EXTREME Inundation Risk
at coast

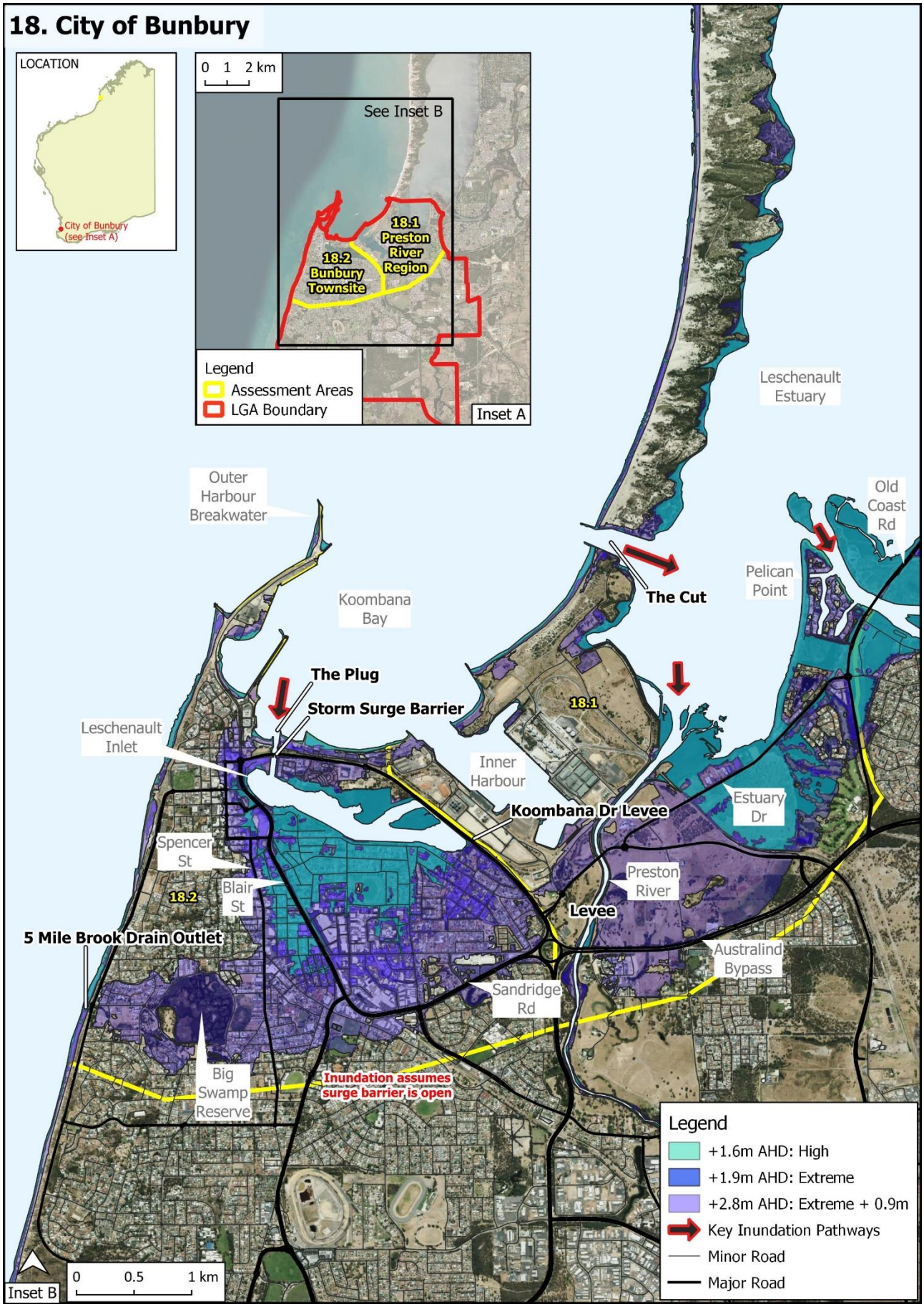
City of Bunbury

Focus

Adaptation Priority | Management at Foreshore | Targeted Mitigation

Actions

Management at Foreshore | Targeted Mitigation | WL Review (CHRMAP) | Damage Assessment | WL Sensitivity Review | Economic Criteria Review | Emergency Plan | Inundation Plan


18. City of Bunbury
LOCATION
City of Bunbury (see Inset A)
0 1 2 km
See Inset B
18.1 Preston River Region
18.2 Bunbury Townsite
Legend
Assessment Areas
LGA Boundary
Inset A
Leschenault Estuary
Outer Harbour Breakwater
Old Coast Rd
Pelican Point
The Cut
Koombana Bay
The Plug
Storm Surge Barrier
18.1
Leschenault Inlet
Inner Harbour
Koombana Dr Levee
Estuary Dr
Spencer St
Blair St
18.2
Preston River Levee
5 Mile Brook Drain Outlet
Australind Bypass
Sandridge Rd
Big Swamp Reserve
Inundation assumes surge barrier is open
Inset B
0 0.5 1 km
Legend
+1.6m AHD: High
+1.9m AHD: Extreme
+2.8m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road

18. BUNBURY

Site Overview:
The authors wish to acknowledge the Wardandi Noongar people as the native title holders of the lands and waters in and around the City of Bunbury. Bunbury is located 180km south of Perth and its community has a rich cultural diversity with a population of over 32,000 residents (2021 census). It is the second largest city in WA serving as a regional townsite and major port for the southwest. The city acts as a hub for the surrounding shires of Harvey, Dardanup and Capel and is an important industrial, tourism and recreation base.

Areas at risk from inundation:
Two inundation exposure areas have been considered for Bunbury LGA, including (i) the area between Collie and Preston Rivers, including Pelican Point, and (ii) parts of Glen Iris and Bunbury townsite around the Leschenault Inlet, including the Central Business District extending into South Bunbury and East Bunbury. 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 have been estimated as:

REGION	WL ARI	1.6m AHD High	1.9m AHD Extreme	2.8m AHD Extreme + 0.9m
18.1 Preston River Region		1.1km²	1.4km²	4.1km²
18.2 Bunbury Townsite		1.2km²	2.2km²	5.7km²

Morphology: Open Ocean Coast; Modified Estuary; Sheltered Bay

The coastal zone of Bunbury has a mixture of morphotypes related to aspect, exposure, and structural control:

- The open ocean shoreline south of Point Casuarina is characterised by relatively high dunes, areas of perched beach/rock control and discrete breakouts connected to swamp land.
- In Bunbury harbour, Koombana Beach is a structurally controlled artificial foreshore formed as part of the modifications to the Estuary to reduce the threat of flooding, and later works to construct Bunbury Inner Harbour.
- The shoreline has low dunes in front of Leschenault Inlet, which have been locally raised with a flood levee and rail embankment.
- The heavily modified estuarine inlet to the north is artificially detached from Leschenault Estuary.
- The Cut was excavated in the 1950s to drain the Leschenault Estuary, Collie and Preston Rivers because Town and Port works blocked effective drainage. Training walls installed to stabilise the ocean entrance led to the formation of unstable flood and ebb tide bars.
- The sediment within the channel has since migrated along the northern training wall into the Estuary. The Estuary itself is very shallow and only suited for very small craft.

Climate: Microtidal; Extra-Tropical and Mid-Latitude Storms; Wave-dominated

- Bunbury is a microtidal environment with dominant diurnal tide and a range of 1.2m (HAT to LAT).
- Bunbury is in wind region A1 (AS1170.2), which means that extreme winds are caused by mid-latitude storms.
- Tropical cyclones or former tropical cyclones occur infrequently in the Bunbury region (southwest WA), mostly between December and April, although occasionally later (e.g., TC Mangga in May 2020).
- Tropical cyclones, particularly those which have experienced extra-tropical transition (such as TC Alby in 1978) can have greater coastal impact than winter storms due to extreme wind speed and unusual storm direction.
- At Bunbury, waves inside Koombana Bay are attenuated due to the sheltering from the outer harbor breakwater. The area is generally well-protected from westerly storms but is more exposed to northerly storms.

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

Development Record: Regional Port

- The traditional owners of the Bunbury area are the Noongar Wardandi people.
- The Bunbury coast is highly modified from its original configuration, including construction of the outer harbour breakwater in the 1890s.
- The Inner Harbour Project in the 1970s included extensive reclamation which divided Leschenault Estuary and redirected Preston River. The southern part of the estuary is now known as Leschenault Inlet. Two new engineered channels were created, the "Plug" at Leschenault Inlet entrance and the "Cut", forming a new ocean connection for Leschenault Estuary.
- Following TC Alby, Bunbury Storm Surge Barrier was constructed across the entrance of the "Plug" in 1980 to protect low lying areas around Leschenault Inlet.

Coastal Inundation History: Frequent Moderate Events; Tidally Modulated

Bunbury tide gauge has one of the longest water level records in Australia, with "paper trace" records back to the 1930s and digital records since 1985. The tide gauge was originally located in the Outer Harbour, later moved to Inner Harbour; with tide gauges either side of storm surge barrier for nearly 20 years. Frequent minor inundation from mid-latitude storm events coincides with tidal & MSL peaks, to cause the greatest incidence of high sea levels around May-July.
The top-3 water level events in known records for Bunbury are:

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 at 0.37m higher than any other event recorded for the area.
- Bunbury's long history of tide gauge recordings shows few extreme water levels generated by TCs, highlighting the rare nature of TC Alby.
- The extreme water level experienced was produced by a large surge combined with high tide conditions.
- Impacts are well documented for the Bunbury area including breaching of the retaining wall along Leschenault Inlet and flooding of approximately 100 homes with 130 people forced to evacuate. Ocean drive was also flooded, and the railway complex was damaged by seawater.
- As a response to the inundation issues experienced at Bunbury, a storm surge barrier through 'the Plug' was installed in 1980 to protect low lying areas surrounding Leschenault Inlet.

Extra-Tropical Storm, May 2003 - ~2.1m CD (1.53m AHD)

- Produced exceptional water levels and strong wave action that led to coastal inundation, particularly at Koombana Beach. Extreme water levels were due to coincidence of high tide with a significant surge peak due to sustained westerly winds.

Ex Tropical Cyclone 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 significant coastal hazard for Bunbury, including impact to properties during TC Alby. As a result, several studies have been undertaken to better understand coastal inundation hazard for the area including:

Geoscience Australia (2010)
Undertook simulation of TC Alby and 'worst-track' cases, for emergency management planning.

Damara (2012)
Coastal Hazard Mapping for Economic Analysis of Climate Change Adaptation in the Peron-Naturaliste Region provided inundation mapping for Leschenault Inlet and Estuary, based on analysis of Bunbury tide gauge data, with additional allowances for projected sea level rise.

CHRMAP (Watertech 2022)

- Identified inundation as a significant risk: Storm duration and constrained water exchange through the estuary/inlet openings have significant impact to the storm tide levels inside the estuary.
- Bunbury Storm Surge Barrier is the most important physical control to mitigate inundation hazard for Bunbury townsite.
- Damage/ loss associated with malfunctioning of Bunbury Storm Surge Barrier could be catastrophic. It is assumed the barrier will be maintained to ensure it remains operational for the planning timeframe.
- Much of the CBD is predicted to be under water during a 100yr and 500yr ARI inundation events in 2120 (0.9m). The crest of Bunbury Storm Surge Barrier is ~+2.1 m AHD, which is overtopped in these scenarios.

Hazard: Existing Controls

- Bunbury storm surge barrier and the associated Koombana Bay levee are significant controls to coastal inundation for Leschenault Inlet. Flood barrier operations are balanced between preventing ingress of coastal inundation and allowing release of stormwater drainage.
- The balance of stormwater drainage and coastal inundation also occurs for Leschenault Estuary, where The Cut provides an important pathway for release of floodwaters from the Collie and Preston Rivers but has increased the potential for coastal inundation to affect the estuary.
- 5 Mile Brook drain outlet incorporates flood gates which prevent flooding along 5 Mile Brook and prevent seawater entering Big Swamp parkland reserve at Hayward Street. This has an objective to prevent salinization.

Assets: Exposure of Coastal Assets to Inundation Impacts[2]

Inundation Level (m AHD)	18.1 Preston River Region			18.2 Bunbury Townsite		
	Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/ Arterial (km)
1.1	0	0 / 0	1 / 1	1	0 / 0	0 / 1
1.2	1	0 / 0	1 / 1	4	0 / 0	0 / 1
1.3	1	0 / 0	1 / 1	217	0 / 0	0 / 1
1.4	1	0 / 0	1 / 2	334	0 / 0	0 / 1
1.5	1	0 / 0	1 / 2	449	2 / 0	0 / 1
1.6	**3**	**0 / 1**	**1 / 2**	**558**	**71 / 0**	**0 / 3**
1.7	3	0 / 2	1 / 3	646	107 / 0	0 / 3
1.8	3	0 / 2	1 / 3	787	160 / 0	0 / 5
1.9	**3**	**0 / 2**	**1 / 3**	**927**	**202 / 0**	**0 / 6**
2.0	5	0 / 9	2 / 4	1048	244 / 0	0 / 6
2.1	5	0 / 9	3 / 4	1243	288 / 0	0 / 8
2.2	6	0 / 14	3 / 4	1390	328 / 1	0 / 9
2.3	7	0 / 15	3 / 4	1591	370 / 1	0 / 10
2.4	23	0 / 17	3 / 4	1891	409 / 1	0 / 12
2.5	53	0 / 19	3 / 5	2075	422 / 1	0 / 13
2.6	137	0 / 20	3 / 5	2209	441 / 1	0 / 15
2.7	202	0 / 20	4 / 5	2311	457 / 1	0 / 16
2.8	**287**	**0 / 20**	**4 / 5**	**2410**	**477 / 1**	**0 / 17**

Other Assets Exposed:

18.1 Preston River

High (~25yr ARI): 1km railway track
Extreme (~100yr ARI): 1km railway track
Extreme +0.9m: 2km railway track

18.2 Bunbury Townsite

Extreme: 1 retirement home
Extreme +0.9m: 1 ambulance station; 1 retirement home; 4 schools; 1km railway track

18.1 Preston River

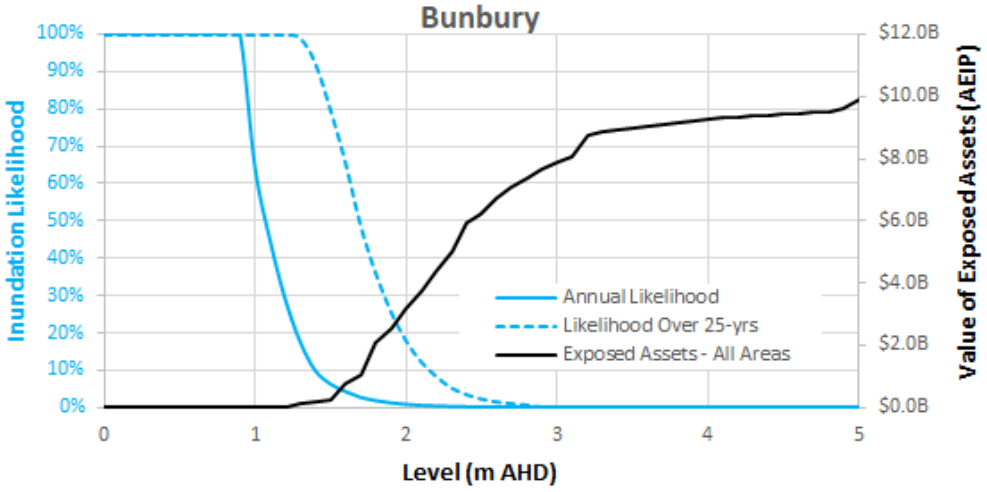
In the Preston River area, most exposure occurs above an inundation level of 2.4m AHD. An industrial building is identified as exposed from a water level of 1.6m AHD (High) increasing to 20 buildings at a level of 2.8m AHD (Extreme +0.9m). In total, 9km of road will be exposed at a water level of 2.8m AHD (Extreme +0.9m).

18.2 Bunbury Townsite

For the Bunbury townsite, a large number of residential buildings are exposed from 1.3m AHD (200) increasing to over 500 buildings at the 'High' level (~25yr ARI), almost 1000 at the 'Extreme' level (1.9m AHD) and close to 2.5k buildings at Extreme +0.9m. A high number of commercial buildings are exposed above 1.6m AHD, increasing to over 200 buildings at 1.9m (~100yr ARI) and almost 500 buildings by 2.8m AHD. A total of 17km of road in the townsite will be inundated by a 2.8m AHD event, as well as an ambulance station, 3km of railtrack, a retirement home and 4 schools.

Assets identified with AEIP occur from +1.3m AHD, with a substantial proportion of identified assets distributed almost evenly between 1.5m and 3.1m AHD. Comparison with estimated inundation likelihood indicates extreme inundation hazard, with 25% per annum likelihood of coastal inundation impact and 100% likelihood over a 25 year period – demonstrating the critical role of existing coastal inundation controls.

[2] Exposure assumes no storm surge barrier.



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
18.1: Preston River Region		$ 13K/yr	$ 34K/yr	$ 90K/yr	$ 99K/yr
18.2: Bunbury Townsite		$ 1.3M/yr	$ 3.8M/yr	$ 9.2M/yr	$ 9.6M/yr
Total Damage		**$ 1.4M/yr**	**$ 3.8M/yr**	**$ 9.3M/yr**	**$ 9.7M/yr**

- The role of storm surge barriers at Bunbury is significant, with approximately $7.0M/yr of the $9.7M/yr of damage mitigated.
- Without storm surge barrier, significant and regular damage would occur to the Bunbury Townsite due to widespread inundation around Leschenault Inlet arriving at +1.3m AHD.
- Bunbury retains enormous residual risk and sensitivity to sea level rise, with the barrier ineffective from inundation scenarios around +2.2m AHD (~200yr ARI).
- Damage from Preston River due to low lying residential properties within the suburb of Pelican Point. These properties may have building floor levels above the ground level

Planning Framework

The City of Bunbury is within the Greater Bunbury Region . Consequently, the planning framework includes Bunbury Local Planning Strategy 2018, Bunbury Local Planning Scheme No. 8, Bunbury Geographe Sub-regional Strategy and Greater Bunbury Region Scheme.

The GBRS and Bunbury planning framework acknowledge Bunbury's exposure to both coastal inundation and stormwater flooding. The City has previously been involved in coastal adaptation planning through Peron-Naturaliste Partnership projects, has developed a local CHRMAP for Koombana Beach, and been part of a regional CHRMAP study, from Capel to Australind, moving towards CHRMAP development. Identified coastal inundation hazard is largely within the area identified as floodplain in the Greater Bunbury Region Scheme Floodplain Management Policy (2017). City of Bunbury Local Planning Scheme No. 8 defines a special control area for flooding and inundation, incorporating the effects of sea level rise.

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

HC1	• Potential for interactions between runoff flooding and coastal inundation have been considered in evaluation of hazard and management plans for Bunbury Storm Surge Barrier. Flood and inundation interactions have been assessed in the draft CHRMAP.
HC2	• The City of Bunbury Local Planning Strategy 2018 defines flood hazard zone based on a 100-yr ARI level. Mapping for GBRS Floodplain Management Policy includes 0.9m sea level rise allowance. Flood mapping is based on river flood levels, which are typically above the commensurate coastal inundation levels.
HC3	• Mapping of coastal inundation hazard in the draft CHRMAP is not yet connected to planning documents, with the area susceptible to coastal inundation hazard within the area subject to river flooding hazard. However, as Bunbury planning framework documents refer to the GBRS Floodplain Management Policy, hazard mapping in the policy can be updated without amending planning documents.
HC4	• Coastal inundation mitigation measures are not specified in Bunbury planning framework, except for enhancement of existing controls.
HC5	• Existing planning policy documents identify pathways for adaptation through increased use of observation systems, evaluation, and progressive enhancement of existing inundation controls. It is expected the draft CHRMAP will outline pathways for adaptation.
HC6	• The Local Planning Strategy acknowledges the role of emergency management for flooding, including coastal inundation hazard, and refers to the State Emergency Management Plan for Flood.
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 defined in Bunbury Local Planning Scheme No. 8, directing compliance with the GBRS Floodplain Management Policy. The SCA is not presently configured to obtain targeted financial recompense for strategic interventions or adaptation.

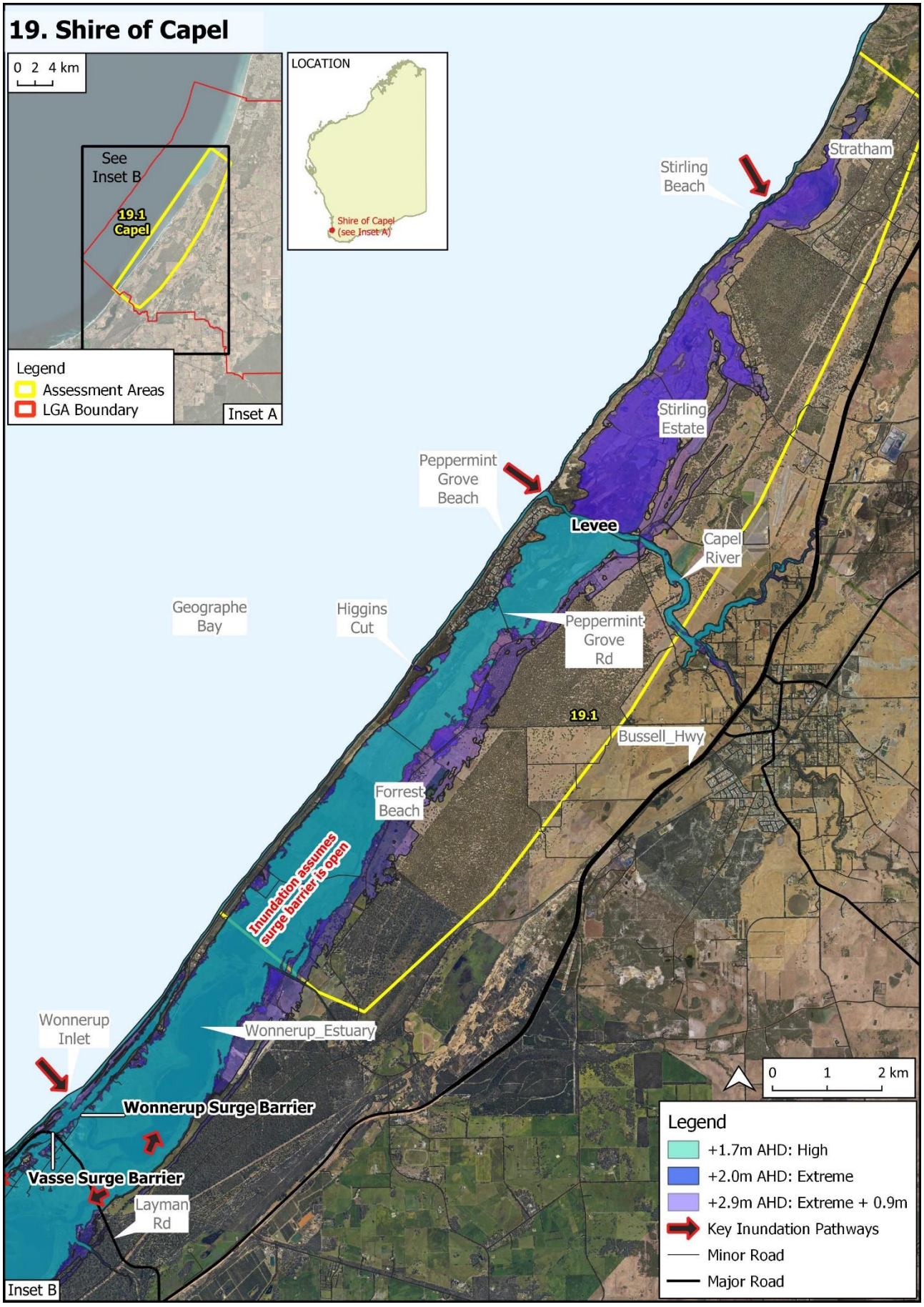
HIGH Inundation Risk
at coast

Shire of Capel

Focus

Actions

Seashore Engineering


19. Shire of Capel
0 2 4 km
See Inset B
19.1 Capel
LOCATION
Shire of Capel (see Inset A)
Legend
Assessment Areas
LGA Boundary
Inset A
Stratham
Stirling Beach
Stirling Estate
Peppermint Grove Beach
Levee
Capel River
Geographe Bay
Higgins Cut
Peppermint Grove Rd
19.1
Bussell_Hwy
Forrest Beach
Inundation assumes surge barrier is open
Wonnerup Inlet
Wonnerup_Estuary
Wonnerup Surge Barrier
Vasse Surge Barrier
Layman Rd
Inset B
0 1 2 km
Legend
+1.7m AHD: High
+2.0m AHD: Extreme
+2.9m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road

19. CAPEL

Site overview:
The authors wish to acknowledge the Bibbulmun Wadandi people as the native title holders of the lands and waters in and around the Shire of Capel. The Shire is located 200km south of Perth in the Southwest region of Western Australia, between the cities of Bunbury and Busselton. The Shire covers 557 km incorporating the coastal communities of Dalyellup and Peppermint Grove Beach and has 27km of coast along Geographe Bay including access at Forrest Beach, Peppermint Grove Beach, Minninup Beach and Dalyellup Beach.

Areas at risk from inundation:
The coastal strip extending from Forest Beach in the south to Stirling Beach just North was considered as one inundation exposure area for the Capel 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	1.7m AHD High	2m AHD Extreme	2.9m AHD Extreme + 0.9m
19.1 Capel		11.5km²	19.4km²	25.9km²

Morphology: Sandy Beaches; Frontal Dunes; Estuarine

- Forest Beach to Capel River Mouth: broad shallow waters and sandy beaches; Parabolic dunes or frontal dunes; Land depression behind the dune.
- Capel River mouth experiences occasional breaches. The location of the river mouth is generally stable, but this is understood to be influenced by occasional active management by the Water Corporation
- North of the Capel River Mouth: Narrow parabolic dunes or frontal dunes; Land depression behind the dune

Climate: Microtidal; Wave Dominated

- The coastal climate for the Shire of Capel is effectively the same as the City of Bunbury (30km north).
- Consequently, Bunbury tide gauge records describe water levels for Capel which experiences microtidal conditions with dominant diurnal tide with range of 1.2m (LAT to HAT).
- The land-sea breeze cycle is a dominant feature of the region, typically with an easterly wind in the morning and a southerly to westerly wind in the afternoon.
- Capel is in Wind region A1 (AS1170.2), which means that extreme winds are caused by mid-latitude storms.
- During the spring-summer (Oct-April) period, the typical wind is predominantly south-easterly to southwesterly. For winter months (May-Sep), however, wind conditions become more variable in speed and direction.
- Along Capel coast, nearshore wave conditions are largely dominated by offshore waves.

Development Record: Agricultural

- The traditional custodians of the Capel region are the Wadandi people.
- Capel region developed with an agricultural focus, as part of the southward extension of European colonial settlement.
- Capel River ocean entrance has been significantly modified, with a cut through the coastal dune undertaken in 1880 to reduce seasonal inundation. This caused salinisation, affecting Stirling wetlands, which extend approximately 15km to the mouth of the Vasse-Wonnerup system. Around 1900, levees were built to contain the river flow, with progressive raising and strengthening over the subsequent 120 years.

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

Coastal Inundation History:

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.

- The extreme water level was produced by a large surge combined with high tide conditions.
- Impacts of TC Alby are well documented for the area with 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. Water levels were due to the 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.
- Caused dune erosion and inundation of low-lying foreshore areas along parts of Geographe Bay.

Hazard: Existing Coastal Inundation Hazard Assessment Summary

- Coastal inundation has not historically been a significant hazard to the coastal communities in the Shire of Capel.
- Pressure from runoff flooding has resulted in artificial opening of the coastal dunes to improve drainage.
- The main negative impact of high-water level events has been salinisation of agricultural areas which have entered through dune breaches.

Capel to Leschenault CHRMAP (2023)

- For the Peppermint Grove area, in 2120, the land depression behind the residential area will be under constant risk of inundation. Most of the residential properties are not predicted to be affected.
- The existing sand dune acts as a natural barrier for coastal inundation. The inundation model assumes ocean water enters the land depression through Higgins Cut, Capel River and culvert openings, and that the sand dune is not eroded.
- For the Capel coast around Stirling Beach area, the inundation extent extends across the land depression adjacent to Capel River. In the north of the management unit, inundation is minimal.

Hazard: Existing Controls

The dune barrier along Capel coast provides the most significant existing control to coastal inundation, separating almost 20km length of Stirling Wetlands from the ocean. The dune barrier is locally perforated by several natural and artificial breaches, including the natural outlet at the Vasse-Wonnerup and an artificial breach at Capel River mouth. Salinisation of the wetlands during high water level events has been mitigated through installation of levees at the mouth of Capel River, and a storm surge barrier near the Vasse-Wonnerup mouth.

Capel River flood levees hydraulically separate Stirling wetlands to the north and south. A small artificial channel from the southern basin to the ocean is typically blocked by beach sand drift, but subject to erosion, the channel can connect the basin to the ocean at +1.8m AHD. The northern basin can connect to the ocean through a small natural channel near Stratham at +2.0m AHD. These two channels are small, and any inundation is likely to be constricted. More substantial inundation flow would occur across the Capel River flood levees above +2.6m AHD.

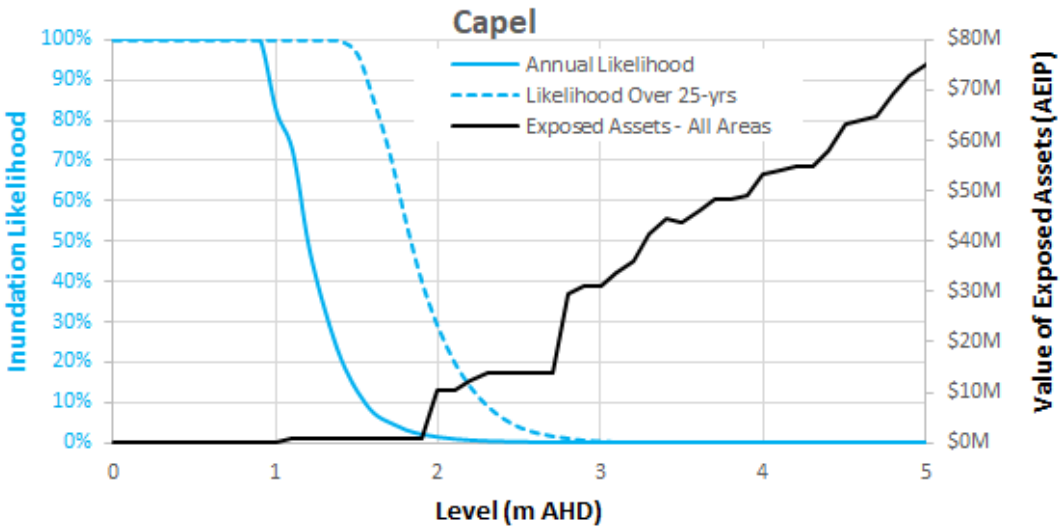
Assets: Exposure of Coastal Assets to Inundation Impacts

Inundation Level (m AHD)	19.1 Capel		
	Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)
1.2	1	0 / 0	1 / 0
1.3	1	0 / 0	1 / 0
1.4	1	0 / 0	1 / 0
1.5	1	0 / 0	1 / 0
1.6	1	0 / 0	1 / 0
1.7	1	0 / 0	1 / 0
1.8	1	0 / 0	1 / 0
1.9	1	0 / 0	1 / 0
2.0	15	0 / 0	1 / 0
2.1	15	0 / 0	1 / 0
2.2	17	0 / 0	1 / 0
2.3	19	0 / 0	1 / 0
2.4	19	0 / 0	1 / 0
2.5	19	0 / 0	1 / 0
2.6	19	0 / 0	1 / 0
2.7	19	0 / 0	1 / 0
2.8	41	0 / 0	1 / 0
2.9	43	0 / 0	1 / 0

- Low exposure of assets along the Capel coast until the 100yr ARI inundation level (2m AHD).
- Between 2m AHD to 2.8m AHD residential building counts remain low and below the threshold for AEIP analysis
- At an inundation of 2.8m AHD, just below the Extreme +0.9m water level scenario (~100yr ARI+0.9m), residential building exposure doubles (41 buildings) with 43 residences exposed by the 2.9m AHD inundation level.
- No commerical or industrial buildings are exposed using the AEIP analysis tool and only 1km of road is exposed from 1.2m AHD

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

Assets identified with AEIP occur from +2.2m AHD, with a substantial proportion of identified assets above 2.8m AHD, beyond which there is a progressive increase in exposure with elevation. Comparison with estimated inundation likelihood indicates minor inundation hazard, with around 12% likelihood of coastal inundation impact 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 significantly increase for an inundation difference of +0.6m. This difference could be developed through choice of event scenarios or statistics, inclusion of wave processes, or allowance for sea level rise. This suggests a need for adaptation planning to consider inundation hazard for the Shire of Capel.



Damage: Inundation Risk Ratings & Damage Assessment

Average Annual Damage		AEIP			
Area	WL ARI	1.7m AHD High	2m AHD Extreme	2.9m AHD Extreme+ 0.9m	All WL
19.1: Capel		$ 47K/yr	$ 55K/yr	$ 76K/yr	$ 77K/yr
Total Damage		**$ 47K/yr**	**$ 55K/yr**	**$ 76K/yr**	**$ 77K/yr**

- Damage from low lying residential properties adjacent to the estuary, which commences at +1.2m AHD. These properties may have building floor levels above the ground level.
- Inundation protection is provided by the storm surge barriers at the Vasse-Wonnerup estuary which is effective to +1.5m AHD.
- Inundation can also occur through multiple pathways into Stirling Wetlands, active under different conditions and at different levels.

Planning Framework

The Shire of Capel is within the Greater Bunbury Region. Consequently, the planning framework includes Capel Local Planning Scheme No. 8, and Greater Bunbury Region Scheme.
The GBRS and Capel Local Planning Scheme No. 8 acknowledge Capel's existing riverine flooding and proximity to wetlands. However, the area identified as floodplain in the Greater Bunbury Region Scheme Floodplain Management Policy does not include coastal inundation hazard. The Shire has previously been involved in coastal adaptation planning through Peron-Naturaliste Partnership projects, including a regional coastal vulnerability study, from Capel to Australind, moving towards CHRMAP development.
Capel Local Planning Scheme No. 8 identifies a special control area for flooding based on GBRS Floodplain Management Policy maps. The extent of mapping does not include coastal areas.

Evaluation of Capel'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	• Capel Local Planning Scheme No. 8 identifies 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, but the extent of mapping in the Shire of Capel does not extend to the coast.
HC3	• Mapping of coastal inundation hazard in the draft CHRMAP is not connected to planning documents. However, as Capel Local Planning Scheme No. 8 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 Capel 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 adaptation. It is expected the draft CHRMAP will outline pathways for adaptation.
HC6	• The planning framework acknowledges the role of emergency management for flooding, including potential for isolation.
HC7	• The planning framework presently does not acknowledge flood proofing or ABCB guidance.
HC8	• A special control area for floodprone areas, is identified in the Capel Local Planning Scheme No. 8, linked to the GBRS Floodplain Management Policy. This does not presently cover the coastal area.

EXTREME Inundation Risk
at coast

City of Busselton

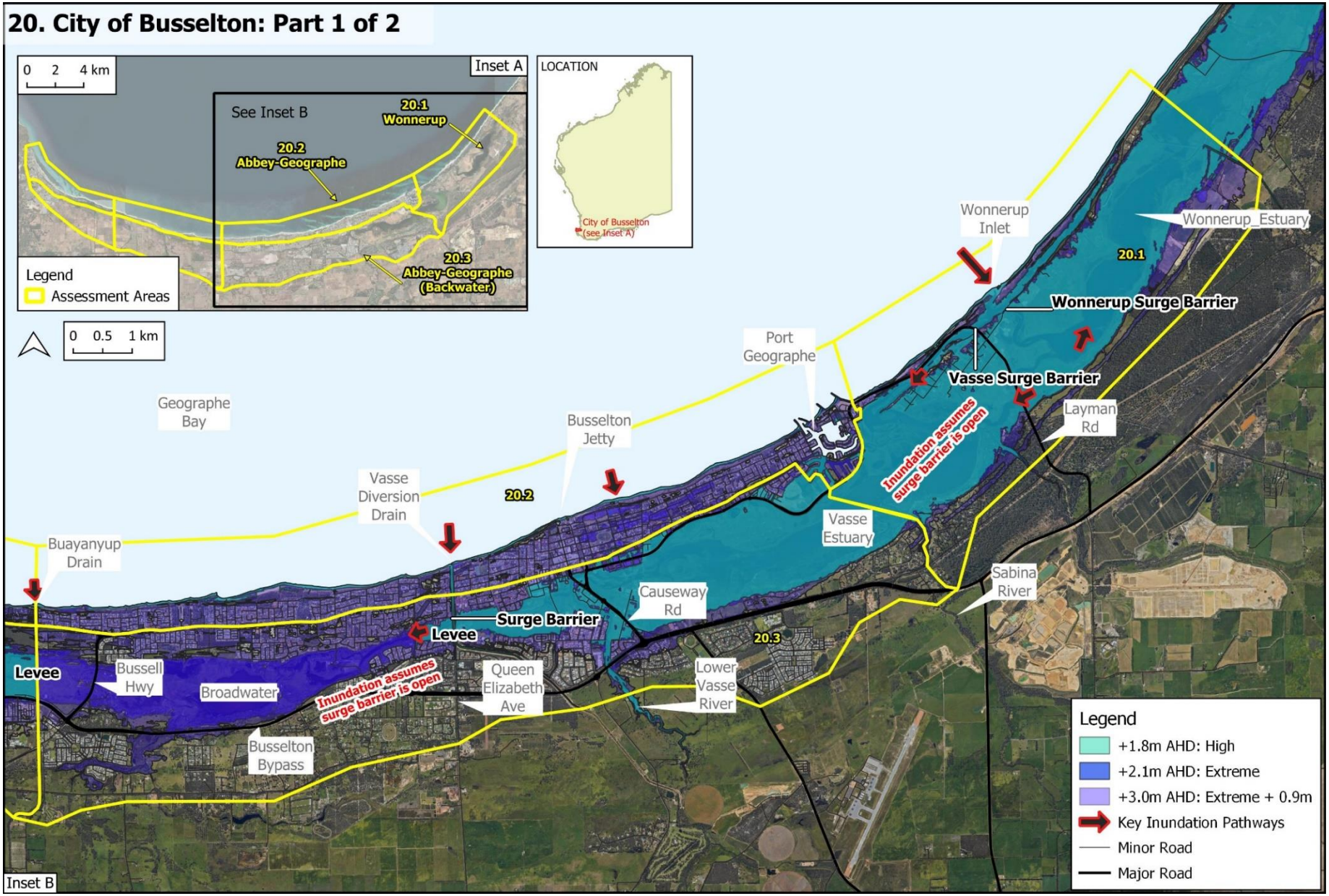
Focus

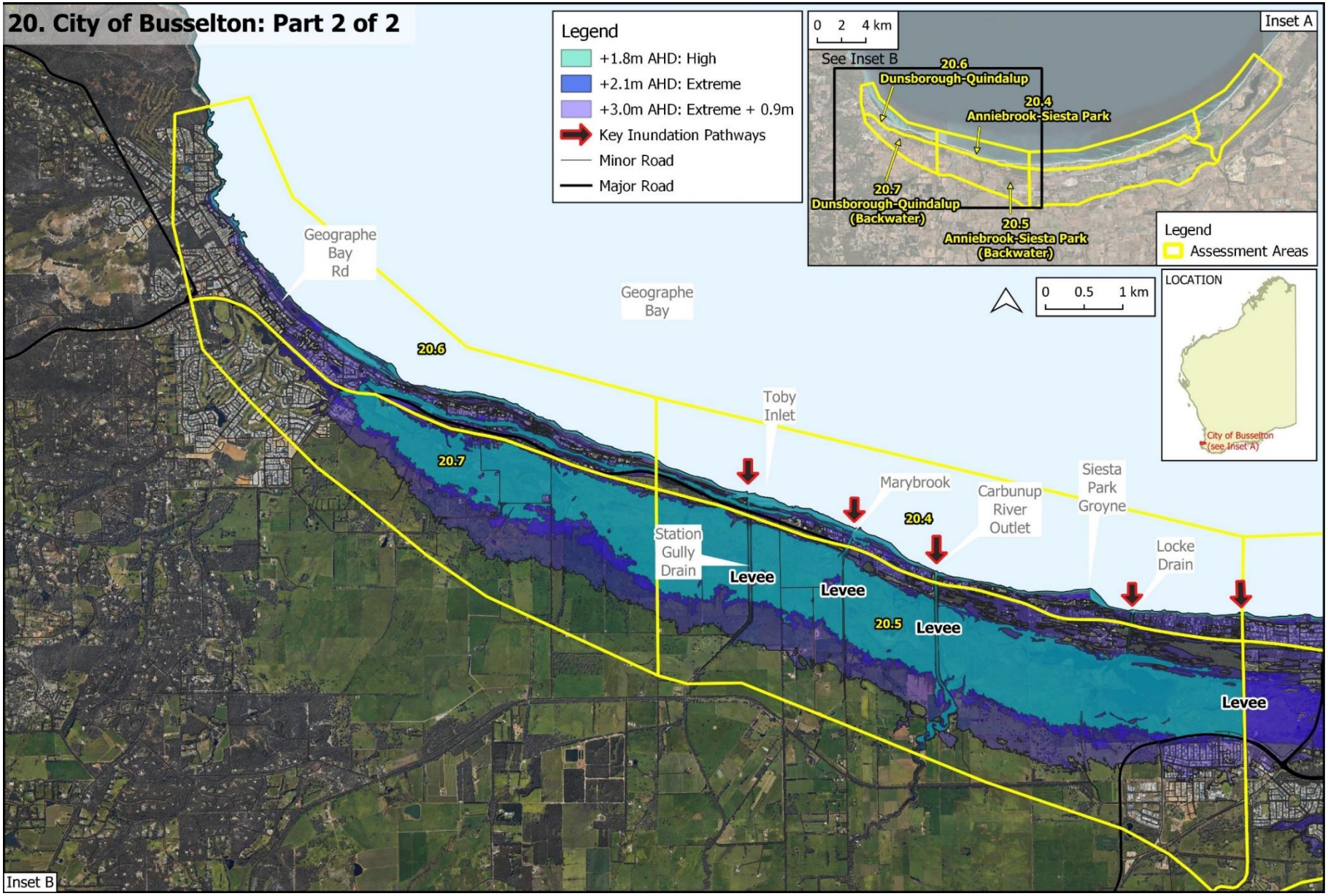
- Active Management
- Adaptation Priority
- Management at Foreshore
- Targeted Mitigation

Actions

- WL Review (CHRMAP)
- Damage Based Assessment
- Economic Criteria Review
- Emergency Management
- Inundation Plan

Seashore Engineering


20. City of Busselton: Part 1 of 2
Inset A
0 2 4 km
See Inset B
20.1
Wonnerup
20.2
Abbey-Geographe
20.3
Abbey-Geographe
(Backwater)
LOCATION
City of Busselton
(see Inset A)
Legend
Assessment Areas
0 0.5 1 km
Wonnerup
Inlet
Wonnerup_Estuary
20.1
Wonnerup Surge Barrier
Port
Geographe
Vasse Surge Barrier
Layman
Rd
Geographe
Bay
Busselton
Jetty
Inundation assumes
surge barrier is open
Vasse
Diversion
Drain
20.2
Vasse
Estuary
Buayanyup
Drain
Sabina
River
Causeway
Rd
Surge Barrier
Levee
20.3
Levee
Bussell
Hwy
Broadwater
Inundation assumes
surge barrier is open
Queen
Elizabeth
Ave
Lower
Vasse
River
Busselton
Bypass
Inset B
Legend
+1.8m AHD: High
+2.1m AHD: Extreme
+3.0m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road


20. City of Busselton: Part 2 of 2
Legend
+1.8m AHD: High
+2.1m AHD: Extreme
+3.0m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road
0 2 4 km
Inset A
See Inset B
20.6
Dunsborough-Quindalup
20.4
Anniebrook-Siesta Park
20.7
Dunsborough-Quindalup (Backwater)
20.5
Anniebrook-Siesta Park (Backwater)
Legend
Assessment Areas
LOCATION
City of Busselton (see Inset A)
0 0.5 1 km
Geographe Bay Rd
Geographe Bay
20.6
20.7
Toby Inlet
Marybrook
Carbunup River Outlet
20.4
Siesta Park Groyne
Station Gully Drain
Levee
Levee
20.5
Levee
Locke Drain
Levee
Inset B

20. BUSSELTON

Site Overview :

The authors wish to acknowledge the Wadandi and Bibbulmun people as the native title holders of the lands and waters in and around the City of Busselton. The City is located in the southwest of the State and is home to a diverse population of an estimated 41,041. Population centres are at Busselton and Dunsborough, with development along a significant part of the coast supporting a substantial non-resident presence, with high levels of tourism, strongly seasonal.

Areas Exposed to Inundation:

Seven inundation exposure areas have been considered for the Busselton LGA. Land area 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 was estimated as:

REGION	WL ARI	1.8m AHD High	2.1m AHD Extreme	3m AHD Extreme + 0.9m
20.1 Wonnerup		5.2km²	5.8km²	8.4km²
20.2 Abbey-Geographe		0.5km²	1.4km²	8km²
20.3 Abbey-Geographe (Backwater)		4.2km²	9.9km²	17km²
20.4 Anniebrook-Siesta Park		0.3km²	0.4km²	1.3km²
20.5 Anniebrook-Siesta Park (Backwater)		7.5km²	8.5km²	12.7km²
20.6 Dunsborough-Quindalup		0.4km²	0.6km²	2km²
20.7 Dunsborough-Quindalup (Backwater)		2.5km²	3.3km²	5.2km²

Morphology: Coastal Floodplain; Low Relief; Coastal Lagoons

- Predominately sandy coastline with nearshore sand bars that historically migrate eastwards.
- Low relief, mostly below 3m AHD with parts below 2m AHD.
- The Vasse-Wonnerup Estuary is a very large, elongated and shallow waterbody, separated from the ocean by beach ridges fringed by estuarine marshland and tidal floodplain with some saline samphire marshes.
- Natural landforms developed due to: small tide range; weak onshore winds; substantial shelter from prevailing ocean swell, and partial shelter from most westerly storm event.
-

Climate: Microtidal; Extra-Tropical Storms; Mid Latitude Depressions

- Microtidal – 1.2m LAT to HAT.
- Coastal orientation gives high sensitivity to northerly storm events, including impacts from low latitude winter storms and southward travelling former tropical cyclones.
- Busselton is in wind region A1 (AS1170.2), which means that extreme winds are caused by mid-latitude storms.
- Surge events in Busselton are typically slightly larger than Bunbury or Fremantle. Resonant response is enhanced due to Geographe Bay orientation and structure.
- Short durations of high-water levels characteristic of meteotsunami have been measured during small extent, southward travelling storms and thunderstorms.
- Water levels within estuaries are likely to be subject to dampening relative to coastal water levels.

[1] Areas were calculated at 0.1m increments with HAT for Busselton taken at 0.8m AHD in this study.

Development Record: Agricultural

- The Wadandi people are the Traditional Custodians of the Busselton area. The Aboriginal name for Busselton is Undalup after the warrior and leader Undal. Wonnerup is place of the women's digging stick.
- The region provided a substantial source of lumber for colonial settlement in southwest Western Australia, until the late 19th Century. Lumber and agricultural products were the key exports from Busselton Jetty, built from 1865.
- Busselton originally had a pastoral focus, with agriculture developing on the low-lying floodplain. This was enhanced by large-scale agricultural drainage in the 1940s, which substantially reduced the incidence of waterlogging.
- A regional drainage network was constructed between 1941 and 1975. Large areas of coastal change along the coast occurred in response to the modification to drainage and subsequent sediment transport processes.
- Busselton developed a significant tourism role from the 1960s, including community camps, and extensive short-stay accommodation, progressively spreading along Geographe Bay coast.
- Increased development of Margaret River wine region saw simultaneous increase to Busselton's role as the largest population centre in the southwest.
- Most development in the City of Busselton is focused on the north-facing, sandy coastline of Geographe Bay and in nodal settlements of Yallingup, Eagle Bay, Bunker Bay and Smiths Beach.

Coastal Inundation History: Frequent Moderate Events

A comparatively limited record of coastal inundation measurement is available for the Busselton area with recordings from the Busselton Jetty tide gauge between 1978-1979 and the Port Geographe Marina from 2002 to present. Frequent minor flooding from mid-latitude storm events coincident with a combined tidal & MSL peak around May-July has been reported for the Busselton area and significant water level events for Busselton can be summarized as follows:

TC Alby April 1978 – 2.44m CD (1.76m AHD)

- Southward tracking cyclone considered most damaging storm to have impacted Busselton in living memory.
- After extra-tropical transition from 3 April, the system expanded and moved rapidly southeast. It passed ~400km west of Bunbury and 200km west of Cape Naturaliste with most extreme water levels recorded at Busselton exceeding 2.4m CD which was 0.2m higher than any other event recorded for Busselton.
- Extreme water level produced by large surge combined with high tide. Surge was likely generated by a large shelf wave and resonant response with increasing surge as the system tracked southward and closer to shore plus moderate wind setup from strong northerly winds which exceeded 100km/hr at Cape Naturaliste.
- Foreshore areas and beachfront roads were inundated along Geographe Bay. Many people were forced to evacuate homes with inundation, generally two blocks inland between Marybrook and Geographe in East Busselton while inundation extended nearly 400m inland to Hester Street and Moylan Way.

Mid latitude Storm/Cold Front, July 2007 - 2.27m CD (1.59m AHD)

- Deep Southern Ocean mid latitude depression and strong cold front.
- Size of storm supported strong winds for over 24 hours with a sharp increase in wind speed and shift from northwest to west at Busselton and Bunbury during the passage of the cold front on July 1st.
- Busselton recorded its second highest ever water level (TC Alby was the highest) and highest ever water level associated with a winter storm.
- Localised coastal inundation of foreshore reserves and beachfront roads along Geographe Bay, under combined influence of waves and water levels as well as localised inundation at Port Geographe marina which typically commences around 2.0m CD (1.32m AHD)

Ex-TC Mangga 2020 - 2.15m CD (1.47m AHD)

- Severe storm associated with ex-TC Mangga, which combined with an upper-level trough and strong cold front, followed by a deep low through the SE.
- Sustained strong northwest to west winds with large waves and high surge.
- Water level elevations more than 1m above predicted tides.
- Coastal inundation is mainly restricted to low lying foreshore reserves and roads such as in Geographe Bay where the combined influence of waves and water levels contributed to inundation of Abbey Beach boat ramp.

Hazard: Existing Coastal Inundation Hazard Assessment Summary

Geoscience Australia (2014)

- Severe runoff flooding and coastal inundation hazard with runoff flooding the initial focus.
- Inundation risk for low to moderate events, in the order of 1 to 20 yr ARI. However, defining levels for less frequent events has been obscured by relative infrequency of northwest storms or ex-tropical cyclones, and unusual synoptic and oceanographic conditions associated with them, including extratropical transition and coastally trapped wave generation.
- Non-probabilistic simulation of 'track-shifted' scenarios based on TC Alby showed large areas exposed to inundation hazard, with modelled levels up to 3.4m AHD.

Baird (2020) & CHRMAP (2022)

- 100-year ARI winter storm level around 2.0m AHD, although with low confidence due to the short record.
- A water level of 1.76m AHD was measured during TC Alby, and coastal inundation impacts were surveyed up to a level of 2.9m AHD.
- Preliminary planning threshold level of 2.9m AHD along the wider Busselton coast (conservative approach), intended to be above the 500-year ARI inundation level for all sites in the region. This value was incorporated into active management by the City of Busselton, as a basis for target finished floor levels.
- Local review of cyclone climatology and hydrodynamic modelling was undertaken to refine the understanding of inundation risk at Port Geographe. A 500-year ARI level of 2.6 m AHD was estimated.

Hazard: Existing Controls

- Finished floor level (FFL) is used as the primary control for inundation hazard mitigation.
- 3.0m AHD FFL is required, based on a combination of runoff flooding and inundation impacts during TC Alby. This is subject to review as part of ongoing adaptation to climate change and sea level rise. The CHRMAP (2022) recommends a FFL at or above 3.8m AHD for new development.
- Existing management acknowledges a significant role played by coastal dunes to limit landward propagation of floodwaters and waves. Dune management includes low point infilling and dune restoration following breaching and overwash events. Acknowledging the potential for inundation events to travel landward past the dunes, and constraints to road access for isolated areas, the City of Busselton has been working with the Bureau of Meteorology and DFES to develop a functional warning system and management plan for coastal inundation. This is supplemented by community social media groups.
- Levees marked in the area 20.5 around Anniebrook-Siesta Park (Backwater) at Toby inlet, Carbunup and Marybrook were primarily designed as agricultural drains to deal with terrestrial flooding but also influence coastal inundation impacts in adjacent low-lying areas.
- Two storm surge barriers are in place in the Vasse-Wonnerup Estuary with heights set up to ~2m AHD. There is presently potential for ingress through low lying land on Layman Road adjacent to the Vasse barrier at +1.5m AHD.

Assets: Exposure of Coastal Assets to Inundation Impacts[2]

Inundation Level (m AHD)	20.1 Wonnerup			20.2 Abbey-Geographe			20.3 Abbey-Geographe (Backwater)			20.4 Anniebrook-Siesta Park		
	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)
1.3	29	0 / 0	0 / 2	0	0 / 0	0 / 1	17	0 / 0	1 / 2	0	0 / 0	0 / 1
1.4	31	0 / 0	0 / 3	0	0 / 0	0 / 1	37	0 / 0	1 / 2	0	0 / 0	0 / 1
1.5	36	0 / 0	0 / 3	0	0 / 0	0 / 1	58	0 / 0	1 / 3	0	0 / 0	0 / 1
1.6	40	0 / 0	0 / 3	0	0 / 0	0 / 1	110	0 / 0	1 / 3	0	0 / 0	0 / 1
1.7	41	0 / 0	0 / 3	4	0 / 0	0 / 1	155	1 / 3	1 / 4	0	0 / 0	0 / 1
1.8	42	0 / 0	0 / 4	6	0 / 0	0 / 1	210	3 / 7	1 / 6	0	0 / 0	0 / 1
1.9	44	0 / 0	0 / 4	6	1 / 0	0 / 1	292	4 / 7	1 / 7	0	0 / 0	0 / 1
2.0	47	0 / 0	0 / 4	21	1 / 0	0 / 1	396	6 / 10	1 / 8	4	0 / 0	0 / 1
2.1	46	0 / 0	0 / 5	291	4 / 0	0 / 1	483	6 / 14	1 / 8	5	0 / 0	0 / 1
2.2	49	0 / 0	0 / 5	521	12 / 0	0 / 1	622	8 / 19	1 / 9	10	0 / 0	0 / 1
2.3	51	0 / 0	0 / 5	1002	44 / 0	0 / 1	803	10 / 25	1 / 9	15	0 / 0	0 / 1
2.4	53	0 / 0	0 / 6	1748	89 / 0	0 / 2	1088	13 / 33	1 / 9	15	0 / 0	0 / 1
2.5	65	0 / 0	0 / 6	2343	129 / 0	0 / 4	1395	15 / 46	1 / 9	28	0 / 0	0 / 1
2.6	69	0 / 0	0 / 6	2854	162 / 0	0 / 6	1854	20 / 56	1 / 10	41	0 / 0	0 / 1
2.7	78	0 / 0	0 / 6	3282	181 / 0	0 / 7	2317	27 / 65	1 / 10	57	0 / 0	0 / 1
2.8	87	0 / 0	0 / 6	3658	190 / 0	0 / 8	2703	31 / 81	2 / 10	67	0 / 0	0 / 2
2.9	96	0 / 0	0 / 6	3906	191 / 0	0 / 9	3037	37 / 91	2 / 11	97	0 / 0	0 / 4
3.0	102	0 / 0	0 / 6	4079	194 / 0	0 / 9	3327	39 / 94	2 / 11	117	0 / 0	0 / 5

Inundation Level (m AHD)	20.5 Anniebrook-Siesta Park (Backwater)			20.6 Dunsborough-Quindalup			20.7 Dunsborough-Quindalup (Backwater)		
	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)
1.3	0	0 / 0	1 / 1	0	0 / 0	0 / 0	0	0 / 0	0 / 1
1.4	0	0 / 0	1 / 1	2	0 / 0	0 / 0	0	0 / 0	0 / 1
1.5	0	0 / 0	1 / 1	3	0 / 0	0 / 0	2	0 / 0	0 / 1
1.6	0	0 / 0	1 / 1	7	0 / 0	0 / 0	2	0 / 0	0 / 1
1.7	1	0 / 0	1 / 1	12	0 / 0	0 / 0	2	0 / 0	0 / 1
1.8	1	0 / 0	1 / 1	17	0 / 0	0 / 0	2	0 / 0	0 / 1
1.9	1	0 / 0	1 / 1	22	0 / 0	0 / 1	3	0 / 0	0 / 1
2.0	3	0 / 0	1 / 1	29	0 / 0	0 / 1	5	0 / 0	0 / 1
2.1	18	0 / 0	2 / 1	42	0 / 0	0 / 1	6	0 / 0	0 / 1
2.2	46	0 / 0	2 / 1	63	0 / 0	0 / 1	7	0 / 0	0 / 1
2.3	96	0 / 0	2 / 1	98	0 / 0	0 / 1	9	0 / 0	0 / 1
2.4	134	0 / 0	2 / 1	132	0 / 0	0 / 2	10	0 / 0	0 / 1
2.5	183	0 / 0	2 / 1	193	0 / 0	0 / 2	12	1 / 0	0 / 1
2.6	224	0 / 0	2 / 1	269	0 / 0	0 / 2	13	1 / 0	0 / 1
2.7	278	0 / 0	2 / 1	349	0 / 0	0 / 2	13	2 / 0	0 / 2
2.8	308	0 / 0	2 / 1	429	0 / 0	0 / 2	13	2 / 0	0 / 2
2.9	338	2 / 0	2 / 1	524	0 / 0	0 / 3	14	2 / 0	0 / 2
3.0	373	2 / 0	2 / 1	627	0 / 0	0 / 3	14	2 / 0	0 / 2

High
Extreme
Extreme +0.9m

Other Assets Exposed:

20.2 Abbey-Geographe - Extreme +0.9m: 1 ambulance station; 1 nursing home; 2 schools

20.3 Abbey-Geographe (backwater) - Extreme +0.9m: 1 nursing home; 3 retirement home.

20.1 Wonnerup

- Primary inundation pathway through the Wonnerup inlet with inundation of the low lying land around the Wonnerup Estuary and possible impact to residential buildings identified as low as 0.8m AHD assuming both the Wonnerup and Vasse surge barriers are open. Secondary pathways moving north and south from Layman Road area and all low lying areas seaward of Tuart Drive exposed for the high water level scenario upwards.
- Relatively low exposure across building categories with only residential buildings impacted increasing from 47 buildings at 2m AHD to 102 buildings at 3m AHD. In total, 6km of arterial roads will be exposed.

20.2 Abbey-Geographe

- Coastal area from Port Geographe to Buayanyup Drain with inundation pathways at Busselton Jetty, Vasse Diversion Drain and Buayanup Drain. Again, inundation assumes that the surge barrier is open.
- Low exposure until 2.1m (high) after which significant exposure of both residential and commercial buildings increasing to over 4000 and almost 200 respectively at a 3m AHD inundation level (extreme) with 9km of arterial road also exposed.

[2] Assumes no storm surge barrier for 20.1 and 20.3

20.3 Abbey-Geographe Backwater

- Flow through the Vasse Estuary area south of Port Geographe inundating the low lying area moving south as far as the surge barrier at the lower Vasse River and Causeway Road and the levee west of Queen Elizabeth Ave.
- High number of residential buildings exposed from 1.3m AHD inundation level onwards with commercial and industrial buildings also progressively exposed from the 1.7m AHD water level. A total of 13km of road will be exposed by 3m AHD.

20.4 Anniebrook-Siesta Park

- Pathway through Locke Drain, Carbunup River Outlet, Marybrook and Toby inlet. Inundation of low lying foreshore areas at 1.8m AHD and some buildings, mainly to the west of Lock Drain, under the extreme water level scenario.
- Relatively low exposure across all categories with residential buildings first exposed at 2m AHD but not included in AEIP analysis of damage until 2.5m AHD. No exposure of commercial or industrial buildings and low exposure of roads until a 2.9m AHD.

20.5 Anniebrook-Siesta Park Backwater

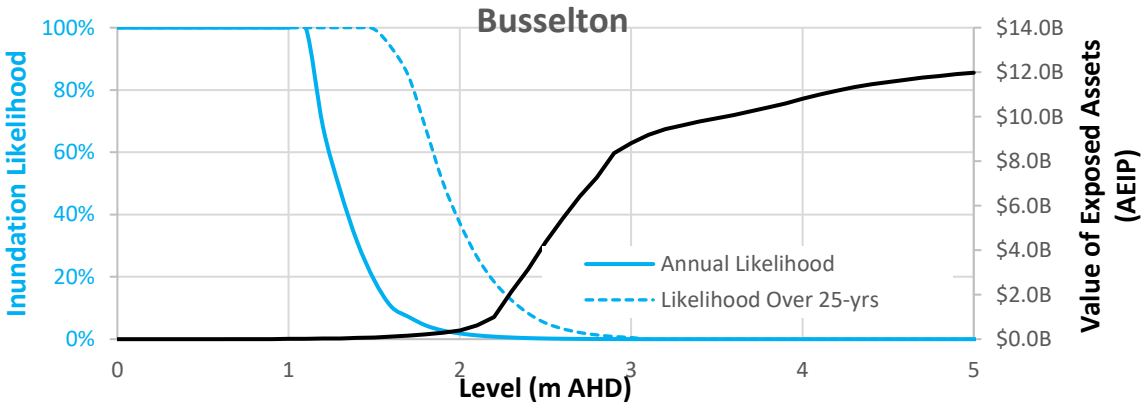
- Primary pathways through Carbunup River Outlet, and Toby inlet flow through lowlying areas south of Caves Road
- A significant number of residential buildings exposed to inundation impacts increasing steadily from 18 buildings at 2.2m AHD to almost 400 buildings by 3m AHD. Only 2 commercial buildings impacted at the 2.9m AHD inundation level with a total of 3km of road.

20.6 Dunborough- Quindalup

- Primary pathways around Geographe Bay Road area with inundation of low lying areas with relatively dense building counts between coast and Caves Road
- Significant residential exposure from 2.1m increasing to over 600 buildings at the 3m inundation level. No exposure of industrial or commercial buildings and minimal exposure of roads until 2.1m AHD.

20.7 Dunsborogh-Quindalup Backwater

- Flow through Geographe Bay Road area extending east
- Low exposure across all categories; at 2.5m AHD a commercial building is exposed



Assets identified with AEIP occur from +1.3m AHD, with a substantial proportion of identified assets between 2.2m and 2.9m AHD. Exposure of assets below 2.2m AHD is considered to be exaggerated due to the coarse resolution of AEIP valuation and steep ground slopes at waterside properties, Consequently a small positioning error can locate the asset at the base of a retaining wall.Comparison with estimated inundation likelihood indicates severe inundation hazard, with around 20% likelihood of coastal inundation impact to significant assets (below 2.2m AHD) over a 25 year period. Notably, this does not include effects of waves, which can extend to higher levels, while a significant proportion of assets are within 20.1 and 20.3 are likely to have lower inundation likelihood due to estuarine dampening. The present level of exposure would significantly increase with additional contributions to inundation. Assets below 3.0m AHD would have a 63% likelihood of inundation in a 25 year period for a difference of +1.2m (e.g. 0.3m freeboard plus 0.9m sea level rise). This difference could be developed through choice of event scenarios or statistics, inclusion of wave processes, or allowance for sea level rise. Existing hazard suggests importance for present-day management of coastal inundation, with the potential future risk indicating a critical need for adaptation planning in Busselton.

Damage: Inundation Risk Ratings & Damage Assessment

Average Annual Damage		AEIP			
Area	WL ARI	1.8m AHD High	2.1m AHD Extreme	3m AHD Extreme+ 0.9m	All WL
20.1: Wonnerup		$ 2.8M/yr	$ 3.1M/yr	$ 3.3M/yr	$ 3.3M/yr
20.2: Abbey-Geographe		$ 2K/yr	$ 17K/yr	$ 1.3M/yr	$ 1.5M/yr
20.3: Abbey-Geographe (Backwater)		$ 1.6M/yr	$ 2.4M/yr	$ 3.7M/yr	$ 3.8M/yr
20.4: Anniebrook-Siesta Park		$ 0K/yr	$ 1K/yr	$ 13K/yr	$ 16K/yr
20.5: Anniebrook-Siesta Park (Backwater)		$ 1K/yr	$ 4K/yr	$ 78K/yr	$ 97K/yr
20.6: Dunsborough-Quindalup		$ 40K/yr	$ 83K/yr	$ 187K/yr	$ 202K/yr
20.7: Dunsborough-Quindalup (Backwater)		$ 13K/yr	$ 22K/yr	$ 35K/yr	$ 36K/yr
Total Damage		**$ 4.4M/yr**	**$ 5.6M/yr**	**$ 8.5M/yr**	**$ 8.9M/yr**

- The low-lying coastal and estuarine foreshores within Busselton have significant risk of damage, with most of damage identified within Wonnerup and Abbey-Geographe Backwater segments.
- While storm surge barriers control inflow to these two segments, the percolation assessment identified potential for ingress through low lying land on Layman Road (+1.5m AHD), next to the storm surge barrier which is set above +2.0m AHD. This pathway implies more frequent inundation, that has not been historically observed, which suggests that the assessment is likely to exaggerate damage from inundation arriving through shallow, constricted flow paths.
- The role of storm surge barriers at Busselton is significant, with approximately $2.6M/yr of estimated damage mitigated, with the assuming effectiveness to +1.5m AHD. This could be enhanced through local raising of Layman Road.
- Overall, Busselton has an enormous residual risk and high sensitivity to sea level rise or exceptional events.

Planning Framework

Busselton planning framework includes Busselton Local Planning Strategy and Local Planning Scheme No. 21. Busselton has completed a series of coastal hazard assessments and has prepared a CHRMAP. The Local Planning Strategy acknowledges the substantial hazards associated with inland flooding and coastal inundation, as well as recognizing that these hazards are likely to change over time. Evaluation of Busselton's planning framework against the Inundation Management Health Check criteria gave:

HC1	• Potential for interactions between runoff flooding and coastal inundation have been variably treated in coastal vulnerability studies.
HC2	• Busselton CHRMAP identifies potential for inundation hazard for a 500-year ARI inundation level, and requires consideration of sea level rise, with an allowance of 0.9m over 100 years.
HC3	• Identified coastal management areas in the Local Planning Scheme No. 21 maps are based on coastal erosion and its active management using coastal protection works. These do not consider coastal inundation hazard.
HC4	• Coastal inundation and flood mitigation measures identified in Busselton planning framework presently focus on use of minimum finished floor levels.
HC5	• The Local Planning Strategy identifies a need to develop an adaptation plan for mitigation of coastal erosion and inundation hazards. The CHRMAP indicates further evaluation is required, with a detailed investigation presently underway.
HC6	• The planning framework acknowledges the role of emergency management for coastal inundation and flooding.
HC7	• The planning framework presently does not acknowledge flood proofing or ABCB guidance.
HC8	• A special control area for coastal management is identified in Busselton Local Planning Scheme No. 21. This is not defined based on coastal inundation hazard.

MODERATE Inundation Risk
at coast

Shire of Augusta-Margaret River: Augusta

Focus

Adaptation Priority

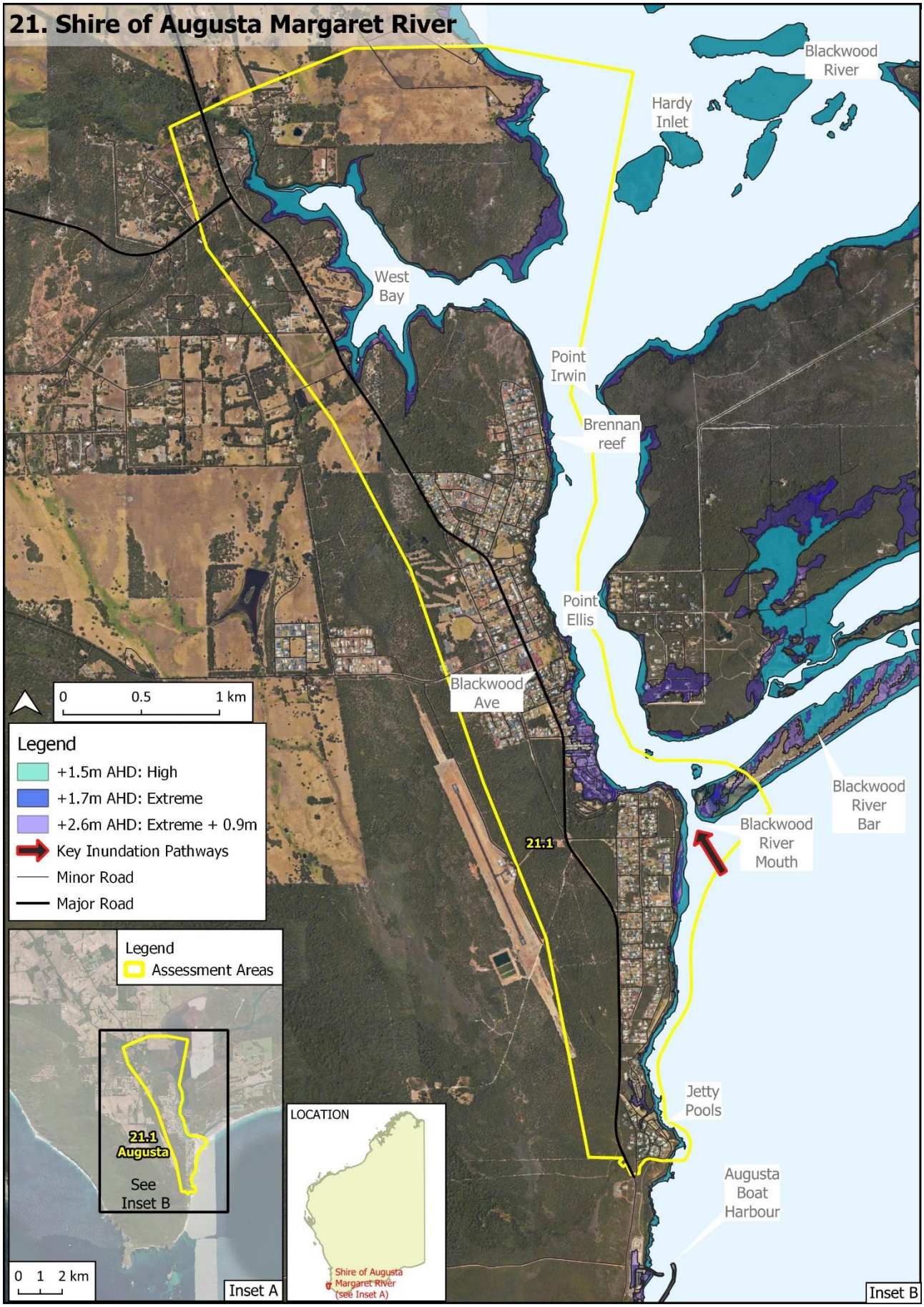
Actions

Management at Foreshore

Targeted Mitigation

WL Review (CHRMAP)

Seashore Engineering


21. Shire of Augusta Margaret River
Blackwood River
Hardy Inlet
West Bay
Point Irwin
Brennan reef
Point Ellis
Blackwood Ave
Blackwood River Bar
Blackwood River Mouth
21.1
Jetty Pools
Augusta Boat Harbour
0 0.5 1 km
Legend
+1.5m AHD: High
+1.7m AHD: Extreme
+2.6m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road
Legend
Assessment Areas
21.1 Augusta
See Inset B
0 1 2 km
Inset A
LOCATION
Shire of Augusta Margaret River (see Inset A)
Inset B

21. AUGUSTA – MARGARET RIVER

Site overview:
The authors wish to acknowledge the Walandi and Pibelmen Boodja people as the native title holders of the lands and waters in and around the Shire of Augusta and Margaret River - Talinup (Augusta) is the Place of Reeds, within Wadandi Boodja (Saltwater People's Country). The Shire is in the south-west region of Western Australia, with both west and south facing coast. This includes approximately 138 km of coast under a mix of private and public tenure, including a significant part in Leeuwin Naturaliste Ridge National Park. The population of 16,791 is diverse with a strong affiliation to protect and enhance the unique natural coastal environment of the region.

Areas at risk from inundation:
One inundation area is considered within the Augusta-Margaret River Shire, around Augusta townsite, on the Blackwood River estuary and adjacent to Flinders Bay 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	1.5m AHD High	1.7m AHD Extreme	2.6m AHD Extreme + 0.9m
21.1 Augusta		0.2km²	0.3km²	0.7km²

Morphology: Sandy/Rocky Open Coast; Low-Energy Sheltered Beaches

Augusta townsite is adjacent to Hardy Inlet where Blackwood River discharges into the Southern Ocean at Flinders Bay. Hardy Inlet contains several small islands, the largest of which are Molloy and Thomas Island. Flinders Bay has developed in the lee of the massive granite outcropping which extends to Cape Leeuwin, southwest of Augusta. This shelter strongly influences dynamics of Blackwood River mouth, which has a permanent bar, but an entrance that has experienced episodes of mobility, including response to artificial breaching.

There are three distinct morphologies present in Augusta townsite:

- Inside Blackwood River mouth, Augusta main settlement has a relatively low wave energy, east facing estuarine shore subject to tides, and occasionally subject to river floods, with enhanced flood risk when the bar is constricted. Long, low sub-tidal terraces are present along the western shoreline increasing in length to the north. A mixture of sandy and rocky shorelines is present with sediments grading from medium sand to fine estuarine silts moving up river.
- On the east side of the Hardy Inlet, east Augusta also has a sheltered setting. This area has developed from previous entrance bars being subject to dune processes, resulting in a sandy shore with a range of elevations. This shore has beaches, areas of wetland and relatively wide sub tidal terraces increasing to the north.
- Development along Flinders Bay coast is sheltered from high energy Indian Ocean waves due to the bay orientation but has exposure to infrequent wave activity from the southeast. There is mixed sand and rocky shore, with several thin perched sandy beaches controlled by granite outcrops.

Climate: Microtidal; Sheltered Open Ocean Coast; Low-Energy Estuarine Environment

- Microtidal – tidal range of 1.4m has been modelled for Flinders Bay, with water levels inside Hardy Inlet being affected by runoff flooding and tidal damping when the Blackwood River mouth is constricted.
- Augusta is in Wind region A1 (AS1170.2), which means that extreme winds are caused by mid-latitude storms.
- Cape Leeuwin provides substantial protection against prevailing southwest swell from the Southern Ocean, but more infrequent southeast waves can enter Flinders Bay relatively unimpeded.

Development Record:

Talinup (Augusta) is within Wadandi Boodja (Saltwater People's Country). Augusta was established in 1830 as one of the earliest European colonial settlements in Western Australia. The sheltered waters of Flinders Bay supported maritime access, which was used opportunistically during early whaling activities. Formation of the timber industry and group settlement scheme characterised early development in the Shire, which transitioned into a strong agricultural industry through dairy, beef, and sheep farming.

[1] Areas were calculated at 0.1m increments with HAT for Augusta taken at 0.8m AHD in this study.

Coastal Inundation History: rare storm events; tidally modulated

- No tide gauge records are available for Augusta and there is no systematic anecdotal evidence of coastal inundation events available. Partial flooding of Molloy Island has been noted, although this is likely to be river flooding, with the perceived risk of river flooding being used as a justification for artificially opening the river entrance.
- Augusta townsite is located at a latitude prone to direct impact from mid latitude storms. However, as the approach of these storms creates westerly winds, Cape Leeuwin provides significant shelter from wave action, and the south-facing coastal orientation reduces the capacity for storm surge to be generated.

Hazard: Existing Coastal Inundation Hazard Assessment Summary

Information regarding potential coastal inundation hazard has been identified in Augusta-Margaret River CHRMAP.

Augusta Main Townsite

- Public infrastructure is located along low lying areas, with both low lying and elevated residences.
- Turner Caravan Park is a large foreshore landholding managed by the Shire in a relatively low-lying foreshore area (between 1m AHD and 3m AHD).
- Potentially subject to both coastal inundation and river flooding hazards.

Flinders Bay Foreshore

- Public infrastructure and a coastal road are located along modest dunes with narrow setbacks.

East Augusta

- Public access path along foreshore has narrow setbacks and low lying.
- Public infrastructure associated with recreational boating and has some resilience to coastal inundation.
- Large number of private properties below 5.0m AHD between Hillview Road and the Cut, including the Turner Caravan Park

Hazard: Existing Controls

There are no strategic controls for coastal inundation mitigation in Augusta. For areas with some potential exposure to coastal inundation, building floor levels have generally been developed 'organically', based on perceived threat associated with more frequent high-water levels, e.g., above the level of wave action for the Flinders Bay coast and above historic river flood levels within Blackwood River.

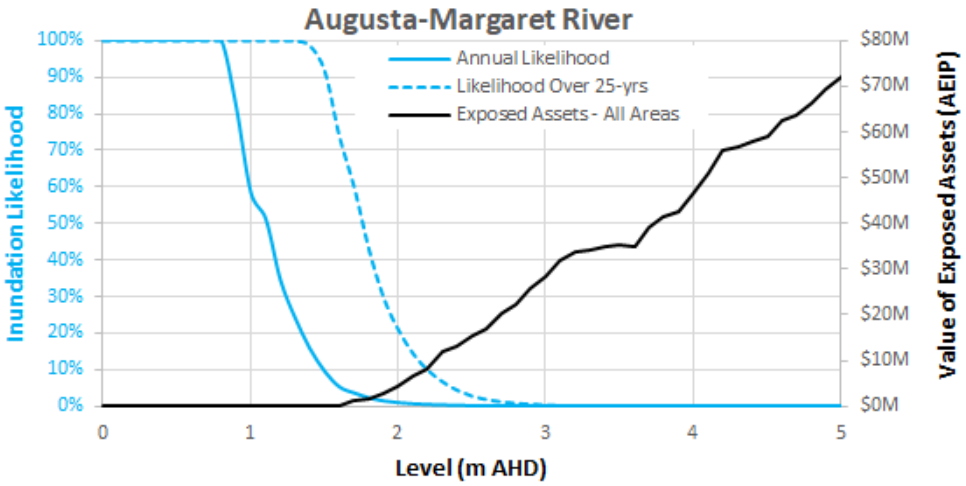
Assets: Exposure of Coastal Assets to Inundation Impacts

Inundation Level (m AHD)	21.1 Augusta		
	Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)
1.5	0	0 / 0	0 / 0
1.6	0	0 / 0	0 / 0
1.7	2	0 / 0	0 / 0
1.8	3	0 / 0	0 / 0
1.9	5	0 / 0	0 / 0
2.0	8	0 / 0	0 / 0
2.1	12	0 / 0	0 / 0
2.2	15	0 / 0	0 / 0
2.3	22	0 / 0	0 / 0
2.4	25	0 / 0	0 / 0
2.5	28	0 / 0	0 / 0
2.6	31	0 / 0	0 / 0

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

- Primary inundation pathway at the Blackwood river mouth with minimal impacts along the open ocean stretch of coastline.
- Inundation along the Blackwood River bar and on the southeast side of East Augusta around Swan lake. Further upstream Thomas Island and the surrounding group of small, largely sandy islands in the Hardy Inlet will be exposed to inundation under a water level of 1.5m AHD while at West Bay the low-lying foreshore areas to the East of Bussel Highway will be impacted.
- In the populated townsite area the majority of exposure is to the East of Blackwood Avenue in the area around Seine Bay and Turner Caravan Park
- No exposure of assets until 1.7m AHD, the extreme water level scenario (~100yrARI) when only 2 residential buildings were identified as impacted (below the AEIP analysis threshold)
- By 2.3m AHD inundation level 22 residential buildings exposed increasing to 31 by the Extreme +0.9m level
- No commercial or industrial buildings or roads exposed using the AEIP approach.

Asset exposure commences around 1.7m AHD and progressively increases, indicating a distribution of assets across the town's sloping grade. This threshold is below 1% recurrence per annum, with approximately 60% likelihood of being reached in a 25 year period. Perception of hazard can be modified through event scenarios or statistics, inclusion of wave processes, or allowance for sea level rise. Consequently, for assets near the shore, there is a difference in hazard between those adjacent to Flinders Bay, and those within the Blackwood River estuary, where there is much lower wave action. Consideration of projected sea level rise, in the order of 0.4-0.5m, would substantially increase hazard, highlighting the importance of adaptation planning for Augusta.



Damage: Inundation Risk Ratings & Damage Assessment

Average Annual Damage		AEIP			
Area	WL ARI	1.5m AHD High	1.7m AHD Extreme	2.6m AHD Extreme+ 0.9m	All Water Levels
21.1: Augusta		$ 0K/yr	$ 0K/yr	$ 11K/yr	$ 14K/yr
Total Damage		**$ 0K/yr**	**$ 0K/yr**	**$ 11K/yr**	**$ 14K/yr**

- Relatively small average annual damage primarily from property on the western bank of the Blackwood River, commencing at +1.8m AHD. Damage is primarily associated with residual risk.

Planning Framework

Augusta-Margaret River planning framework includes a Local Planning Strategy and Local Planning Scheme No. 1. The Shire has previously completed a CHRMAP. The value of the coast is highlighted within the planning documents, and the need to develop resilience to climate change is identified in the Local Planning Strategy.

Evaluation of Augusta-Margaret River's planning framework against the Inundation Management Health Check criteria gave:

HC1
- Coastal inundation hazard in Augusta-Margaret River is acknowledged to interact with waves and runoff flooding in different settings along the coast.

HC2
- There is limited information available to characterize inundation hazard within Augusta-Margaret River Shire, with no long-term instrumentation. The CHRMAP suggests a target level for 100-yr ARI plus 0.9m sea level rise allowance, which was estimated at +3m AHD. Potential hazard was identified using the +5m AHD contour due to limitations of available data.

HC3
- Coastal inundation hazard mapping is not presently available.

HC4
- Coastal inundation mitigation measures are not identified in the planning framework. The CHRMAP suggests accommodation within available building lots as part of the building cycle.

HC5
- Existing planning policy documents identify the need to enhance resilience to climate change, but do not specify preferred adaptation pathways, except acknowledgement of SPP2.6 in the CHRMAP.

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

HC7
- The planning framework presently does not acknowledge flood proofing or ABCB guidance.

HC8
- A special control area that considers coastal inundation has not been defined. This limits the capacity to obtain targeted funding to support strategic mitigation.

HIGH Inundation Risk
at coast

City of Albany

Focus

Adaptation Priority

Targeted Mitigation

Actions

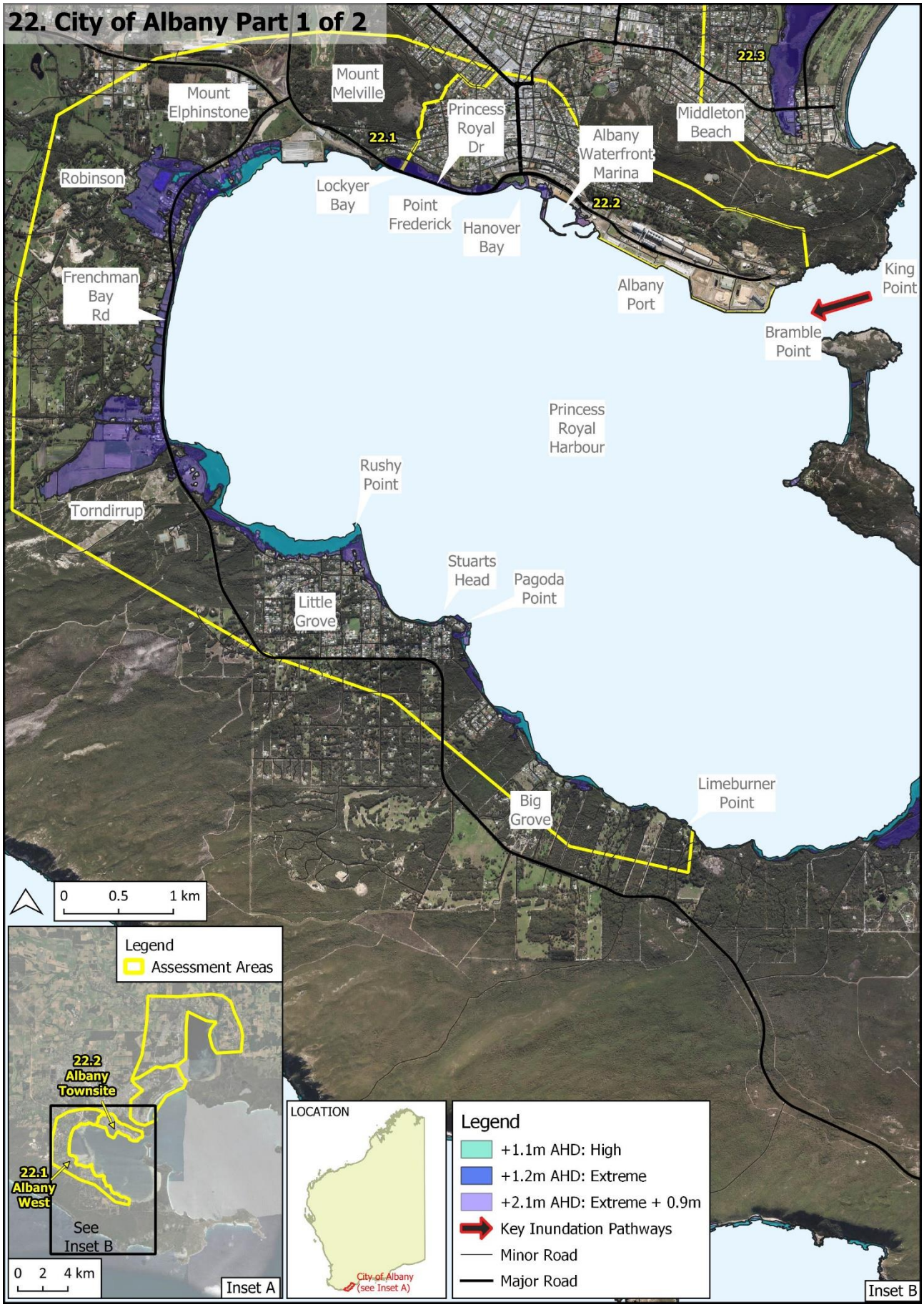
WL Review (CHRMAP)

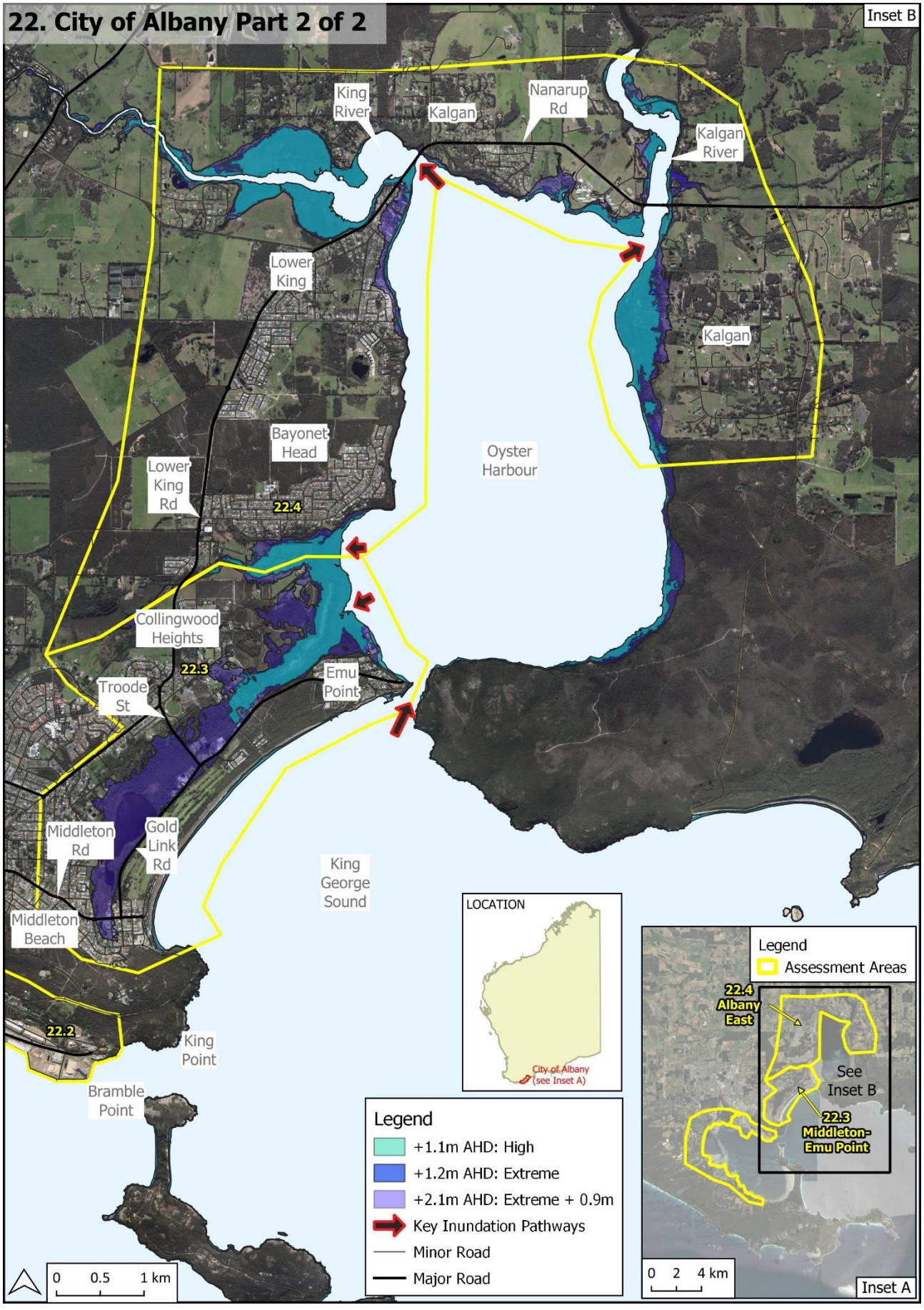
Targeted Mitigation

Damage Assessment

WL Sensitivity Review

Seashore Engineering


22. City of Albany Part 1 of 2
Mount Elphinstone
Mount Melville
Princess Royal Dr
22.1
22.3
Middleton Beach
Albany Waterfront Marina
22.2
Robinson
Lockyer Bay
Point Frederick
Hanover Bay
Frenchman Bay Rd
Albany Port
King Point
Bramble Point
Princess Royal Harbour
Rushy Point
Torndirrup
Stuarts Head
Pagoda Point
Little Grove
Big Grove
Limeburner Point
0 0.5 1 km
Legend
Assessment Areas
22.2 Albany Townsite
22.1 Albany West
See Inset B
0 2 4 km
Inset A
LOCATION
City of Albany (see Inset A)
Legend
+1.1m AHD: High
+1.2m AHD: Extreme
+2.1m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road
Inset B


22. City of Albany Part 2 of 2
Inset B
King River
Kalgan
Nanarup Rd
Kalgan River
Lower King
Kalgan
Bayonet Head
Oyster Harbour
Lower King Rd
22.4
Collingwood Heights
22.3
Troode St
Emu Point
Middleton Rd
Gold Link Rd
King George Sound
Middleton Beach
22.2
King Point
Bramble Point
LOCATION
City of Albany (see Inset A)
Legend
+1.1m AHD: High
+1.2m AHD: Extreme
+2.1m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road
0 0.5 1 km
Legend
Assessment Areas
22.4 Albany East
See Inset B
22.3 Middleton-Emu Point
0 2 4 km
Inset A

22. ALBANY

Site Overview:
The authors wish to acknowledge the Menang people as the native title holders of the lands and waters in and around the City of Albany. The City's (population 40,115) is in the Great Southern region of Western Australia, centred around the port city of Albany. Albany townsite is located around the margins of three connected basins, being Princess Royal Harbour (PRH), Oyster Harbour (OH) and King George Sound (KGS). These water bodies are natural harbours, and have a mixture of sandy, rocky, and walled shores, with substantial intertidal areas and shallow seagrass meadows. The port of Albany is within Princess Royal Harbour, with a shipping channel dredged through to King George Sound. The port has a bulk products focus, exporting mainly grain and woodchips, in the order of 3 to 4 million tonnes per annum. Other smaller trades are the export of silica sand and the import of fertiliser and fuel.

Areas at risk from inundation:
Four inundation exposure areas have been considered for the City of Albany 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
22.1 Albany West		0.1km²	0.2km²	1.6km²
22.2 Albany Townsite		0km²	0km²	0.1km²
22.3 Middleton-Emu Point		0.4km²	0.4km²	2.5km²
22.4 Albany East		1.1km²	1.2km²	2.1km²

Morphology: Sheltered; Intertidal & Subtidal Terraces; Exposed Open Ocean Beach

- Albany's coastal morphology is strongly influenced by the interaction of mobile sandy sediment with emergent, mainly granite outcrops forming Vancouver Peninsula. Rock features have controlled the development and persistence of sandy features, subject to wind, wave and tidal processes. The significant shelter provided by Vancouver Peninsula has enabled formation of the three basins which connect to the ocean through King George Sound.
- King George Sound is connected to the Indian Ocean through a broad east-facing passage, which allows diffracted swell to enter and almost direct exposure under rare southeast wind waves. Moderate wave energy has generated long arcuate beaches, characteristic of wave arriving from the entrance to the Sound.
- Princess Royal Harbour is roughly 4 km wide and 8 km long, orientated north-west to south-east direction and connected via Ataturk Channel to King George Sound. Princess Royal Harbour has a low wave energy setting and is characterized by extensive areas of intertidal flats. Shoreline profiles range from relatively steep either side of the entrance (along the harbour's northeast) to areas of long, gentle slopes. Within the harbour there are sections of 'sandy', 'rocky' (generally 'hard rock') and 'mixed sandy and rocky' coast as well 'hardened' shorelines being controlled by coastal structures.
- Oyster Harbour is the shallowest of the three basins, with the King and Kalgan Rivers flowing in, providing a limited supply of finer sediment and nutrient runoff, creating a more estuarine setting than the other two basins. Oyster Harbour has a low wave energy setting, with extensive areas of intertidal flats, widening to about 800m at the mouth of Kalgan River.

Climate: Microtidal; Highly Sheltered from Ocean Swell

- Microtidal – LAT to HAT range is 1.4m CD (0.79m AHD); predominantly diurnal but with semi-diurnal phases during spring and autumn.
- Water levels also impacted by wind- and wave-driven setup, storm surge within King George Sound transmitted through the entrance to the harbour and, to a minor extent, freshwater input from rainfall.
- Albany is located at a latitude prone to direct impact from mid latitude storms. However, as the approach of these storms creates westerly winds, Vancouver Peninsula provides significant shelter from wave action, and the east-facing coastal entrance to King George Sound reduces the capacity for storm surge to be generated.

[1] Areas were calculated at 0.1m increments with HAT for Albany taken at 0.8m AHD in this study.

- Princess Royal Harbour and Oyster Harbour have sheltered wave climates, with narrow entrance channels restricting waves from King George Sound and the open ocean; more exposed conditions with greater swell penetration are along Middleton Beach, in King George Sound.
- Albany is in Wind Region A1 (AS1170.2), which means that extreme winds are caused by mid-latitude storms.
- Wind climate is variable with most extreme conditions during winter (June to September). Wind direction during this period is predominantly westerly to northwest. During the summer months (November to March), winds are lighter and predominantly easterly to south-easterly

Development Record: Regional Port

- The City of Albany is situated in the Wagyl Kaip and Southern Noongar region of Noongar boodja. The Menang people are the traditional custodians of the country around Albany.
- Menang names for locations in Albany include Miaritch (Oyster Harbour), Mammang Koort meaning whale heart (King George Sound) and Binalup meaning First light or Morning light (Middleton Beach).
- Albany was the first British settlement, initially established as a military outpost.
- It's excellence as a natural port provided a focus for European colonial activity, being an arrival point for settlers, an import point for supplies and a way station for transit from the Swan River Colony towards colonial settlements in eastern Australia.
- Albany became the focal point for whaling and sealing activities along the south coast of Western Australia, with significant processing facilities on Vancouver Peninsula, separated from the townsite, which became a hub for agricultural activities across the surrounding region.
- Following closure of the whaling station in 1978, focus of Albany Port shifted to being a bulk products port, exporting mainly grain and woodchips. Other smaller trades are the export of silica sand and the import of fertiliser and fuel.
- The shoreline along Albany Townsite (segment 21.2) is heavily modified with shoreline hardening between Point Fredrick and Melville Point, Albany Waterfront Marina (constructed in 2011) and Albany port.
- The shoreline at Emu Point (segment 21.3) is heavily modified with a range of coastal protection structures constructed from the 1980s including revetments, groynes and detached breakwaters.
- The shoreline at Oyster Harbour has been modified with construction of Emu Point Boat Harbour (including dredged channel and basin) and Lower King Boat Ramp (including dredged basin).

Coastal Inundation History: Mid-latitude Depressions; Wave Dominated; Rare TCs

Albany has a digital water level record extending for over 36 years from 1987, with paper-tape records understood to have been collected from 1951, and possibly earlier. The most significant events in the Albany water level record were recorded as follows:

June 2022[2] – 1.8m CD (1.14m AHD)
Encroached on French and Bayview Drive Road in the northwest of the harbour

Ex TC Mangga, May 2020 - 1.75m CD (1.09m AHD)

- Severe storm associated with ex-TC Mangga, which combined with an upper-level trough and strong cold front, followed by a deep low through the SW. Generated water level elevations more than 0.5m above the predicted tide. At Albany, coincidence of peak surge and high tide occurred which resulted in the highest water level in the 33 year record up to 2020, marginally above the previous high in July 2007

Mid latitude storm/cold front, July 2007 – 1.72m CD (1.06m AHD)

- Deep Southern Ocean mid latitude depression and strong cold front which passed the southwest corner of WA with an intensity of 966hPa. The most significant water levels were recorded in closest proximity to the storm at Busselton and Albany, where the second highest water level at both sites was recorded. The peak of 1.72m at Albany occurred when the storm produced sustained westerly winds whilst position to the east This peak sits only slightly above a cluster of over 50 events above 1.6m CD recorded across the sites 33-year record.

The paper-tape record for Albany indicates three comparable events over 1951-1978, with 1.9m CD in May 1962, 1.8m CD in June 1964 and 2.0m CD in June 1965. Five events reaching 1.7m CD were recorded.

[2] Not included in the water level analysis used as the basis for inundation modelling for this study because available data up to 2020 were used for all sites.

Hazard: Existing Coastal Inundation Hazard Assessment Summary

Emu Point to Middleton Beach CHRMAP (2019)
Relatively small number of assets identified as being impacted by inundation.

- All beaches are immediately vulnerable to inundation and foreshore reserves progressively. However, these assets have a very high adaptive capacity to temporary inundation.
- At Ellen Cove the Three Anchors, adjacent toilets and Surf Lifesaving Club become highly vulnerable by 2070 to 2090
- Flinders Parade has a medium vulnerability by 2120.
- At Oyster Harbour the toilets near the boat pens become vulnerable to inundation by 2030 and increase in vulnerability to be extremely vulnerable by 2120. Medium-term (20-50 years) adaptation planning is required to address the inundation vulnerability of the Three Anchors, toilets and Surf Life Saving Club at Ellen Cove and toilets near the boat pens at Oyster Harbour Beach.

Draft Princess Royal Harbour CHRMAP (Cardno 2022)
The extent of inundation for the present day, 2047, 2072, and 2122 planning timeframe was approximated and mapped as part of the CHRMAP carried out in 2022. Inundation hazard levels were derived based on:

- Allowance for extreme water levels attributed to the astronomical tide and inverse barometer effects, based on an extreme value analysis of measured water level data between 1987 and present, within PRH.
- Allowance for wave set-up, which ranged between 0.1 m and 0.7 m, depending on incidental wave conditions and the slope and form of the nearshore seabed and shoreline.
- Allowance for freshwater runoff from adjacent catchments. This was assessed to be relatively minor, in the order of 0.02m, and highly localised to discharge locations.

The extent of inundation hazard was estimated based on LiDAR data collected in 2021. This study identified several areas of low-lying topography potentially subject to coastal inundation in the present day. Areas include Mount Elphinstone, Robinson, Little Grove, and Big Grove foreshores.

Hazard: Existing Controls

There are no strategic controls for coastal inundation mitigation in Albany. For areas with some potential exposure to coastal inundation, building floor levels have generally been developed 'organically', based on perceived threat associated with more frequent high-water levels, e.g., above the level of high tides along Princess Royal Harbour and Oyster Harbour foreshores.

Assets: Exposure of Coastal Assets to Inundation Impacts

Inundation Level (m AHD)	22.1 Albany West			22.2 Albany Townsite			22.3 Middleton-Emu Point			22.4 Albany East		
	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 / 0	2	0 / 0	0 / 0	2	0 / 0	0 / 1
1.1	1	0 / 0	0 / 1	0	0 / 0	0 / 0	2	0 / 0	0 / 0	5	0 / 0	0 / 1
1.2	1	0 / 0	0 / 1	0	0 / 0	0 / 0	2	0 / 0	0 / 0	12	0 / 0	0 / 1
1.3	6	0 / 0	0 / 1	0	0 / 0	0 / 0	4	0 / 0	0 / 0	13	0 / 0	0 / 1
1.4	8	0 / 0	0 / 1	0	0 / 0	0 / 0	5	0 / 0	0 / 0	16	0 / 0	0 / 1
1.5	16	0 / 0	0 / 2	0	0 / 0	0 / 0	7	0 / 0	0 / 0	19	0 / 0	0 / 1
1.6	29	0 / 0	0 / 2	0	0 / 0	0 / 0	34	0 / 0	0 / 1	24	0 / 0	0 / 1
1.7	38	0 / 0	0 / 2	0	0 / 0	0 / 0	37	0 / 0	0 / 2	25	0 / 0	0 / 1
1.8	50	0 / 0	0 / 2	0	0 / 0	0 / 0	41	0 / 0	0 / 2	28	0 / 0	0 / 1
1.9	61	0 / 0	0 / 3	0	0 / 0	0 / 0	44	0 / 0	0 / 3	32	0 / 0	0 / 1
2.0	79	0 / 0	0 / 3	1	0 / 0	1 / 0	58	0 / 0	0 / 3	37	0 / 0	0 / 1
2.1	91	0 / 0	0 / 3	1	0 / 0	1 / 0	67	0 / 0	0 / 3	41	0 / 0	0 / 1

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

22.1 Albany West

- Primary pathway through low lying foreshore seaward of Frenchman Bay Rd adjacent to the Old Albany Woolstores from the ~25yr ARI level, moving landward across Freshman Bay Rd at the 100yr ARI level (1.2m AHD).
- At 1.2m AHD the western side of the Harbour along Frenchman Bay Road is exposed to inundation impacts extending significantly landward in the Torndirrup area where an additional flow pathway is identified at Princess Avenue.
- To the south around Rushy Pont and Little Grove exposure is generally restricted to the low-lying wetland areas adjacent to the shoreline with some inundation of buildings in the Rushy Point area likely at the 1.2m AHD inundation level ~100yr ARI as well as around Stuarts Head (Sailing Club infrastructure) and the Panorama Caravan park just to the South
- Residential buildings are exposed from 1.1m AHD but fall below the AEIP analysis threshold until 1.6m AHD which is well above the 100yr ARI (1.2m AHD). Exposure of residential buildings continues to increase with inundation levels up

to the 2.1m AHD level considered for 100yr ARI+0.9m. No Commercial or industrial buildings identified as exposed in this area and 3km of road exposed by 2.1m AHD level.

22.2 Albany Townsite

- Primary pathway at the Harbour entrance near King Point with secondary pathways at the Albany waterfront marina and Point Frederick.
- Exposure generally low through this area for all inundation levels considered with the exception of the low lying wetland area adjacent to Princess Royal Drive around Point Frederick which becomes inundated at a water level of 1.2m (~100yr ARI) and the walling associated with the Albany Waterfront Marina.
- Negible exposure of buildings using AEIP analysis (1 house at 2m AHD) and 1km of major road exposed.

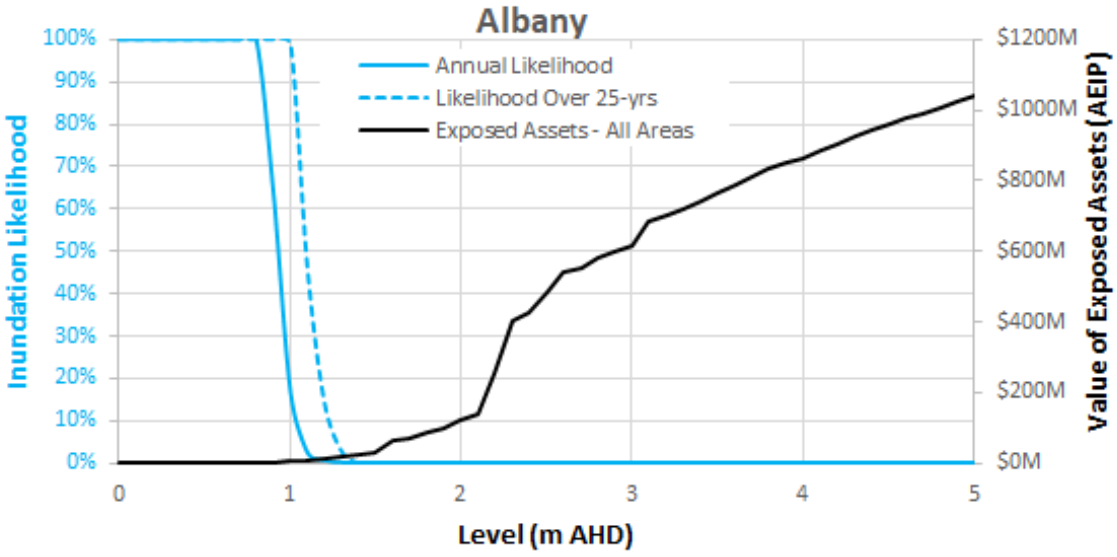
22.3 Middleton-Emu Point

- North of Emu point, a significant area of low lying land in the Collingwood Heights area moving towards Troode Street will be exposed to inundation impacts from 1.1m AHD, moving southwest landward of Gold Links Road towards the Middleton Beach commercial and residential area with widespread flooding of low lying wetlands at 2.1m AHD (~100yr ARI +0.9m)
- Residential buildings exposed from 1m AHD increasing to 34 by 1.6m inundation level and 67 at the 100yr ARI +0.9m. No commercial or industrial buildings flagged as exposed; 3km of road at inundation level of 2.1m AHD.

2.4 Albany East

- Primary pathway through opening at Emu point with inundation pathways at mouth of Kalgan River, through low-lying wetlands on western flanks of the East Kalgan foreshore and the area are White Island and Johnson Creek south of Nanarup Road.
- A further pathway is identified at the lower King River with inundation exposure of low lying land adjacent to the river banks at the 1.1m AHD level (~25yr ARI) and the residential and commercial areas along the eastern side of the Lower King area. The Esplanade road and housing in the Lower King are currently frequently flooded from the Oyster Harbour.
- AEIP analysis identified 5 residential buildings exposed to inundation at 25yr ARI, 12 buildings at the 100yr ARI and increasing to 41 buildings by 2.1m AHD (~100yr ARI +0.9m). No other buildings exposed; 1km of arterial road exposed at 2.1m AHD inundation level

Asset exposure commences around 1.5m AHD, with a substantial increase in exposure around 2.2m AHD. This represents a low present-day exposure to inundation hazard. However, comparison with estimated inundation likelihood indicates these thresholds would be reached by inundation differences of +0.2m and +0.9m respectively. This difference could be developed through choice of event scenarios or statistics, inclusion of wave processes, or allowance for sea level rise. This suggests a need for adaptation planning to consider inundation hazard for Albany.



Damage: Inundation Risk Ratings & Damage Assessment

Average Annual Damage		AEIP			
Area	WL ARI	1.1m AHD High	1.2m AHD Extreme	2.1m AHD Extreme+ 0.9m	All Water Levels
22.1: Albany West		$ 0K/yr	$ 1K/yr	$ 2K/yr	$ 2K/yr
22.2: Albany Townsite		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
22.3: Middleton-Emu Point		$ 18K/yr	$ 22K/yr	$ 25K/yr	$ 25K/yr
22.4: Albany East		$ 8K/yr	$ 11K/yr	$ 15K/yr	$ 15K/yr
Total Damage		**$ 25K/yr**	**$ 34K/yr**	**$ 41K/yr**	**$ 41K/yr**

- The majority of damage occurs from Middelton-Emu Point and Albany East segments, which is primarily due to residential building set on low lying rural land around Oyster Harbour.
- Both segments have damage from residential dwellings down to +1.0m AHD. These properties may have building floor levels above the ground level.
- An inlet at Emu Point results provides an inundation pathway, with arrival to Middleton Beach at +1.6m AHD. This area contributes to residual risk.

Planning Framework

Albany planning framework includes Albany Local Planning Strategy and Albany Local Planning Scheme No. 1. Albany has completed a CHRMAP for Emu Point to Middleton Beach and is working towards completion of a CHRMAP for Princess Royal Harbour.

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

- HC1 • Coastal inundation has been considered as a discrete hazard.
- HC2 • Albany Local Planning Scheme No. 1 identifies flood hazard is associated with 100-yr ARI flood level recurrence. Coastal inundation hazard identified in the Emu Point to Middleton Beach CHRMAP does not have an associated recurrence interval defined, or the factors contributing to it, although use of PSWL implies inclusion of wave setup.
- HC3 • Mapping of coastal inundation hazard is not available from publicly accessible documents.
- HC4 • The major tool for mitigation of coastal inundation or flood hazard is definition of minimum finished floor levels. Strategic actions for inundation mitigation are considered in the Emu Point to Middleton Beach CHRMAP but are not applicable for the geographic areas evaluated in detail.
- HC5 • Existing planning policy documents identify the need for adaptation to respond to coastal hazards, but do not explicitly define preferred pathways. Adaptation pathways described in the Emu Point to Middleton Beach CHRMAP do not relate to areas susceptible to coastal inundation hazard.
- HC6 • The planning framework does not acknowledge the role of emergency management for coastal inundation management.
- HC7 • The planning framework presently does not acknowledge flood proofing or ABCB guidance.
- HC8 • A special control area that considers coastal inundation has not been defined. This limits the capacity to obtain targeted funding to support strategic mitigation.

LIMITED Inundation Risk
at coast

Shire of Esperance

Focus

Adaptation Priority

Management at Foreshore

Targeted Mitigation

Actions

Management at Foreshore

Seashore Engineering


23. Shire of Esperance
Inset B
Bandy Creek
Bandy Creek Boat Harbour
23.3
Castletown
23.2
Chadwick
Tanker Jetty
The Esplanade
Esperance Bay
Esperance
Bow Park
23.1
Taylor St Jetty
Port of Esperance
Dempster Head
0 0.5 1 km
Legend
Assessment Areas
23.2 Chadwick-Castletown
23.3 Bandy Creek
23.1 Esperance Town
See Inset B
0 2 4 km
Inset A
Legend
+1.3m AHD: High
+1.4m AHD: Extreme
+2.3m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road
LOCATION
Shire of Esperance (see Inset A)

23. ESPERANCE

Site Overview:
The authors wish to acknowledge the Kepa Kurl Wudjari people as the native title holders of the lands and waters in and around the Shire of Esperance. The Shire is in the Goldfields-Esperance region of Western Australia, about 400 km south of the town of Kalgoorlie and about 720 km east-southeast of Perth. The Shire has a population of over 14,000 residents and stretches over 500km from the mouth of the Oldfield Inlet (west) to the beginning of the Great Australian Bight (beyond Israelite Bay). The Esperance townsite is located approximately midway along the coastline and is home to almost three-quarters of the Shire's population. Esperance is an important regional port and is becoming increasingly popular as an ecotourism destination, noted for its crystal-clear waters, white sand, annual whale migrations, fur seal and sea lion colonies and national parks.

Areas at risk from inundation:
Three inundation areas are considered in this assessment between Dempster Head in the west through to Bandy Creek in the East and including the Esperance town site which is situated at the western end of Esperance Bay 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	1.3m AHD High	1.4m AHD Extreme	2.3m AHD Extreme + 0.9m
23.1 Esperance Town		0km²	0km²	0.1km²
23.2 Chadwick-Castletown		0km²	0km²	0km²
23.3 Bandy Creek		0.1km²	0.1km²	0.2km²

Morphology: Sandy Beaches; Rocky Headland; Structural Modifications at Townsite

- The Shire of Esperance coast extends over 500km along the Southern Ocean, with a complex array of landforms and features. Steep cliffs and granite headlands define a mix of large and small bays, with white sandy beaches, creating stunning scenery. Much of the Shire's coastline is in reserves managed by DBCA.
- The main townsite is Esperance, which has a narrow foreshore and includes areas of low topography.
- Esperance Bay is characterised by complex bathymetry with the presence of numerous offshore islands and reefs. The shape of Esperance Bay suggests the dominance of southwest waves and the importance of sheltering provided by Dempster Head.
- Prevailing sediment transport is from west to east, which combined with increasing wave exposure, has resulted in coastal dune heights increasing from west to east.
- Lower-lying areas were occupied close to shore as the townsite grew and Port infrastructures built on the remnant dune system for much of the foreshore. This resulted in seawall installation to protect the foreshore road. Only the eastern part of Castletown beach presently retains a foreshore dune system.
- Seagrass meadows are the most common benthic habitat between 5 and 30 m water depth, however mixed sandy, seagrass and macroalgal communities are also common at similar depths.

Climate: Microtidal; Exposed, Open Ocean Coast; Wave Dominated

- Tidal range at Esperance is microtidal with a range of 1.4m CD (0.8m AHD) from LAT to HAT
- Esperance is in Wind Region A1 (AS1170.2), which means that extreme winds are caused by mid-latitude storms.
- Esperance region is exposed to an energetic wave climate, with frequent large Southern Ocean swell conditions. However, this is partly sheltered by the Recherche Archipelago, and with substantial sheltering against southwesterly waves provided by Dempster Head to the townsite. Exposure increases along the shoreline to the east.
- On the west side of Esperance Bay, the Port of Esperance is partly sheltered from swell by Charley and Cull Islands. The harbour basin is further protected by a 1200m long breakwater, which effectively extends wave sheltering to much of the town foreshore.

[1] Areas were calculated at 0.1m increments with HAT for Esperance taken at 0.8m AHD in this study.

Development Record: Regional Port & Tourism Hub

- The Kepa Kurl Wudjari people of the Nyungar nation are the traditional custodians of the Esperance coastal area.
- Kepa Kurl (pronouced 'Kep-pa Kurl') is the Wudjari name for 'Esperance'. 'Kepa' translates to water and 'kurl' to boomerang. Kepa Kurl means 'where the waters lie like boomerangs' and refers to the shape of the two bays closest to the Esperance townsite.
- Esperance originally developed as a regional supply point for vessels transiting along the southern coast of Australia, being the last significant point of shelter before South Australia. Development of the townsite included services for agricultural and marine activities, including whaling, sealing, and fishing.
- Development of jetties for both supply and export occurred in the late 1890s, with a deepwater jetty built in the 1930s and construction of major breakwaters at Esperance Port in the 1960s.
- The Port of Esperance is a vital trade hub, connecting key industries in regional WA with the rest of the world. Its major exports are iron ore, nickel, and grain.
- Development of the Port and Bandy Creek boat harbour, together with Tanker Jetty headland and a range of smaller groynes and seawalls, dissected the once continuous 10 km beach that ran from Wylie Head to Dempster Head.
- Ongoing Beach nourishment has been used for over 20 years for management of Esperance foreshore, including placement at Castletown Beach, downdrift of the foreshore seawall. Sedimentation at Bandy Creek boat harbour was biannually excavated and placed east of the harbour entrance. In 2021 a trial of back-passing the Bandy Creek boat harbour dredging sand to Castletown Beach was carried out. In 2022 the Shire started the installation of a 3.5km long buried pipeline between Bandy Creek Boat Harbour and Castletown beach to enable permanent dredging sand back-passing. The project is expected to be completed in 2024.
- Bandy Creek is the only watercourse flowing to Esperance Bay. When the boat harbour was constructed at the creek mouth, a weir was installed, to limit streamflow and sedimentation from the creek.

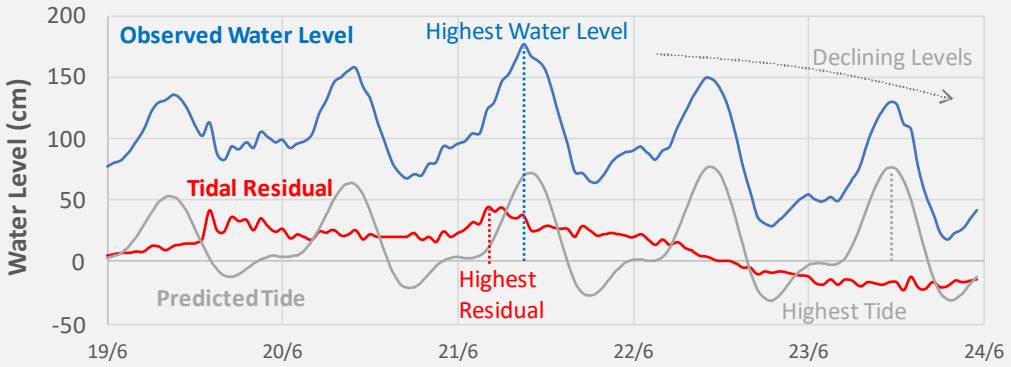
Coastal Inundation History:

The water level record at Esperance extends for over 35 years from 1987.

The three highest water level events recorded at Esperance are similar in character, with a sustained surge event caused by a severe mid-latitude storm, coinciding with a predicted high tide phase. 'Worst-case' timing if the surge arrived at the tidal peak could have contributed 0.05-0.15m additional elevation, with higher tide phases of 0.02-0.05m occurring within several days.

Extra-tropical storm, 17 May 2003 – 1.9m CD (1.3m AHD)
This was a strong extra-tropical storm (986 hPa) with a high northerly excursion and slow passage, which created a 2-day surge on the west coast, and a slightly smaller 4-day surge at Esperance (0.53m max). The surge peak was approximately 4 hours before the second highest predicted tide of the year, with the highest water level at the time of high tide.

Mid-latitude storm, 21 June 2009 – 1.89m CD (1.29m AHD)
An intense mid-latitude storm (971 hPa) caused a 4-day surge at Esperance (0.44m max). The surge peak was approximately 5 hours before the highest tide phase of the year, with the highest water level at the time of high tide, when surge had declined to 0.38m.



Extra-tropical storm, 23 May 2009 – 1.89m CD (1.29m AHD)
A severe extra-tropical storm (981 hPa) passed eastward around 38° latitude, causing a 4-day surge at Esperance (0.54m max). The surge peak was approximately 7 hours before the second highest predicted tide of the year, with the highest water level at the time of high tide.

Hazard: Existing Coastal Inundation Hazard Assessment Summary

CHRMAP (BMT JFA 2016)

- Three inundation hazard areas have been mapped along Esperance. They represent potential areas impacted by storm surge flooding processes, resulting in temporary inundation of the landscape. Coastal hazards were characterised for three time horizons (present day, year 2060 and year 2100) considering storm events and allowance for sea level rise based on coastal planning policy. No allowance for groundwater connectivity was made.
- The coastal inundation hazard areas identified in this study were flagged as being "partially mitigated" in places where protective structures exist. In particular, the presence of an adequately maintained seawall along the recently developed foreshore is considered to be an effective inundation control measure (within its design capacity) for up to 50 years horizon.

Three areas were identified as prone to inundation, including:

- Town Centre and Foreshore (south of Esperance Jetty landing),
- Tourist Nodes (along Norseman Rd and Goldfields Rd), and
- West Castletown (between Walmsley St and Westmacott St).

Hazard: Existing Controls

Coastal inundation control is informally provided by the presence of foreshore reserve and roads, running along the whole length of the townsite. The southern half of the roadway is protected by seawall following erosion, and the northern half retains a narrow strip of coastal dune.

- The foreshore reserve in the southern half of the town is between +2.3m to +3.6m AHD, rising to the north, with areas of the town to landward being below +2.6m AHD.
- The foreshore reserve in the northern half of Esperance is from +2.9m AHD near Esperance Caravan Park, up to +8m AHD near the eastern end of Castletown Quays.

Typically, the foreshore reserve is in the order of 60-80m. For some parts the coastal dune is narrow, which determines that its capacity to mitigate inundation hazard may be compromised by storm erosion or longer-term recession.

Assets: Exposure of Coastal Assets to Inundation Impacts

Inundation Level (m AHD)	23.1 Esperance Town			23.2 Chadwick-Castletown			23.3 Bandy Creek		
	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)
1.2	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.3	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.4	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.5	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.6	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.7	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.8	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.9	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
2.0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
2.1	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
2.2	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
2.3	19	0 / 0	0 / 1	0	0 / 0	0 / 0	0	0 / 0	0 / 0

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

23.1 Esperance Town

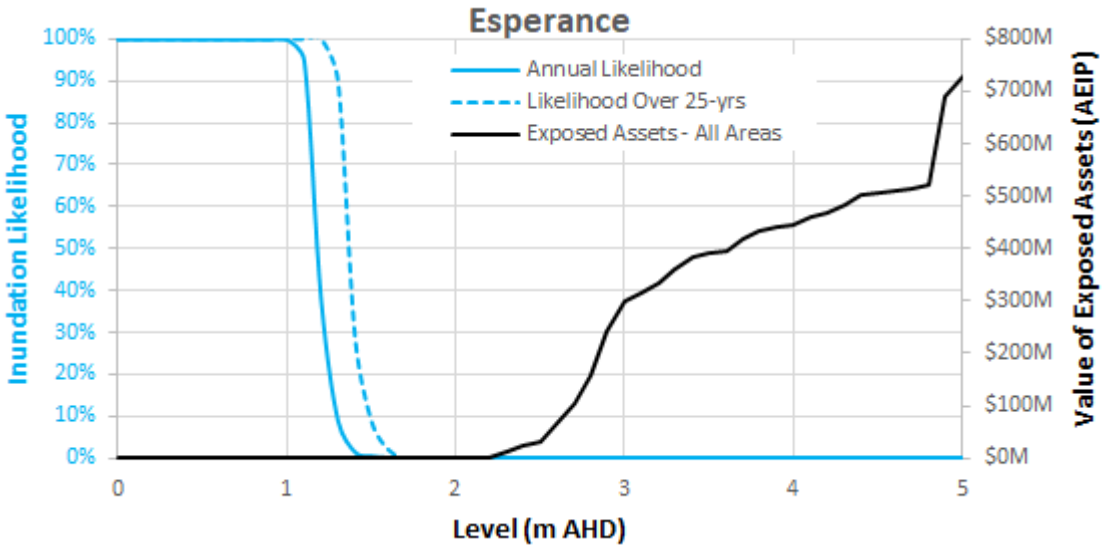
- Primary pathway at Taylor Street Jetty through Esperance Bow Park at inundation level of 1.4m and crossing the Esplanade at 2.3m AHD.
- No exposure of assets until 2.3m AHD inundation level (19 residential buildings and 1km of road)

23.2 Chadwick-Castletown – no exposure

23.3 Bandy Creek

- Primary pathway through Bandy Creek boat harbour. Low lying areas along either side of the channel within Bandy Creek inundated from 1.3m AHD
- No buildings exposed for water level scenarios considered

Substantial increase in asset exposure around 2.7m AHD indicates high senstivity to an inundation difference of around 1.3m. This difference could be developed through event scenarios or statistics, inclusion of wave processes, or allowance for sea level rise. The moderate foreshore reserve along Esperance coast means consideration of erosion and wave processes can substantially increase definition of hazard extent. Inclusion of both wave runup and sea level rise allowance in Esperance CHRMAP consequently resulted in a far greater perception of inundation hazard than this analysis. This discrepancy highlights the importance of both foreshore reserve management and adaptation planning for Esperance.



Damage: Inundation Risk Ratings & Damage Assessment

Average Annual Damage		AEIP			
Area	WL ARI	1.3m AHD High	1.4m AHD Extreme	2.3m AHD Extreme+ 0.9m	All Water Levels
23.1: Esperance Town		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
23.2: Chadwick-Castletown		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
23.3: Bandy Creek		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
Total Damage		**$ 0K/yr**	**$ 0K/yr**	**$ 0K/yr**	**$ 0K/yr**

Planning Framework

The Shire of Esperance planning framework includes Esperance Local Planning Strategy and Local Planning Scheme No. 24, which acknowledge the long-term potential for increasing coastal inundation hazard. The planning framework is supported by Esperance Coastal Hazard and Vulnerability Assessment and Esperance Coastal Hazard Adaptation Strategy (CHAS).

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

HC1	• Potential influence of waves during coastal inundation events was incorporated in coastal vulnerability assessment in the CHAS.
HC2	• Esperance Local Planning Scheme No. 24 maps identify a special control area including coastal inundation hazard based on a 500-yr ARI storm water level plus wave runup and 0.9m sea level rise.
HC3	• Mapping of coastal inundation hazard in Local Planning Scheme No. 24 maps corresponds to hazard evaluation in the CHAS, although hazard mapping is not explicitly connected.
HC4	• Inundation mitigation measures identified in Esperance CHAS are strategic in nature, including construction of a levee within the foreshore reserve, protection low-lying developed areas, and raising the dunes along the northern half of Esperance foreshore.
HC5	• Existing planning policy documents refer to Esperance CHAS for preferred coastal adaptation pathways.
HC6	• The planning framework does not acknowledge the role of emergency management for coastal inundation management. However, emergency management is acknowledged as part of the pathway for longer-term coastal adaptation in the CHAS.
HC7	• The planning framework presently does not acknowledge flood proofing or ABCB guidance. However, building controls are acknowledged as part of the pathway for longer-term coastal adaptation in the CHAS.
HC8	• A special control area for coastal hazards is identified in Esperance Local Planning Scheme No. 24, developed using hazard assessment outlined in the CHAS.