Jetty tide gauge, which remains the highest in the Mandurah records.
- Observations in a network of tide gauges demonstrated the influence of wind set-up within the Peel-Harvey Estuary, with an increase in water level from north to south of 1.2m associated with strong north-north-west winds acting directly along the alignment of the Harvey Estuary.

Extra Tropical Storm – May 2003 1.56m CD (1.02m AHD)

- Exceptional water levels leading to localised inundation throughout the State.
- Highest ever recorded water level for present day Mandurah tide gauge due to coincident timing of high tide and a significant surge peak generated by sustained westerly winds.
- Building foundation affected by inundation in canal estate.

Ex Tropical Cyclone Mangga May 2020 – 1.55m CD (1.01m AHD)

- Western and southern parts of WA experienced once in a decade weather when the storm associated with ex-TC Mangga combined with an upper-level trough and strong cold front followed by a deep low through the SW.
- Generated water levels more than 0.5m above predicted tides. For Mandurah, a water level of 1.55m CD was recorded and Peel tide gauge 1.52m.
- Coastal inundation which was mainly restricted to low lying foreshore reserves and roads with limited inundation damage reported. Known inundation included some residential areas surrounding canal estates (e.g., Halls Head).

Hazard: Existing Coastal Inundation Hazard Assessment Summary

Damara (2007)

Development in flood prone areas and implications of climate change was examined for the Mandurah region:

- Coastal inundation hazard was distinct from estuarine inundation hazard until opening of Dawesville Channel in 1994, which provided a more direct connection of Peel-Harvey estuary to the ocean than the constricted Mandurah Channel.
- Changes caused by the artificial channel substantially increased tides in the estuary, enhanced inundation pathways and led to increased inundation risk.

Damara (2012)

- Coastal Hazard Mapping for Economic Analysis of Climate Change Adaptation in the Peron-Naturaliste Region provided inundation mapping for Mandurah and Peel-Harvey Estuary with additional allowances for projected sea level rise.
- It identified the potential for overland flooding affecting the council building and adjacent residential areas.

Northern Beaches CHRMAP (GHD, 2020)

- More recently, inundation hazard mapping has been conducted for Mandurah Northern Beaches using a combination of tide gauge analysis and simulated worst-track for a storm equivalent to TC Alby.
- Inundation hazard assessment identified that the southern end of investigated shoreline, Mandurah Ocean Entrance and Mandurah Marina are in an area with high risk of coastal inundation due to the low elevation of land (~2m AHD).

Hazard: Existing Controls

- Existing controls to inundation hazard are largely associated with the minimum fill level defined for sub-divisions. This has varied over time, and between developments, with older areas generally being filled to a lower level. Many of the canal waterways were established during the 1980s through 1990s, and consequently these have similar levels. However, as many were built prior to opening of Dawesville Channel, their effective standard of protection against inundation has reduced.
- Redesign of foreshore walling in Manjar Bay was intended to limit inundation and wave effects along the town promenade.

Assets: Exposure of Coastal Assets to Inundation Impacts

Inundation Level (m AHD)	15.1 Mandurah Northern Beaches			15.2 Mandurah Northeast			15.3 Wannanup-Halls Head			15.4 Peel Inlet West			15.5 Harvey Estuary		
	Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/ Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/ Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)
1.0	0	0 / 0	0 / 1	0	0 / 0	0 / 1	0	0 / 0	0 / 0	0	0 / 0	0 / 1	0	0 / 0	0 / 1
1.1	0	0 / 0	0 / 1	0	0 / 0	0 / 1	0	0 / 0	0 / 0	0	0 / 0	0 / 1	2	0 / 0	0 / 1
1.2	**3**	**0 / 0**	**0 / 1**	**0**	**0 / 0**	**0 / 1**	**0**	**0 / 0**	**0 / 0**	**0**	**0 / 0**	**0 / 1**	**8**	**0 / 0**	**0 / 1**
1.3	4	0 / 0	0 / 1	11	0 / 0	0 / 1	0	0 / 0	0 / 0	3	0 / 0	0 / 1	16	0 / 0	0 / 1
1.4	**9**	**0 / 0**	**0 / 1**	**16**	**0 / 0**	**0 / 1**	**0**	**0 / 0**	**0 / 0**	**5**	**0 / 0**	**0 / 1**	**21**	**0 / 0**	**0 / 1**
1.5	16	2 / 0	0 / 1	21	0 / 0	0 / 1	0	0 / 0	0 / 0	16	0 / 0	0 / 1	34	0 / 0	0 / 1
1.6	28	4 / 0	0 / 1	29	0 / 0	0 / 1	0	0 / 0	0 / 0	22	0 / 0	0 / 1	49	0 / 0	0 / 1
1.7	51	7 / 0	0 / 1	42	0 / 0	0 / 1	0	0 / 0	0 / 0	32	0 / 0	0 / 1	57	1 / 0	0 / 1
1.8	82	10 / 0	0 / 1	63	0 / 0	0 / 1	0	0 / 0	0 / 0	36	0 / 0	0 / 1	63	1 / 0	0 / 1
1.9	124	10 / 0	0 / 1	75	0 / 0	0 / 1	0	0 / 0	0 / 0	70	0 / 0	0 / 2	73	1 / 0	0 / 1
2.0	176	16 / 0	0 / 1	103	0 / 0	0 / 1	0	0 / 0	0 / 0	101	0 / 0	0 / 2	74	1 / 0	0 / 1
2.1	212	18 / 0	0 / 1	120	0 / 0	0 / 1	18	0 / 0	0 / 0	131	0 / 0	0 / 2	79	1 / 0	0 / 1
2.2	271	21 / 0	0 / 2	146	0 / 0	0 / 1	22	0 / 0	0 / 0	167	0 / 0	0 / 2	83	1 / 0	0 / 1
2.3	**304**	**27 / 0**	**0 / 2**	**258**	**0 / 0**	**0 / 1**	**21**	**0 / 0**	**0 / 0**	**212**	**0 / 0**	**0 / 2**	**86**	**1 / 0**	**0 / 2**

High (~25yr ARI)

Extreme (~100yr ARI)

Extreme +0.9m

Other Assets Exposed: 15.1 Mandurah Northern Beaches

Extreme +0.9m: 1 waste management site

15.1: Mandurah Northern Beaches

- Coast parallel dunes constrain inundation pathways to lower lying depressions that run between the dunes and connect to Mandurah Ocean Marina and Manjar Bay.
- Identified exposure below 1.4m AHD is for foreshore residential buildings and above 1.4m AHD, inundation extends landward, exposing a mix of commercial and residential buildings.
- The two inundation pathways connect around 1.6m AHD, causing potential isolation for Mandurah Peninsula area.

15.2: Mandurah Northeast

- Inundation over the foreshore road occurs in Soldiers Cove above 1.8m AHD, with extensive areas of inundation across reclaimed and filled areas of Waterside Canals and Mariners Cove around 2.3 to 2.4m AHD. It is noted that estimation of inundation exposure through this area is likely to be exaggerated due to the resolution of AEIP.
- Southeast of Coondanup foreshore reserve, a few residences adjacent to the Serpentine river mouth are subject to inundation above 1.2m AHD, with increasing exposure of buildings from 1.3m AHD, resulting in isolation of the peninsula and widespread inundation exposure above 1.8m AHD.

15.3: Wannanup-Halls Head

- Exposure is indicated for canal-side residential buildings within Northport. Exposure at low-levels may be exaggerated due to the resolution of AEIP.

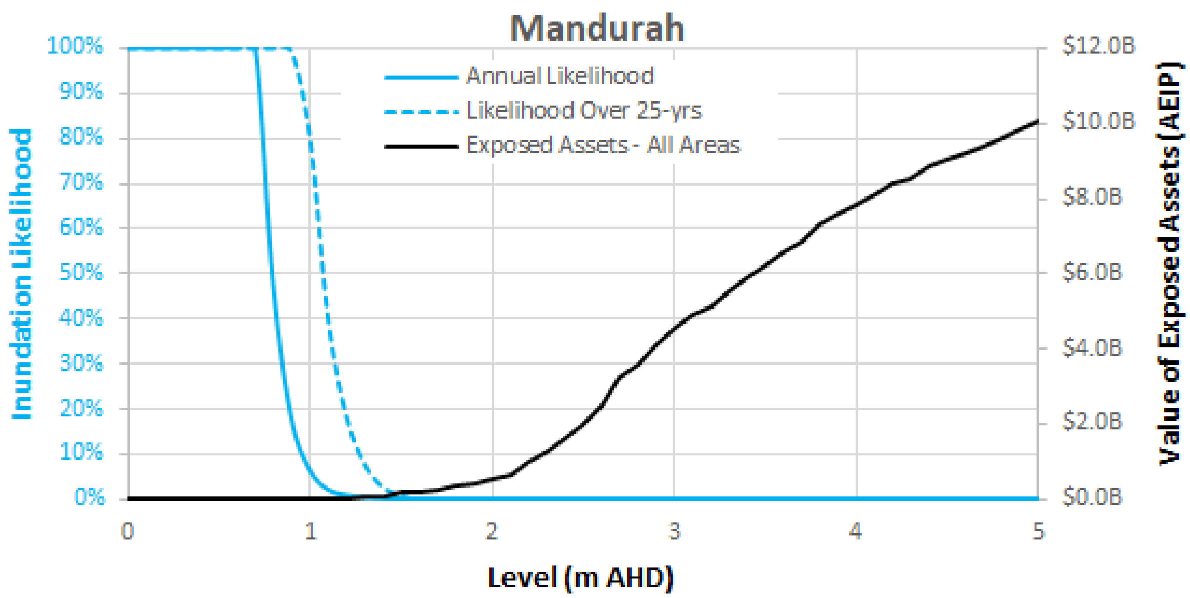
15.4 Peel Inlet West

- Older reclamation area northeast of Port Mandurah experiences inundation from around 1.2m AHD. This also affects the play precinct not identified through AEIP buildings. The infilled foreshore area east of Port Mandurah is affected around 1.7m AHD, and a small pocket of residences can be affected on either side of Old Coast Road to the southeast.
- Inundation hazard generally affects Port Mandurah residential buildings above 2.1m AHD, although there is capacity for flow to cut across Old Coast Road around Brindabella Crescent by around 2.0m AHD.
- Inundation across Erskine potentially occurs via a number of wetlands and WSUD drainage reserves, breaking out across roads at approximately 2.1m AHD, and crossing Sticks Boulevard at approximately 2.3m AHD.
- Direct inundation across Novara foreshore potentially occurs from 1.5m AHD, potentially affected at lower levels through wave action. There is a higher level of infill for East Falcon, with inundation commencing around 2.1m AHD, including flow across Queen Parade.

15.5: Harvey Estuary

- Inundation exposure along the west side of Harvey Estuary commences around 1.2m AHD, with isolated inundation along foreshore roads. Buildings generally start to be impacted around 1.1m AHD at Park Ridge and Estuary Hideaway Holiday Park, with progressively increasing exposure along the entire length of the foreshore.

Assets identified with AEIP occur from 1.4m AHD, with a substantial increase in assets between 2.1m and 2.7m AHD. Comparison with estimated inundation likelihood indicates limited interaction, with less than 1% likelihood of coastal inundation impact over a 25 year period. Notably, this does not include effects of waves, which can extend to higher levels. Substantial increase in asset exposure from 2.1m AHD indicates high sensitivity to an inundation difference of around 0.9m. This difference could be developed through choice of event scenarios or statistics, inclusion of wave processes, or allowance for sea level rise. Implicitly, present-day focus for inundation management should focus on isolated low-lying foreshore areas, effective use of foreshore reserves to mitigate wave action, and development of longer-term adaptation plans.



Damage: Inundation Risk Ratings & Damage Assessment

Average Annual Damage		AEIP			
Area	WL / ARI	1-1.2m AHD High	1.2-1.4m AHD Extreme	2.1-2.3m AHD Extreme+ 0.9m	All WL
15.1: Mandurah Northern Beaches		$ 0K/yr	$ 8K/yr	$ 72K/yr	$ 72K/yr
15.2: Mandurah Northeast		$ 0K/yr	$ 3K/yr	$ 11K/yr	$ 11K/yr
15.3: Wannanup-Halls Head		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
15.4: Peel Inlet West		$ 0K/yr	$ 1K/yr	$ 4K/yr	$ 4K/yr
15.5: Harvey Estuary		$ 6K/yr	$ 27K/yr	$ 44K/yr	$ 44K/yr
Total Damage		**$ 6K/yr**	**$ 39K/yr**	**$ 132K/yr**	**$ 132K/yr**

- Greatest damage within the Mandurah Northern beaches segment, where inundation ingress occurs along Ormsby Terrace and Cooper Street, from +1.4-1.5m AHD.
- Smaller contributions from Mandurah Northeast and Harvey Estuary, which have exposure of residential properties identified at as low as +1.0m AHD. These properties may have building floor levels above the ground level.
- Corrections applied in damage assessment following ground truthing of canal estates residential buildings captured within the percolation assessment.
- Mandurah has overall high sensitivity, with substantially greater damage occurring with sea level rise.

Planning Framework

The City of Mandurah planning framework includes a Local Planning Strategy and Local Planning Scheme No. 12. The Strategy acknowledges Mandurah's existing estuarine flooding and coastal inundation hazards, as well as anticipated future increases to coastal erosion and inundation hazards. The City requires all plans and proposals for land adjacent to the waterfront to assess impacts of climate change and extreme weather events.

The City of Mandurah Local Planning Scheme No. 12 does not refer to coastal hazards directly, but identifies a special control area for flooding, which doesn't distinguish between runoff flooding or coastal inundation. The City of Mandurah has not yet completed a CHRMAP, with climate change adaptation studies completed prior to inclusion of CHRMAP within SPP 2.6. The main document describing management of potential coastal stresses is the Strategic Assessment Report (SAR).

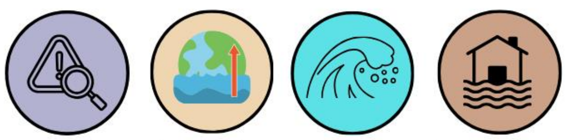
Evaluation of Mandurah's planning framework against the Inundation Management Health Check criteria gave:

- HC1 — Interactions between coastal inundation and runoff were identified in floodplain mapping.
- HC2 — Mandurah Local Planning Scheme No.12 nominates a minimum flood level to consider being for a 1 in 100-year recurrence level. Mapped areas of estuarine flooding and coastal inundation include an allowance for 0.9m sea level rise.
- HC3 — A flood prone area is mapped in the Local Planning Scheme No. 12. The original source of information is not referred to, obscuring the processes used to defined inundation hazard.
- HC4 — There is limited preference for inundation mitigation measures outlined in Mandurah planning framework, except for definition of a minimum habitable floor level for buildings adjacent to Peel-Harvey Estuary.
- HC5 — The SAR applied a strategic evaluation of pathways for adaptation, setting directions for refinement of existing management practices, with a focus on flexibility.
- HC6 — The planning framework does not specifically acknowledge the role of emergency management for coastal hazards.
- HC7 — Mandurah Local Planning Scheme No. 12 acknowledges flood proofing and specifically nominates guidance from ABCB, which supports external update of best practice.
- HC8 — A special control area for flood prone areas has been identified, encompassing both coastal inundation and estuarine flooding. If appropriate the SCA can be used for special area rates or a levy to obtained targeted funding to support a local intervention.

MODERATE Inundation Risk
at coast

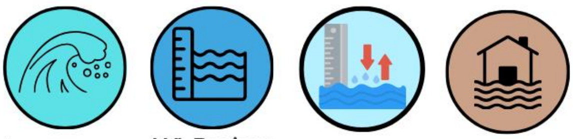
Shire of Murray

Focus



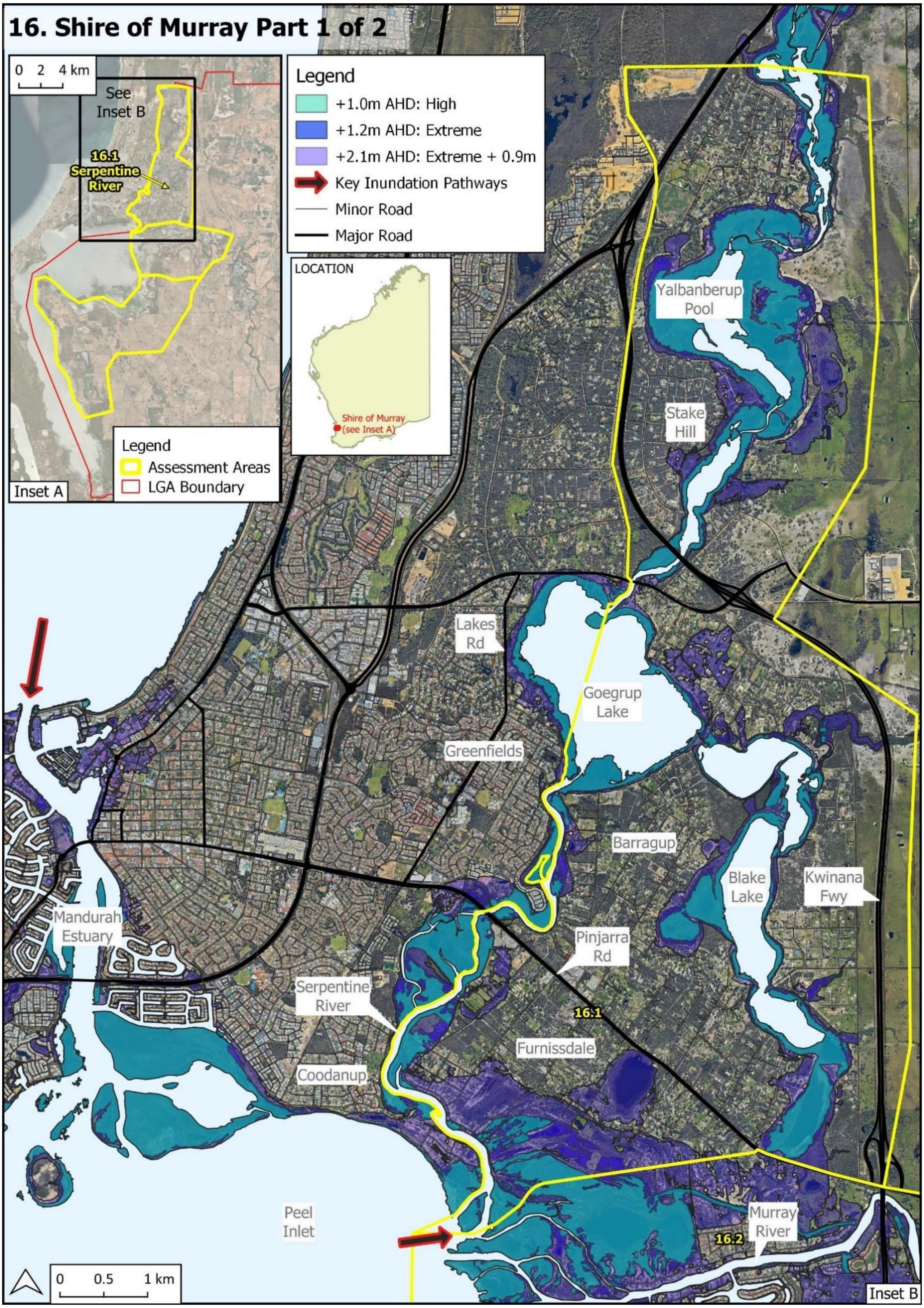
Active Management | Adaptation Priority | Management at Foreshore | Emergency Management

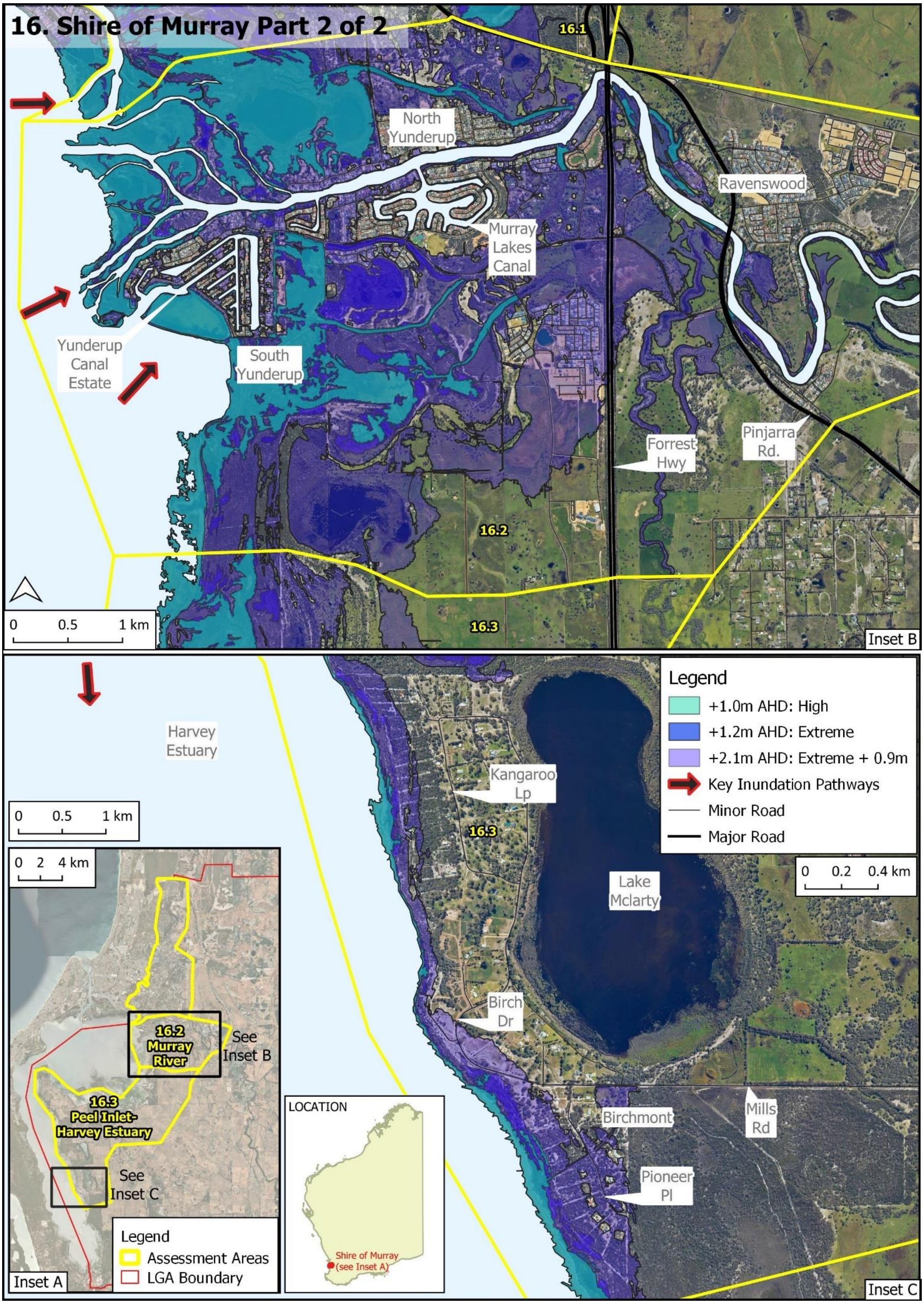
Actions



Management at Foreshore | WL Review (CHRMAP) | WL Sensitivity Review | Emergency Plan

Seashore Engineering


16. Shire of Murray Part 1 of 2
0 2 4 km
See Inset B
16.1 Serpentine River
Inset A
Legend
Assessment Areas
LGA Boundary
Legend
+1.0m AHD: High
+1.2m AHD: Extreme
+2.1m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road
LOCATION
Shire of Murray (see Inset A)
Yalbanberup Pool
Stake Hill
Lakes Rd
Goegrup Lake
Greenfields
Barragup
Blake Lake
Kwinana Fwy
Mandurah Estuary
Pinjarra Rd
Serpentine River
16.1
Furnissdale
Coodanup
Peel Inlet
Murray River
16.2
0 0.5 1 km
Inset B


16. Shire of Murray Part 2 of 2
16.1
North Yunderup
Ravenswood
Murray Lakes Canal
Yunderup Canal Estate
South Yunderup
Forrest Hwy
Pinjarra Rd.
16.2
16.3
0 0.5 1 km
Inset B
Harvey Estuary
0 0.5 1 km
Kangaroo Lp
16.3
Legend
+1.0m AHD: High
+1.2m AHD: Extreme
+2.1m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road
0 0.2 0.4 km
Lake Mclarty
0 2 4 km
Birch Dr
16.2 Murray River
See Inset B
16.3 Peel Inlet-Harvey Estuary
Birchmont
Mills Rd
LOCATION
See Inset C
Pioneer Pl
Legend
Assessment Areas
LGA Boundary
Shire of Murray (see Inset A)
Inset A
Inset C

16. MURRAY

Site Overview:
The authors wish to acknowledge the Bindjareb Noongar people as the native title holders of the lands and waters in and around the Shire of Murray. The Shire is located along the eastern margin of Peel-Harvey Estuarine System, including the mouths of Murray and Serpentine Rivers. The Shire is predominantly rural, with rural-residential areas in the main township of Pinjarra, the small townships of Dwellingup and North Dandalup, as well as numerous smaller settlements. Land is used predominantly for agriculture (mainly cattle, with some pigs and horses and orcharding), mining, forestry, and conservation. The Shire encompasses a total land area of about 1,700 square kilometres and has more than 18,000 residents.

Areas at risk from inundation:
Three inundation exposure areas have been considered for the Shire of Murray with land areas above Highest Astronomical Tide[1] (HAT) potentially inundated under high (~25yr ARI), extreme (~100yr ARI), and extreme +0.9m (~100yr ARI +0.9m) water levels estimated as:

REGION	WL	1m AHD	1.2m AHD	2.1m AHD
	ARI	High	Extreme	Extreme + 0.9m
16.1 Serpentine River		2.5km²	3.5km²	9km²
16.2 Murray River		4.2km²	5.7km²	16.4km²
16.3 Peel Inlet-Harvey Estuary		7.2km²	9.9km²	23.6km²

Morphology: Estuarine; Delta; Marshes; High Barrier/Dunes; Low Relief Floodplain

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 Murray, Serpentine, and Harvey Rivers, along with local catchment drainage.
Land surrounding the estuary has been shaped by coastal, alluvial or lagoonal processes:

- 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.
- 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

The mix of land forming processes has created several different morphotypes along the Shire of Murray foreshore. These indicate active processes and influence pathways by which the foreshore can potentially change over time. Major foreshore features for the two estuary basins are:

Peel inlet
- Flood delta
- Serpentine River basin chain
- Murray River delta
- Terraced shore

Harvey Estuary
- Perched shore
- Subtidal bars
- Sill
- Harvey River delta

Climate: Microtidal; Sheltered; Wind Set-Up

- A micro-tidal, mainly diurnal climate with tidal peaks in June and December.
- Highest Astronomical Tide (HAT): Peel 1.02m CD (+0.47m AHD); Harvey 1.07m CD (+0.52m AHD)
- Water level inside Peel-Harvey is affected by a range of short term and longer-term influences that result in tidal residual or surge effects that can cause water levels significantly higher than HAT. Typically, passage of winter storms cause water levels above HAT several times per year.
- Both basins are substantially sheltered from direct influence of ocean waves, notably prevailing swell.
- Murray is in Wind Region A1 (AS1170.2), which means that extreme winds are caused by mid-latitude storms.

[1] Areas were calculated at 0.1m increments with HAT for Peel-Harvey taken at 0.5m AHD in this study.

Influences on water level in Peel-Harvey causing difference from the predicted tide level include:

- Surges associated with low barometric pressure and storm events with westerly winds.
- Minor, occasional surges are associated with passage of continental shelf waves.
- Local wind set-up is 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 along Harvey Estuary caused water levels in the south of the estuary almost 1.2m higher than in the north.
- Extreme water levels between May to July, when seasonal peaks for mean sea level, surge and tide are in phase.
- Likelihood of high-water level events increases during periods of elevated mean sea levels (La Niña) and highs in the lunar nodical tidal cycle.
- There are a range of different storm types which can generate high water levels in Peel-Harvey Estuary.

Development Record: Rural

- The Bindjareb and Wilman peoples of the Noongar nation are the traditional owners of the land on which the Shire of Murray stands.
- 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.
- There are two existing communities in the Shire of Murray on Peel-Harvey foreshore, with urban development in Yunderup and low density semi-rural development at Birchmont. Development has been proposed at Point Grey.

The Estuary has a long history of modification which impacts shoreline stability and likely inundation impacts into the future. In rough order of occurrence:

- Clearing and drainage to support agricultural use of catchment.
- Modification of the Mandurah ocean entrance and Mandurah Channel, to improve navigation estuary-ocean water exchange.
- Foreshore infrastructure with increased residential and recreational pressure adjacent to the estuary: stabilisation (walling) and boat ramps.
- Hydrology of Harvey and Serpentine Rivers modified: land drainage, flood management and water supply. Changes to the hydrology and land-use altered estuarine water chemistry, resulting in progressive eutrophication of the waterway.
- Suite of management actions including construction of Dawesville Channel, opened in 1994, which substantially increased tidal exchange into the estuary to enhance water quality.

Coastal Inundation History:

- Prior to opening of Dawesville Channel in 1994, coastal inundation inside Peel-Harvey Estuary was below the annual peak developed through river flooding, with the singular exception of TC Alby.
- During TC Alby extreme north-northwest winds caused setup towards the southern end of Harvey Estuary, where low-lying areas were inundated. A difference of 1.2m was measured on water loggers around the estuarine system, below the ocean level in the north of Peel Inlet.
- There has been a tide gauge in Peel inlet, offshore from Yunderup, providing measured water level at hourly intervals since 1984.
- Subsequent to opening of Dawesville Channel, the effect of river runoff on estuary water levels was reduced, and the effect of coastal inundation was substantially increased, with daily tide range increasing substantially.

The highest levels measured at Peel tide gauge since 1994 are:

- **16 May 2003: 1.58m CD (1.03m AHD),** due to passage of a large winter storm, producing sustained westerly winds, coincident with a high tide phase.
- **25 May 2020: 1.50m CD (0.95m AHD).** Associated with the passage of TC Mangga and its interaction with a mid-latitude storm.

Hazard: Existing Coastal Inundation Hazard Assessment Summary

Coastal inundation hazard was distinct from estuarine inundation hazard until opening of Dawesville Channel in 1994, which provided a more direct connection of Peel-Harvey estuary to the ocean than the constricted Mandurah Channel.

Installation of water level recorders through Peel-Harvey Estuary in the 1970s was to support agricultural drainage plans, and to inform mosquito management. This network of gauges captured the impact of TC Alby in 1978, which was subsequently used as a design event for coastal and estuarine inundation, as this was the standout event from both Fremantle and Bunbury long-term tide gauges.

A permanent tide gauge, collecting digital data was installed in 1990, partly to support investigations for Dawesville Channel. Additional gauges were deployed throughout the estuary to characterize exchanges between the ocean and the estuary basins, to verify the changes caused by the artificial channel, which substantially increased tides in the estuary. Various evaluations of the tide gauge data set have been conducted, including Damara (2008) and Eliot & McCormack (2019), with changes over time relating to increased data. Separately, simulations of TC Alby, should it have occurred with Dawesville Channel in place, and alternative scenarios for storm track and sea level rise, were undertaken (Macpherson *et al*. 2011, GEMS 2012).

GHD (2010) *Murray Drainage and Water Management Plan and Associated Studies* and Damara (2012) *Coastal Hazard Mapping for Economic Analysis of Climate Change Adaptation in the Peron-Naturaliste Region* provided inundation mapping for Peel-Harvey Estuary, based on Damara (2008), with additional allowances for projected sea level rise.

Murray LGA has further been subject to detailed inundation hazard assessment as part of its CHRMAP (Baird 2021)

CHRMAP Inundation Assessment Approach:

- CHRMAP study considered the risk of coastal inundation to low lying coastal areas under extreme coastal flooding events.
- Design water levels were extrapolated from Peel Inlet tide gauge data for 2-yr, 10-yr, 100-yr ARI, and a simulated design storm was modelled based on TC Alby for an extreme case (500+ yr ARI).
- Mapping of inundation areas for the CHRMAP shows depth above the land surface, defined by LIDAR surveys.
- Inundated areas were defined using a ‘hydro-connectivity’ algorithm, ensuring connection to the ocean.

CHRMAP Inundation Assessment Findings:

- There are wide intertidal areas with low foreshore slopes around Murray Delta and Austin Bay. This creates large differences in inundated area from general tides, at around +0.3m above MSL, to winter storm water levels, which reach 0.6m to 0.8m above MSL a few times a year.
- Developed areas of Murray Delta Islands and South Yunderup are marginally above typical winter water levels. Projected sea level rise will increase the frequency of coastal inundation, with a sea level rise of +0.9m resulting in areas below 1.2m AHD being subject to inundation under general tides, i.e. regular submergence outside of extreme events. Areas below 1.7m AHD would typically be inundated several times a year during large winter storms.

Hazard: Existing Controls

There are substantial parts of the Shire of Murray built within or adjacent to floodplain areas. Consequently, the Shire has an extensive history of flood management, which provides a significant basis for the management of coastal inundation.
The major control to inundation hazard is provided through development controls, including minimum ground levels and minimum floor levels. These are presently based on runoff flooding.
The man-made lake south of Yunderup was built with an identified objective to reduce flooding. It effectively provides a barrier to wave effect associated with coastal inundation events.

Assets: Exposure of Coastal Assets to Inundation Impacts

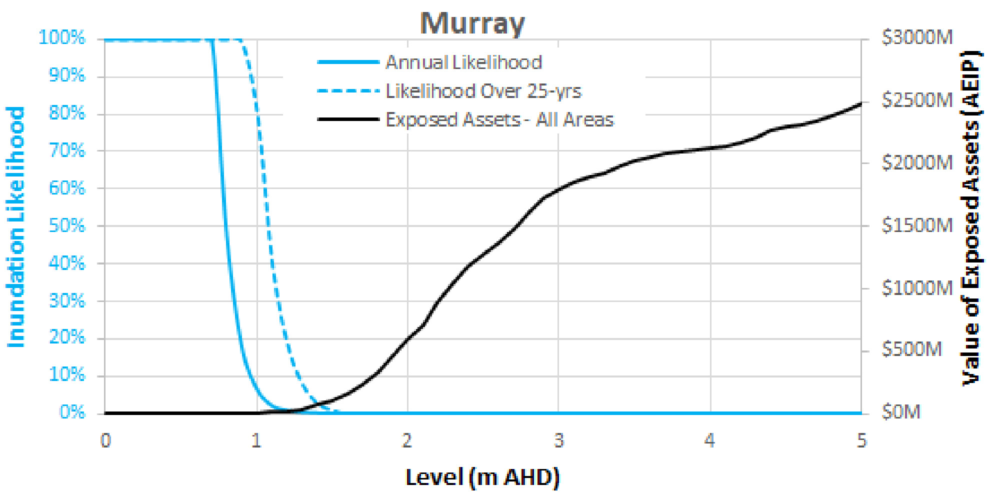
Inundation Level (m AHD)	16.1 Serpentine River			16.2 Murray River			16.3 Peel Inlet-Harvey Estuary		
	Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/ Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)
0.8	0	0 / 0	1 / 1	0	0 / 0	1 / 1	0	0 / 0	1 / 0
0.9	0	0 / 0	1 / 1	0	0 / 0	1 / 1	0	0 / 0	1 / 0
1.0	2	0 / 0	1 / 1	14	0 / 0	1 / 1	0	0 / 0	1 / 0
1.1	2	0 / 0	1 / 1	23	0 / 0	1 / 1	0	0 / 0	1 / 0
1.2	2	0 / 0	1 / 1	35	0 / 0	1 / 1	0	0 / 0	1 / 0
1.3	2	0 / 0	1 / 1	59	0 / 0	1 / 1	3	0 / 0	1 / 0
1.4	34	0 / 0	1 / 1	85	0 / 0	2 / 1	5	0 / 0	1 / 0
1.5	76	0 / 0	1 / 1	118	0 / 0	3 / 1	5	0 / 0	1 / 0
1.6	99	0 / 0	1 / 1	175	1 / 0	3 / 1	5	0 / 0	1 / 0
1.7	109	0 / 0	1 / 1	293	1 / 0	3 / 1	6	0 / 0	1 / 0
1.8	122	0 / 0	1 / 1	454	1 / 0	4 / 1	7	0 / 0	1 / 0
1.9	134	0 / 0	1 / 1	642	1 / 0	4 / 1	9	0 / 0	1 / 0
2.0	142	0 / 0	1 / 1	850	1 / 0	5 / 1	10	0 / 0	1 / 0
2.1	159	0 / 0	1 / 1	1037	1 / 0	6 / 1	10	0 / 0	1 / 0

High (~25yr ARI)
Extreme (~100yr ARI)
Extreme +0.9m

- Small number of residential buildings exposed beween +1.0m and +1.2m AHD in Serpentine River and Peel-Harvey estuary areas (below AEIP thresholds) with significantly higher numbers in Murray River area.
- Increased exposure of residential buildings between 1.2m and 2.1m AHD for both Serpentine and Murray with 2km and 7km of roads impacted in 16.1 and 16.2 respectively.
- Low exposure along Peel-Harvey foreshore (in the Shire of Murray) for all water levels considered, with residential building counts below the 20-building threshold for AEIP identification of value.

Other Assets Exposed:
16.2 Murray River
Extreme +0.9m: Inundation reaches the school grounds at +1.6m AHD

Assets identified with AEIP occur from +1.0m AHD, with a substantial proportion of identified assets distributed almost evenly between 1.7m and 2.9m AHD. Comparison with estimated inundation likelihood indicates active inundation hazard, with 80% likelihood of coastal inundation impact over a 25 year period. Notably, this does not include effects of waves, which can extend to higher levels. Increased asset exposure from 1.7m AHD indicates high senstivity to an inundation difference from +0.4m. This difference could be developed through choice of event scenarios or statistics, inclusion of wave processes, or allowance for sea level rise. This highlights the significance of longer-term adaptation planning for the Shire of Murray.



Damage: Inundation Risk Ratings & Damage Assessment

Average Annual Damage		AEIP			
	WL	1m AHD	1.2m AHD	2.1m AHD	All Water Levels
Area	ARI	High	Extreme	Extreme+ 0.9m	
16.1: Serpentine River		$ 0K/yr	$ 3K/yr	$ 6K/yr	$ 6K/yr
16.2: Murray River		$ 0K/yr	$ 24K/yr	$ 46K/yr	$ 46K/yr
16.3: Peel Inlet-Harvey Estuary		$ 0K/yr	$ 0K/yr	$ 1K/yr	$ 1K/yr
Total Damage		**$ 0K/yr**	**$ 27K/yr**	**$ 53K/yr**	**$ 53K/yr**

- Corrections applied to remove residential building lower than +1.1m AHD in the damage assessment following ground truthing.
- Greatest damage within the Murray River segment, with residential exposure identified from +1.1m AHD. These properties may have building floor levels above the ground level.
- Murray River and Serpentine River segments have sensitivity to sea level rise.

Planning Framework

The City of Murray planning framework includes Local Planning Scheme No. 4. The Scheme acknowledges Murray's existing riverine flooding and proximity to wetlands, including the Peel-Harvey estuarine shore. The Shire requires all plans and proposals for land adjacent to river or estuarine shores to maintain an adequate foreshore reserve, protecting wetlands, foreshore vegetation and fauna habitats. The Shire has developed a draft CHRMAP covering areas of the Shire potentially affected by coastal hazards over the next 100 years. The City of Murray Local Planning Scheme No. 4 does not refer to coastal hazards directly, but identifies a special control area for flooding, which doesn't distinguish between runoff flooding or estuarine water levels (which are determined by coastal inundation). Notably, existing coastal inundation hazard is below runoff flooding levels at a commensurate 100-yr ARI level.

Evaluation of Murray's planning framework against the Inundation Management Health Check criteria gave:

HC1
- Potential for interactions between runoff flooding and coastal inundation was not evaluated in coastal vulnerability studies.

HC2
- Murray Local Planning Scheme No. 4 identifies a flood hazard zone based on a 100-yr ARI level, plus 0.5m freeboard. This is based on river flood levels and does not directly identify coastal inundation. Coastal vulnerability studies evaluated conditions up to 500-year ARI, with 0.9m sea level rise.

HC3
- Mapping of coastal inundation hazard in the CVS does not have direct connection to planning documents, with the area presently subject to coastal inundation hazard encompassed by the area subject to river flooding hazard. However, as Murray Local Planning Scheme No. 4 refers to the Murray Floodplain Development Strategy, the strategy may be updated without needing to amend planning documents.

HC4
- Flood mitigation measures identified in Murray planning framework include nominating a minimum building floor level. This may also be relevant to coastal inundation hazard.

HC5
- Pathways for adaptation to inundation in the draft CHRMAP are focused on building design to accommodate inundation hazard or use of land filling, with wider scale management supported by a Special Control Area.

HC6
- The planning framework does not acknowledge the role of emergency management for coastal hazards.

HC7
- The planning framework presently does not acknowledge flood proofing. The CHRMAP identifies opportunities to mitigate inundation hazard through building design within a special control area, but ABCB guidance is not identified.

HC8
- A special control area for coastal hazards is proposed within the draft CHRMAP. Lack of an SCA limits capacity to obtain targeted financial recompense to support strategic interventions or adaptation.

HIGH Inundation Risk
at coast

Shire of Harvey

Focus

Adaptation Priority

Management at Foreshore

Actions

Management at Foreshore

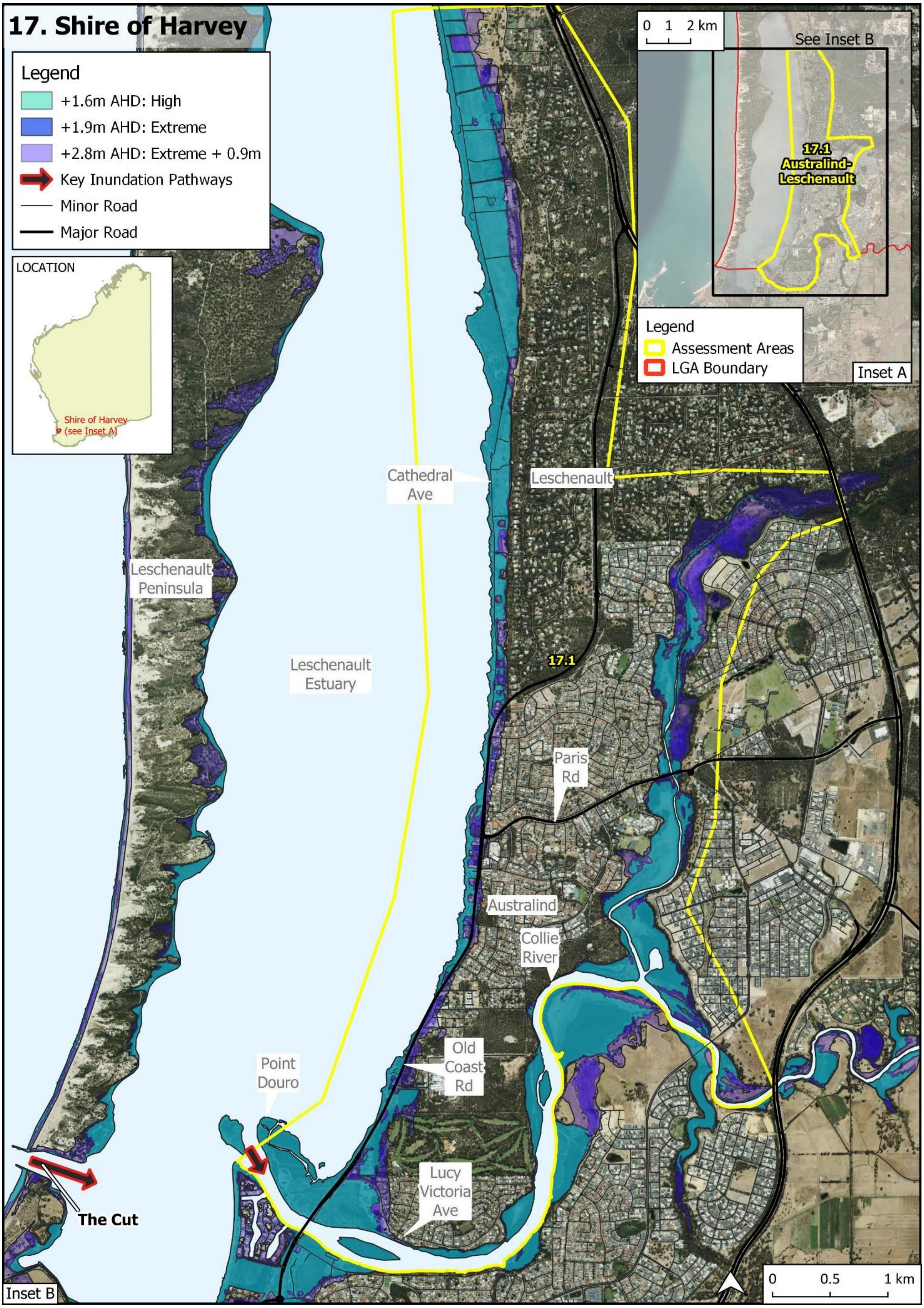
Targeted Mitigation

WL Review (CHRMAP)

Damage Assessment

Emergency Plan

Seashore Engineering


17. Shire of Harvey
Legend
+1.6m AHD: High
+1.9m AHD: Extreme
+2.8m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road
LOCATION
Shire of Harvey
(see Inset A)
0 1 2 km
See Inset B
17.1
Australind-Leschenault
Legend
Assessment Areas
LGA Boundary
Inset A
Cathedral Ave
Leschenault
Leschenault Peninsula
Leschenault Estuary
17.1
Paris Rd
Australind
Collie River
Old Coast Rd
Point Douro
Lucy Victoria Ave
The Cut
Inset B
0 0.5 1 km

17. HARVEY

Site overview:

The authors wish to acknowledge the *Binjareb and Wardandi Noongar* people as the native title holders of the lands and waters in and around the Shire of Harvey. The Shire extends over 1,735km^2 encompassing the coastal communities of Binningup, Myalup and Parkfield and is located in the South-West Region between the two regional cities of Bunbury and Mandurah. Its diverse population is 29,631 with manufacturing the largest employer. The Shire has also identified sustainable tourism development as a means to diversify its economy.

Areas at risk from inundation:

One inundation exposure area has been considered for the Harvey LGA, from Buffalo Road at the northern end of Leschenault Estuary to 'The Cut' in the south, with land areas above Highest Astronomical Tide[1] (HAT) potentially inundated under high (~25yr ARI), extreme (~100yr ARI), and extreme +0.9m (~100yr ARI +0.9m) water levels estimated as:

REGION	WL	1.6m AHD	1.9m AHD	2.8m AHD
	ARI	High	Extreme	Extreme + 0.9m
17.1 Australind-Leschenault		3.3km^2	4.3km^2	6.4km^2

Morphology: Sandy Shore; High Coastal Dune Barrier; Estuarine foreshore

The coastal area is characterized by a mainly sandy shore in front of a high coastal dune barrier seaward of Lake Preston and Leschenault Estuary. This coast is the southern part of a ridge-lagoon coastal sequence which extends from Bunbury to Mandurah, separated from Geographe Bay sandy coast by the natural boundary at Casuarina Point.

Wider Harvey Coast:

- Almost continuous sandy beach, backed by coastal dunes of varying height.
- Transgressive barrier dune system, with a history of instability.
- Landward of the dune system is a low-lying area, which for more than half of the Shire's coast is occupied by permanent water bodies of Lake Preston and Leschenault Estuary. The area between the two is used for intensive agriculture, with drains required to prevent seasonal waterlogging.
- Approximately the southern third of the Harvey coast is within Leschenault Peninsula Conservation Park

Australind area:

- Foreshore is characterised by a narrow sandy beach fronted by a nearshore terrace of variable width and depths of -0.5m AHD to -1.0m AHD.
- Ocean water exchange occurs through an engineered entrance at the Cut, with riverine flows from the Collie River.

Climate: Microtidal; Open Ocean Coast with Moderate Waves; Sheltered Estuary

- The Shire of Harvey has an almost west-facing coast, exposed to seasonal westerly storms and frequent southwest to westerly sea breezes.
- Microtidal principally diurnal tide with a range of 1.4m from lowest to highest astronomical tide, of which 0.3m is produced by the seasonal mean sea level cycle.
- Harvey is in Wind Region A1 (AS1170.2), which means that extreme winds are caused by mid-latitude storms.
- Mid latitude lows typically cause severe winds 3-8 times per year.
- Dissipating TCs create severe wind conditions roughly once per decade.
- Storm surges up to 1.0m mostly occur in winter, with a similar scale to the tide.
- Along the open ocean coast, wave conditions are generally moderate, with prevailing south-west swell interacting with locally generated wind-waves.
- No local wave observations within the Leschenault Estuary are available, however, the wave climate is expected to be almost exclusively linked to local winds acting across available fetches.
- Influences of winds, waves and storm surge are all strongest during winter months, providing a substantial difference between summer and winter coastal conditions.
- Application of a directional extreme coastal wind climate suggests wind wave heights around the Australind area within the estuary are relatively low, requiring exceptional conditions to exceed a wave height of 0.7m (i.e. >100yr ARI event).

[1] Areas were calculated at 0.1m increments with HAT for Harvey taken at 0.7m AHD in this study.

Development Record: Agricultural

The local Aboriginal people and traditional custodians of the Australind and Harvey areas are the Binjareb and Wardandi Noongar people who have a rich social, spiritual and historical connection to this country.

Wider Harvey coast:

- Quindalup Dune systems' general poor suitability for agricultural use, along with its inherent physical instability and environmental sensitivity, has resulted in minimal agricultural development. Low-lying land behind the dunes are used for agricultural purposes, although this area is potentially subject to waterlogging, and irrigation relies on shallow aquifer groundwater extraction.
- Australind was established as an agricultural community, as part of early colonial settlement program.
- An alternative entrance to Leschenault Estuary was constructed in 1951 as part of flood mitigation works for Bunbury, with the estuary truncated and Preston River diverted.
- The new entrance cut through Leschenault Peninsula was unstable, leading to installation of rock armour training walls.
- Part of the geomorphic response to the Cut was to form both ebb and flood tide shoals (outside and inside) adjacent to the entrance. A substantial volume of sand is in these features, with growth of the flood tide shoal occurring simultaneously to erosion to either side of the Cut, suggesting infilling with marine sand.
- In the winter 2012 a breach occurred in the rock revetment on the northern side of the Cut resulting in the transport of sand into the Cut and the formation of an unstable sand bar between 2012 and 2014.
- In 2014 emergency works were completed at the Cut to repair the breach and prevent further inflow of sand into the channel.

Australind area:

- Construction of Australind boat ramp in the late 1960s to early 1970s, included a dredged channel and basin, and disposal by side-casting and for onshore reclamation.
- Growth of Australind from the 1970s occurred as part of mineral sand mining. Pipelines to transfer mineral sands waste products across the Leschenault Estuary to the ocean resulted in disturbance to the estuary waters, the dunes and the adjacent nearshore area.

Coastal Inundation History

Most information describing meteorological and coastal processes for Harvey has been inferred from the Bunbury record. Due to its proximity, this information is generally deemed to be applicable for assessment of Harvey coastal processes and hazards. Small differences in water levels measured at Bunbury tide gauges and within Leschenault Estuary occur due to influence of estuarine damping upon coastal flooding.

Tropical Cyclone Alby, 1978 – 2.4m CD (1.83m AHD)

- TC Alby was the most extreme water level event in the Bunbury tide gauge record and 0.37m higher than any other event recorded for the area.
- Bunbury has a long history of tide gauge recordings, with few extreme water levels generated by TCs highlight the rare nature of the Alby event.
- The extreme water level was produced by a large surge combined with high tide.
- Impacts of TC Alby are well documented for the Bunbury area with specific focus on Leschenault inlet and a detailed summary available from BoM (2022a).

Extra-tropical storm , May 2003 - ~2.1m CD (1.53m AHD)

- Produced exceptional water levels and strong wave action that led to inundation of the foreshore and road area. Water levels were due to coincident timing of high tide, and a significant surge peak generated by sustained westerly winds.

Ex TC Mangga, May 2020 ~2m CD (1.43m AHD)

- Storm generated water levels more than 0.5m above predicted levels.
- Inundation of low-lying foreshore areas.

Hazard: Existing Coastal Inundation Hazard Assessment Summary

- Coastal Inundation has been a relatively infrequent coastal hazard over the history of the Shire, with limited flooding of Australind foreshore roads.
- The drainage network and the lands it drains are presently susceptible to coastal flooding due to very extreme ocean water levels, estimated to have 100 to 500 year average recurrence interval (ARI).
- Projected sea level rise is expected to progressively increase the likelihood of coastal flooding affecting parts of the Harvey coast. This will occur through increased recurrence of flooding at the existing hotspots (Australind and the lowlands north of Leschenault Estuary which are not considered in this analysis due to a lack of buildings), and extension of the area affected by floods.
- Damara (2012) *Coastal Hazard Mapping for Economic Analysis of Climate Change Adaptation in the Peron-Naturaliste Region* provided inundation mapping for Leschenault Estuary, based on analysis of Bunbury tide gauge data, with additional allowances for projected sea level rise.

Harvey CHRMAP (2016)

- Australind foreshore area has experienced relatively infrequent coastal hazard over the history of the Shire, but increased recurrence of flooding will occur with projected sea level rise. Impact to assets, including constraint to their use, were described as medium for existing scenario (0-0.2m SLR; 2016-2065), transitioning to high for the moderate scenario (0.2-0.5m SLR; 2045-2115).
- Land levels based on 2016 lidar survey suggests inundation of the foreshore reserve begins around +1.2m AHD, with inundation across much of the reserve and foreshore houses at +1.6m AHD, generally to the edge of the road.

Capel to Leschenault CHRMAP (2016)

- Inundation along the eastern shoreline of the estuary is a risk from the present day. This affects foreshore reserve and residential / commercial assets.
- Significant portions of land may be affected by tidal inundation by 2120.
- The majority of this is foreshore reserve, with the exception of the Australind Tourist Park.
- The predicted extent of inundation is greater than the extent of erosion, especially along the eastern shoreline of the estuary**.**

Hazard: Existing Controls

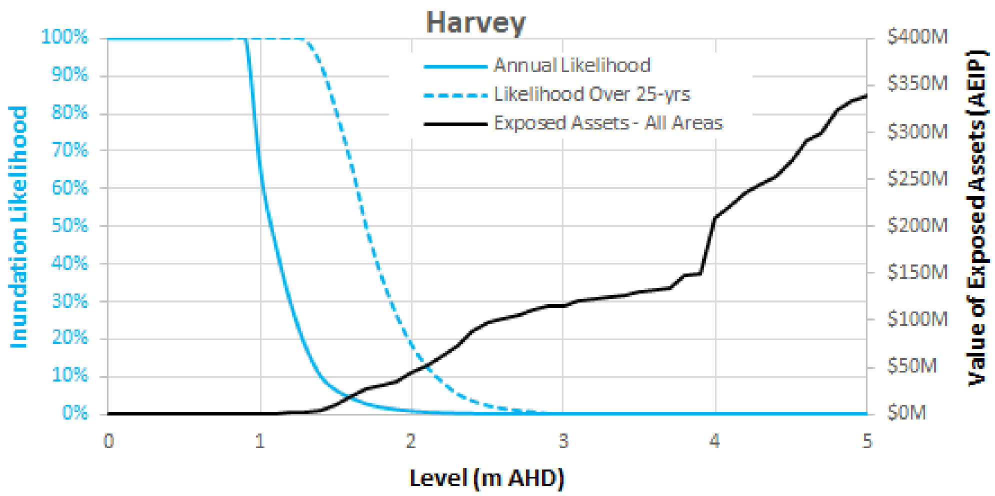
- There are substantial parts of Australind foreshore within or adjacent to the Leschenault Estuary floodplain area, into which both the Collie and Preston rivers drain. Consequently, the Shire has an extensive history of flood management, which provides a significant basis for the management of coastal inundation. This is incorporated in the Greater Bunbury Region Scheme Floodplain Management Policy.
- Australind foreshore roads provide a limited, informal control on coastal inundation hazard, with the road level slightly raised above the adjacent foreshore areas. Old Coast Road provides a barrier to inundation to around +1.6m AHD, whereas parts of Cathedral Ave are lower, at around +1.0m AHD, with some lower-lying semi-rural blocks to landward.
- The major control to inundation hazard is provided through development controls, with minimum habitable floor levels based on runoff flooding.
- Buffalo road influences the distribution of high water events in the northern part of Leschenault Estuary. The nature of the control provided is dependant on the characteristics of the event.

Assets: Exposure of Coastal Assets to Inundation Impacts

Inundation Level (m AHD)	17.1 Australind-Leschenault Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)
1.1	0	0 / 0	1 / 1
1.2	2	0 / 0	1 / 1
1.3	4	0 / 0	1 / 1
1.4	6	0 / 0	1 / 1
1.5	13	0 / 0	1 / 1
1.6	28	0 / 0	1 / 2
1.7	38	0 / 0	1 / 3
1.8	43	0 / 0	1 / 4
1.9	49	0 / 0	1 / 5
2.0	60	0 / 0	1 / 6
2.1	73	0 / 0	1 / 6
2.2	88	0 / 0	1 / 6
2.3	104	0 / 0	1 / 7
2.4	127	0 / 0	1 / 7
2.5	139	0 / 0	1 / 7
2.6	145	0 / 0	1 / 7
2.7	152	0 / 0	1 / 7
2.8	160	0 / 0	1 / 7

- Assets identified with AEIP occur from +1.5m AHD, with a substantial proportion of identified assets distributed almost evenly between 1.5m and 3.0m AHD, with a further jump at around +4.0m AHD due to a scarp along the edge of the estuary.
- Comparison with estimated inundation likelihood indicates active inundation hazard, with 6% likelihood of coastal inundation impact per annum and around 80% likelihood over a 25 year period. Notably, this does not include effects of waves, which can extend to higher levels. The present level of exposure would approximately double for an inundation difference of +0.4m, when existing assets would be impacted every two years on average.
- This difference could be developed through choice of event scenarios or statistics, inclusion of wave processes, or allowance for sea level rise. This highlights the increasing level of inundation management projected for the Shire of Harvey in Australind.

(cyan)	High (~25yr ARI)
(blue)	Extreme (~100yr ARI)
(purple)	Extreme +0.9m



Damage: Inundation Risk Ratings & Damage Assessment

Average Annual Damage		AEIP			
Area	WL / ARI	1.6m AHD High	1.9m AHD Extreme	2.8m AHD Extreme+ 0.9m	All Water Levels
17.1: Australind-Leschenault		$ 49K/yr	$ 122K/yr	$ 232K/yr	$ 239K/yr
Total Damage		**$ 49K/yr**	**$ 122K/yr**	**$ 232K/yr**	**$ 239K/yr**

- Damage includes low lying areas adjacent to estuary, with residential building exposure identified from +1.2m AHD resulting in damage from moderate to extreme events.
- Damage to buildings under moderate events possibly overstated due to interaction between building footprints included in AEIP and the percolation assessment. Estuarine dampening could also reduce water levels, relative to coastal levels recorded at the tide gauge.

Planning Framework

The Shire of Harvey is within the Greater Bunbury Region. Consequently, the planning framework includes Harvey Local Planning Strategy, Harvey District Planning Scheme No. 1, and Greater Bunbury Region Scheme.

The GBRS and Harvey Local Planning Strategy acknowledge Harvey's existing riverine flooding and proximity to wetlands, including Leschenault estuarine shore. The Shire has developed a CHRMAP covering areas of the Shire potentially affected by coastal hazards over the next 100 years, with a regional CHRMAP study, from Capel to Australind, presently in draft form. Identified coastal inundation hazard is within the area identified as floodplain through the Greater Bunbury Region Scheme Floodplain Management Policy.

Harvey Local Planning Strategy recommends definition of a special control area for flooding and inundation, incorporating the effects of sea level rise. Corresponding policy instruments are not presently available. Notably, existing coastal inundation hazard is below runoff flooding levels at a commensurate 100-yr ARI level.

Evaluation of Harvey's planning framework against the Inundation Management Health Check criteria gave:

- HC1 — Potential for interactions between runoff flooding and coastal inundation were not evaluated in coastal vulnerability studies. This has been addressed in the draft CHRMAP.
- HC2 — Harvey Local Planning Strategy defines flood hazard zone based on a 100-yr ARI level, with habitable floor levels requiring an additional 0.5m freeboard. Mapping for GBRS Floodplain Management Policy includes 0.9m sea level rise allowance. Flood mapping is based on river flood levels, which are above the commensurate coastal inundation levels.
- HC3 — Mapping of coastal inundation hazard in the draft CHRMAP is not connected to planning documents, with the area susceptible to coastal inundation hazard within the area subject to river flooding hazard. However, as Harvey Local Planning Strategy refers to the GBRS Floodplain Management Policy, hazard mapping in the policy can be updated without amending planning documents.
- HC4 — Flood mitigation measures identified in Harvey planning framework include nominating a minimum habitable floor level. This may also be relevant to coastal inundation hazard.
- HC5 — Existing planning policy documents do not identify pathways for inundation, although the opportunity for landowners to fill up to 1.5m is identified, subject to limited change to the floodplain hydraulics. It is expected the draft CHRMAP will outline pathways for adaptation.
- HC6 — The planning framework does not acknowledge the role of emergency management for coastal hazards.
- HC7 — The planning framework presently does not acknowledge flood proofing or ABCB guidance.
- HC8 — A special control area for floodprone areas, including coastal inundation, is proposed in the Harvey Local Planning Strategy. Lack of an SCA limits capacity to obtain targeted financial recompense to support strategic interventions or adaptation.