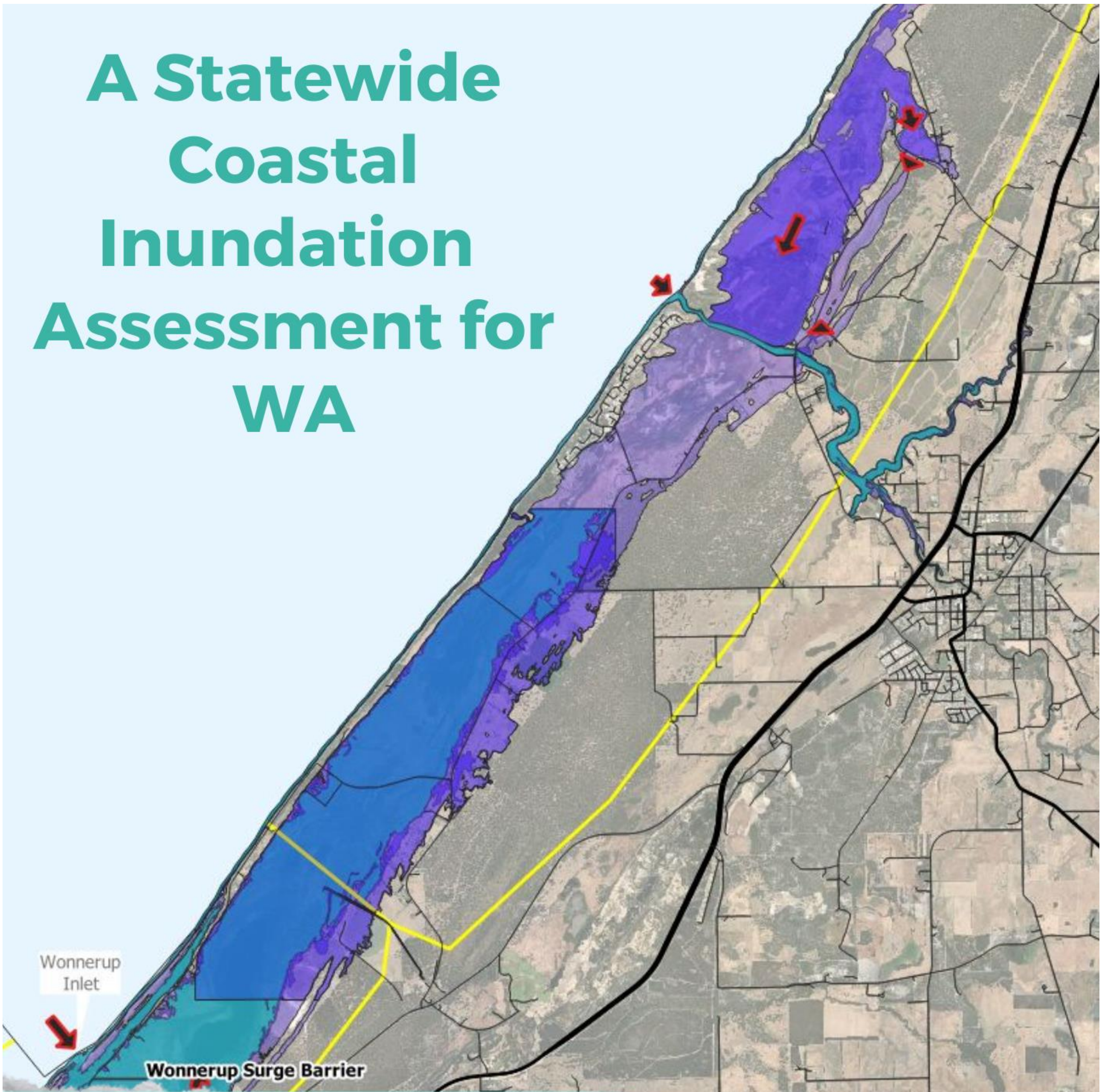
A Statewide Coastal Inundation Assessment for WA



APPENDIX A

SITE SUMMARIES

Seashore Engineering

Department of Planning, Lands and Heritage
Department of Transport
GOVERNMENT OF WESTERN AUSTRALIA

HIGH Inundation Risk
at Coast

Shire of Broome

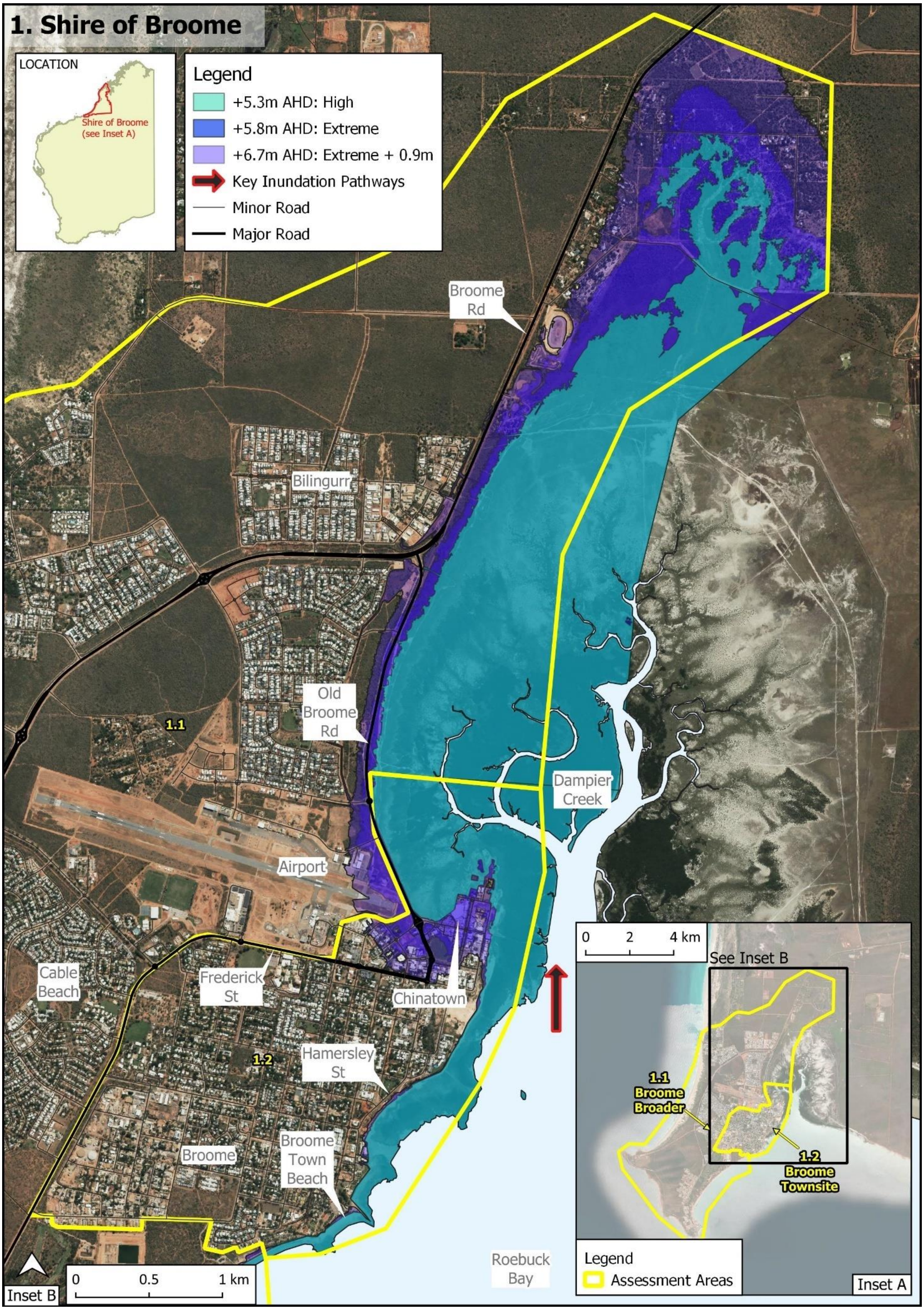
Focus

Adaptation Priority | Emergency Management

Actions

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

Seashore Engineering


1. Shire of Broome
LOCATION
Shire of Broome (see Inset A)
Legend
+5.3m AHD: High
+5.8m AHD: Extreme
+6.7m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road
Broome Rd
Bilingurr
Old Broome Rd
1.1
Dampier Creek
Airport
Cable Beach
Frederick St
Chinatown
1.2
Hamersley St
Broome
Broome Town Beach
Roebuck Bay
0
0.5
1 km
Inset B
0
2
4 km
See Inset B
1.1 Broome Broader
1.2 Broome Townsite
Legend
Assessment Areas
Inset A

1. BROOME

Site overview:

The authors wish to acknowledge the Yawuru people as the native title holders of the lands and waters in and around Rubibi (the town of Broome). The Shire of Broome has an extraordinary prehistoric presence preserved by isolation. It has fossilised tracks made by dinosaurs 130 million years ago, some of the oldest recorded Aboriginal art in Australia and some of the earliest recorded European visits. Broome has a population of 16,907 residents and is the largest town on Western Australia's tropical Kimberley coast, Broome is the service and trade hub of the region, servicing agricultural, pastoral, mining, oil and gas production, and conservation jobs across the Kimberley. It also serves as the gateway for tourists and visitors to the Kimberley, including international visitors by cruise ship and aircraft.

Areas at risk from inundation:

Two inundation exposure areas have been considered for Broome 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	5.3m AHD	5.8m AHD	6.7m AHD
	ARI	High	Extreme	Extreme + 0.9m
1.1 Broome Broader		0km²	1.5km²	3.1km²
1.2 Broome Town		0km²	0.2km²	0.4km²

Morphology: Coastal Peninsula with Sandy Beach, Rocky Cliffs; Floodplain

- Broome townsite is on Dampier Peninsula, on the northwest side of Roebuck Bay.
- Broome is located on a low-lying, gently undulating plain of red Pindan sandstone rising to roughly 3-8m AHD.
- The town is bordered by mangrove flats and tidal creeks to the east, eroded rocky outcrops to the south and a beach and dune system to the west.
- The low-lying areas around Dampier Creek (Chinatown) are particularly vulnerable to inundation.
- Mangrove cover in the nearshore areas of northern Town Beach and within Dampier Creek (Chinatown) play role to reducing wave height at the shoreline in extreme cyclonic events and may partly attenuate storm surge.
- A barrier dune system at Cable Beach, Entrance Point, Simpson's Beach and parts of Town Beach provides protection from coastal inundation to inland areas as does the natural rock structure of Gantheaume Cliffs.
- Broome's south coast is wave-cut platform, with exposed Pindan cliff sediments covered by more recent Quaternary sediments, with occasional outcrops of Broome Formation and Coastal Limestone.

Climate: Macrotidal; Tropical cyclones; Tide Dominated

- Macrotidal with range from LAT to HAT of over 10m.
- Broome is in the Wet-Dry tropics, with a Wet season (Nov-April) and a Dry season (May-Oct). 90% of region's annual rainfall occurs in the Wet season, with stormwater flooding, drainage issues and tropical cyclone events.
- Broome is in Wind Region C, experiencing occasional tropical cyclones. Since 1910, 22 cyclones have caused gale force winds (~1 every 4 years) but few of these cyclones have been intense or large scale, with the greatest damage caused by direct hit storms.
- During most of the year, Broome coast is subject to background westerly swell that originates in the southern Indian Ocean.

Development Record: Regional Service Centre; Tourist Hub

The Yawuru people as the native title holders of the lands and waters in and around Rubibi. Key present-day industries include tourism, fishing (including pearl fishing) and offshore resource projects.

- Commercial activities are mainly within Broome town centre area and Chinatown.
- Up to 60,000 visit Broome each year, with the coast a critical asset for both lifestyle and recreation focus.
- The recent Guwarri Town Beach Project, on the southeast edge of Broome, is part of the 'Old Broome Development Strategy' and it plays an important role in the recreation, culture and heritage of the area. It was designed to withstand Broome's seasonal cyclonic weather conditions and its associated Water Park was rebuilt to comply with Australian Safety Standards.

[1] Areas were calculated at 0.1m increments with HAT for Broome taken at 5.3m AHD in this study.

Coastal Inundation History: Rare Storm Events; Tidally Modulated

TC 1910 – Accounts of substantial wreckage of pearling luggers and very large amounts of seaweed wrack, coral wash-up, and strewn wreckage along the beaches in historic newspaper articles ("Disastrous hurricane at Broome", 1910).

TC 1956 – Storm of the century – Landfall 20km south of Broome.

TC Rosita, April 2000 – 10.574m CD (5.18m AHD)
Small, intense cyclone, landfall 35km south of Broome with max intensity of 930hPa with northerly wind gusts at Broome reaching 153km/h.

- Storm surge debris up to 1m along property fences reported at Thangoo homestead, ~3.5km inland likely due to greater wind set up from powerful winds acting across Roebuck Bay
- Limited inundation with impact of higher storm surge to south mitigated by sparse population and positioning of the few buildings on dune ridges.
- Surge occurred during a spring tide but WL did not exceed HAT due to relatively short-lived surge with spike in tidal residual observed over 4 hours;
- Impacts of TC Rosita in Broome included:
    - Buildings and structures were damaged due to wind, water and fallen trees.
    - Two homesteads were destroyed.
    - Disruption to power services, tourist industry impacts and road flooding.
    - Significant stock losses.

Hazard: Existing Coastal Inundation Hazard Assessment Summary

Cardno (2015)

- Coastal Vulnerability Study for Broome Town site
- For projected climate change and sea level rise scenarios, coastal hazard due to storm surge inundation is forecast to increase for the coastal areas of Broome, affecting existing developed areas.

Baird (CHRMAP 2017)

- Approximately 30km of coastline surrounding Broome townsite was assessed in the CHRMAP.
- Chinatown, Broome's commercial business hub, was identified as susceptible to inundation as a result of coastal inundation, due to its low-lying topography.
- Existing assets on Chinatown peninsula will not be inundated by a 1 in 100yr event at present day sea level.
- Under projected sea level rise, inundation risk increases rapidly and by 2070 the Chinatown area be subject to tidal flooding without storm conditions. A coastal protection structure would be required to prevent damage.

Hazard: Existing Controls

There are no formal controls to provide strategic mitigation of coastal inundation hazard. Existing seawalls and structures are property-level protection, installed to provide stabilisation of retained infill, or resist erosion following degradation of the coastal mangrove fringe.

Assets: Exposure of Coastal Assets to Inundation Impacts

Inundation Level (m AHD)	1.1 Broome Broader Residential Buildings	1.1 Broome Broader Commercial /Industrial Buildings	1.1 Broome Broader Roads Major/Arterial (km)	1.2 Broome Town Residential Buildings	1.2 Broome Town Commercial /Industrial Buildings	1.2 Broome Town Roads Major/ Arterial (km)
5.0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
5.1	0	0 / 0	0 / 0	0	0 / 0	0 / 0
5.2	0	0 / 0	0 / 0	2	0 / 0	0 / 0
5.3	0	0 / 0	0 / 0	7	0 / 0	0 / 0
5.4	1	0 / 0	1 / 0	8	0 / 0	0 / 0
5.5	1	0 / 0	1 / 0	8	0 / 0	0 / 0
5.6	1	0 / 0	1 / 0	11	9 / 0	0 / 1
5.7	2	0 / 0	1 / 0	13	17 / 0	0 / 1
5.8	5	0 / 0	1 / 0	18	20 / 0	0 / 2
5.9	10	0 / 0	1 / 0	34	22 / 0	0 / 2
6.0	14	0 / 0	2 / 0	36	26 / 0	0 / 2
6.1	16	0 / 0	2 / 0	42	28 / 0	0 / 2
6.2	21	0 / 0	2 / 0	48	31 / 0	0 / 2
6.3	33	0 / 0	2 / 0	52	33 / 0	0 / 2
6.4	38	0 / 0	2 / 0	54	37 / 0	0 / 2
6.5	39	0 / 0	2 / 0	54	40 / 0	0 / 2
6.6	45	0 / 0	2 / 0	62	40 / 0	0 / 2
6.7	51	0 / 0	2 / 0	65	43 / 0	0 / 3

Other Assets Exposed:

1.1 & 1.2

High: N/A
Extreme: 1 airport
Extreme +0.9m: 1 airport

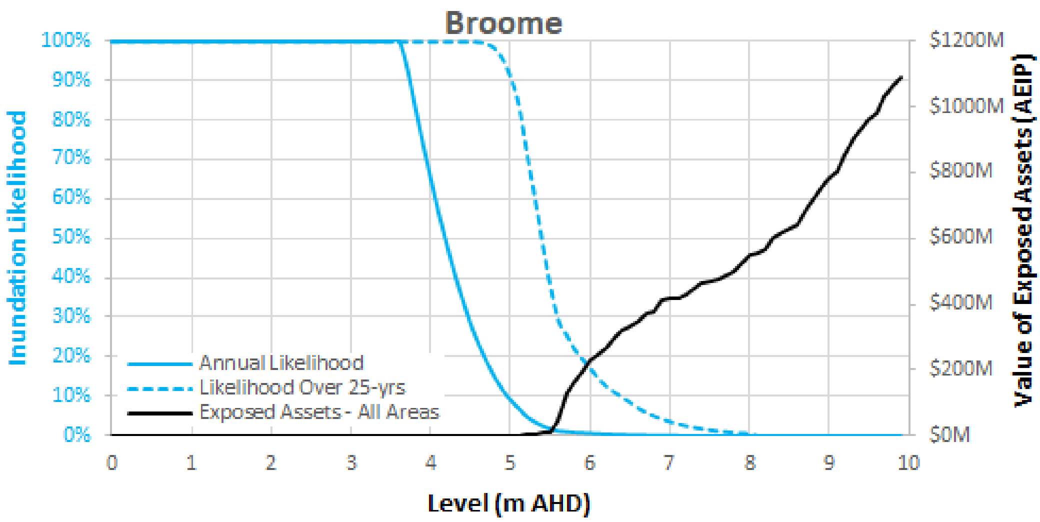
High (~25yr ARI)
Extreme (~100yr ARI)
Extreme +0.9m

1.1 Broome Broader
Exposure of residential buildings becomes significant from ~6.2m AHD (21 buildings) increasing to 51 buildings exposed at an inundation level of 6.7m AHD (Extreme water level scenario +0.9m).
No exposure of commerical or industrial buildings and limited exposure of roads from 5.4m AHD (1km increasing to 2km at 6m).

1.2 Broome Town
Exposure is initially predicted at a water level of approximately 5.2m AHD for Broome townsite increasing to 18 residential buildings and 20 commerical buildings at a water level of 5.8m AHD which corresponds to an extreme water level scenario (~100yr ARI) for the townsite.

No roads are exposed to inundation impacts until ~ 5.6m AHD (1km) with exposure of 3km of major roads upwards of 6.7m AHD. No industrial buildings are exposured to inundation impacts.

Comparison of exposed assets and estimated inundation likelihood across both exposure areas indicates assets identified via AEIP are affected by inundation above 5.6m AHD. This represents a low annual hazard (1-2%/year), with approximately 40% likelihood of exceedance of a 25 year period. Potential for extreme surge events due to tropical cyclones gives a high residual risk, although there is low confidence in the estimation of extreme event likelihoods above 6m AHD. The assessment excludes wave driven inundation however the additional influence of waves is likely to be limited, due to the low-lying areas of Broome being within Roebuck Bay.



Damage: Inundation Risk Ratings

Average Annual Damage Area	WL ARI	AEIP 5.3m AHD High	 5.8m AHD Extreme	 6.7m AHD Extreme+ 0.9m	 All Water Levels
1.1: Broome Broader		$ 0K/yr	$ 2K/yr	$ 28K/yr	$ 94K/yr
1.2: Broome Town		$ 1K/yr	$ 29K/yr	$ 286K/yr	$ 598K/yr
Total Damage		**$ 1K/yr**	**$ 31K/yr**	**$ 314K/yr**	**$ 692K/yr**

Total Damage for Broome is summarised using the AEIP approach which indicates relatively low damage for the Broome Broader area ($94k/yr) while average annual damage for the townsite is much higher, almost $600k/yr considering all inundation scenarios, reflecting the high density of commercial buildings exposed around the Chinatown area. Exposure of residential buildings at the townsite occurs from the high water level scenario (~25yr ARI) level upward with a significant number of commercial buildings included from the extreme scenario (~100yr ARI) associated with Broome Airport and Chinatown precinct.

Planning Framework

The Shire of Broome Local Planning Scheme No 6 (LPS6), identifies special control areas for coastal hazards (erosion & inundation) and for local flooding. The scheme was established in 2015 and has been supported by a Local Planning Strategy and a CHRMAP. Evaluation of Broome's planning framework against Inundation Management Health Check criteria gave:

- HC1 — Interactions between coastal inundation, wave impacts and runoff flooding risks are identified. Drainage scour has not been assessed but is associated with several problem points.
- HC2 — The basis for mapping of coastal hazard is reported independently in Broome CVS, using a 500yr ARI inundation level, with 0.9m SLR.
- HC3 — LPS6 is structured to support updating risk maps. These follow from the study used to develop them, but hazards are combined (i.e., require interpretation for selection of mitigation options).
- HC4 — LPS6 outlines minimum fill and floor levels. Options for strategic or property level protection have been considered through the CHRMAP process.
- HC5 — Adaptation is through revision and update of the policy (i.e., tied to development).
- HC6 — The planning framework acknowledges the role of emergency management but does not explicitly identify policy interactions.
- HC7 — Special control areas for flooding (SCA4) and coastal hazards (SCA9) do not have provisions related to building requirements or ABCB flood proofing guidance.
- HC8 — A special control area for coastal hazards has been defined, supporting capacity to obtain targeted financial recompense to support strategic interventions or adaptation.

HIGH Inundation Risk
at Coast

Town of Port Hedland

Focus

Active Management

Targeted Mitigation

Emergency Management

Actions

Management at Foreshore

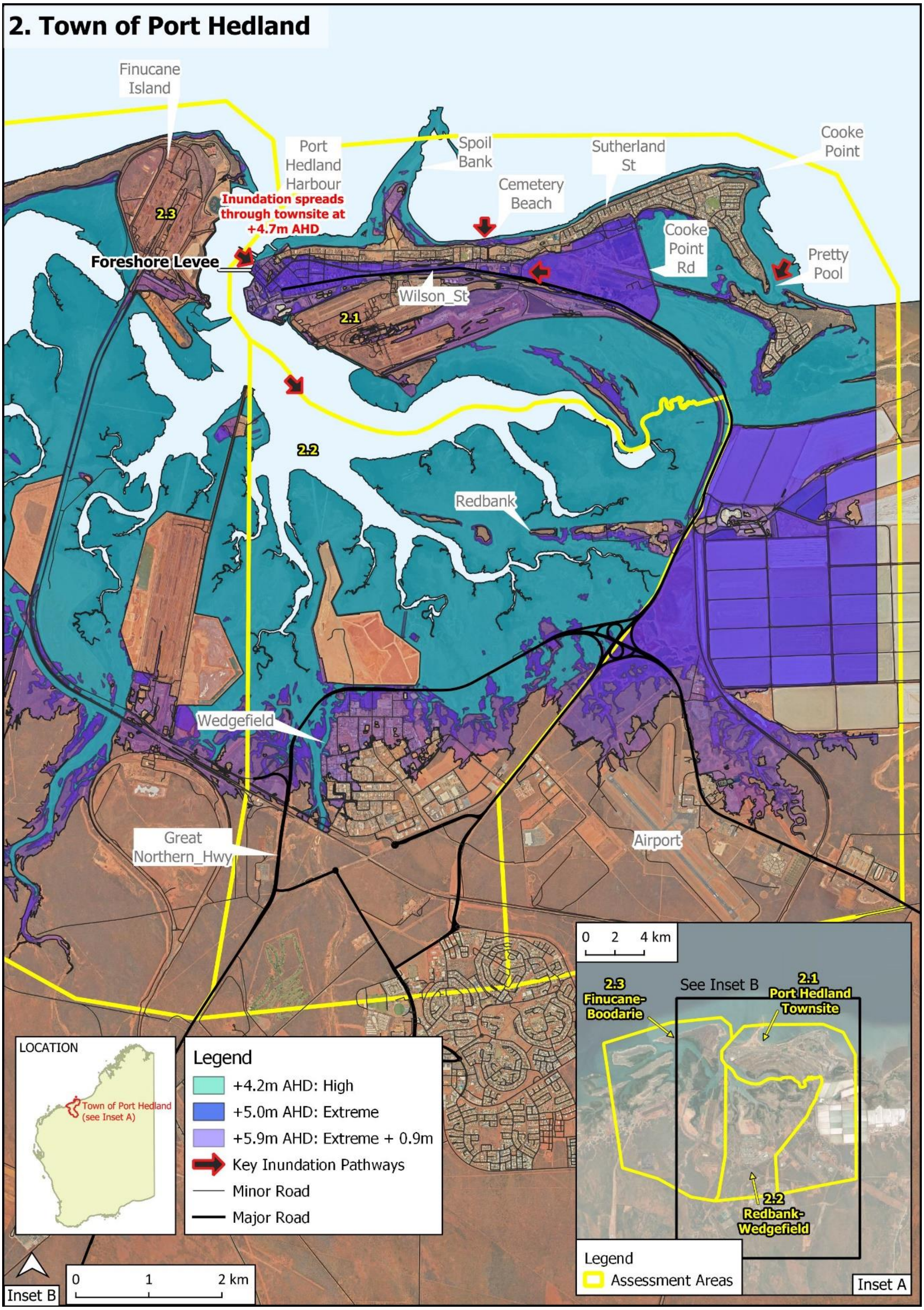
WL Review (CHRMAP)

Damage Based Assessment

WL Sensitivity Review

Emergency Plan

Seashore Engineering


2. Town of Port Hedland
Finucane Island
Port Hedland Harbour
Spoil Bank
Sutherland St
Cooke Point
Cemetery Beach
Inundation spreads through townsite at +4.7m AHD
Foreshore Levee
Cooke Point Rd
Pretty Pool
Wilson_St
2.3
2.1
2.2
Redbank
Wedgefield
Great Northern_Hwy
Airport
LOCATION
Town of Port Hedland (see Inset A)
Legend
+4.2m AHD: High
+5.0m AHD: Extreme
+5.9m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road
Inset B
0 1 2 km
0 2 4 km
2.3 Finucane-Boodarie
See Inset B
2.1 Port Hedland Townsite
2.2 Redbank-Wedgefield
Legend
Assessment Areas
Inset A

2. PORT HEDLAND

Site Overview:

The authors wish to acknowledge the Kariyarra, Ngarla, and Nyamal people as the native title holders of the lands and waters in and around the Town of Port Hedland. The Town of Port Hedland (known by the Kariyarra people as Marapikurrinya) is a local government area in Pilbara region of WA containing twin settlements of Port Hedland and South Hedland, with the industrial precinct of Wedgefield. The Town has a population of more than 15,984 people from diverse cultural backgrounds that are employed across a wide range of sectors. Port Hedland is one of the most important mining regions in Australia with an estimated gross regional product of $8.75 billion and continues to be a vital part of the Pilbara region's arts and culture, ecology, tourism and regional services hub.

Areas at risk from inundation:

Three inundation exposure areas have been considered for the Port Hedland 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	4.2m AHD High	5m AHD Extreme	5.9m AHD Extreme + 0.9m
2.1 Port Hedland Townsite		0.7km²	13.8km²	19.5km²
2.2 Redbank-Wedgefield		1.4km²	3.1km²	5.6km²
2.3 Finucane-Boodarie		3.6km²	8km²	14.2km²

Morphology: Macrotidal; Coastal Floodplain; Low Relief

- Port Hedland Townsite is located adjacent to a large tidal network not connected to a major river. The Kariyarra word for Hedland is Marapikurrinya which refers to the hand like formation of the tidal creeks coming off the harbour (mara - hand, pikurri - pointing straight and nya - a place name marker).
- Naturally occurring harbour, formed from a very large tidal inlet behind a break along rocky coastline, with a limited catchment area.
- Part of the wider east Pilbara macrotidal coastal floodplain, characterised by extensive low-lying tidal systems, landward of coastal ridges.

Climate: Macrotidal; Tropical Storms; Semi-arid

- Macrotidal with a range of 7.6m from HAT to LAT.
- Port Hedland is located in the centre of Wind Region D (AS1170.2). It is subject to the most frequent, intense tropical cyclones affecting Australia's mainland.
- Typically, 2-3 tropical cyclones pass close each year causing severe winds; capacity to cause coastal inundation is highly influenced by timing relative to astronomic tides, and the storm pathway.
- Tropical cyclones passing southward 40-100km to the west of Port Hedland have generated the highest observed storm surges.

Development Record: Regional Centre; Port; Resources Hub

- Port Hedland is situated on the traditional lands of the Kariyarra people.
- Major regional center in Western Australia's Pilbara Region playing a pivotal role in WA economy, particularly for mining exports, through the busiest shipping port in Oceania.
- Initial European development of Port Hedland occurred on a narrow coastal strip of comparatively high land. However, this was a very limited area, separated from the hinterland by low swampy areas, subject to tidal inundation.
- Initial evaluation of inundation hazard, combining a 10' high surge with highest astronomic tide (~7m AHD), was used to create the Kelly Line, delineating minimum land levels suitable for habitation. Consequently, Port Hedland developed as two distinct sites: 'old' Port Hedland on the coastal strip and South Hedland located inland. Subsequent growth of the town, including causeway construction and reclamation works, has progressively seen the two areas of development draw closer together, although they are still separated by a strip of low-lying intertidal land; much of the foreshore has been hardened in recent years with construction of seawalls at West End, Sutherland Street and Goode Street.
- The Spoilbank Marina project to alleviate demand on existing boat launching facilities and improve access and safety for recreational boaters is in its final stages of construction[2]. The marina is in a previously undeveloped area and will utilize minimum FFLs for development of new land.

[1] Areas were calculated at 0.1m increments with HAT for Port Hedland taken at 3.7m AHD in this study.

[2] As at October, 2023 with expected completion date in late 2024.

Coastal Inundation History: Rare Tropical Cyclones; Tidally Modulated

Port Hedland has a moderate length of in situ coastal inundation measurements with tide gauge records for over 35 years from 1984. This record provides limited capacity for extreme event inundation hazard assessment with statistical or modelling methods required to integrate the combined effects of large surges & tides. Two of the largest coastal inundation events since establishment of the townsite occurred in 1939 & 1942. Photographs & anecdotal evidence used to estimate flood level as 9.8m CD (5.9m AHD). In recent times the most significant water level events for Port Hedland were:

TC Veronica, March 2019 – 8.26m CD (4.37m AHD)

- Highwater levels observed during TC Veronica were concurrent with the annual tidal peak.
- Peak water level was just below the level required to initiate inundation of substantial low-lying area around CBD and residential areas (~4.7m AHD) which occurs when a low section of walled foreshore near Richardson Street is overtopped.
- Very high levels of property damage due to rainfall and some wind damage. Extended industry disruption with 'code reds' issued by DFES, including coastal inundation threat, requiring people to shelter for 39 hours in Port Hedland.
- Contributed to almost $2 billion of revenue losses for shipping industry due to nearly 5-day closure of port operations. Cemetery Beach Park and a low section of Sutherland Street inundated; rubbish, debris and large rocks scattered along the road near the port; BHP reported water damage to some buildings at Port Nelson rail and port facilities.

TC Vance, March 1999 – 7.87m CD (3.98m AHD)

- Category 5 cyclone before landfall in the south part of Exmouth Gulf with wind speeds up to 267km/hr at Exmouth.
- Occurred coincident with annual peak tides in the northwest which combined with a sustained regional positive surge signal to generate elevated water levels across the northwest shelf.
- Port Hedland foreshore experienced dune deflation and erosion but no direct damage due to inundation.

TC Glenda, March 2006 - 7.77m CD (3.88m AHD)

- One of the strongest tropical cyclones to occur off the WA coast on record, it reached a peak of 910hPa when it was 350km North of Port Hedland.
- Peak surge of 1m at Port Hedland observed as it passed offshore at low tide.
- More modest regional positive surge over the high spring tide was still able to produce a water level above HAT at Port Hedland.

Hazard: Existing Coastal Inundation Hazard Assessment Summary

BOM (1991)

- BOM tropical cyclone surge modelling, recreating historic events to create a surge distribution statistically combined with tidal distribution. Subsequent evolutions of model incorporated track shifting and wave setup and corresponded to a reduction of the 100yr ARI level from around 7.0m AHD to around 6.0m AHD.

GEMS (2000)

- Storm Surge Study was one of earliest assessments in Australia to provide probabilistic assessment with full spatial coverage across the townsite; range of tolerable inundation thresholds for different assets; intended for town planning; a key first step in movement towards probability-based thresholds for tropical cyclones in WA coastal planning.
- Identified a narrow, low buffer to inundation at Richardson Street, which will be overwhelmed at approximately 4.7m AHD.

LandCorp (2010)

- Coastal Vulnerability Assessment as part of the Pilbara Cities program (LandCorp). High resolution ALS topography and Monte Carlo methods used to generate synthetic storm database simulated over 10,000 years. The approach followed methods developed in Queensland. Present-day 100yr ARI level was estimated at 5.0m AHD.
- Key outcome of progressively refined coastal inundation techniques has been lowering of levels for given recurrence. This has been partly obscured by increase in recurrence criteria for coastal planning, from 100yr ARI to 500yr ARI.

CHRMAP (GHD 2019)

- This assessment provides a representation of the areas within the townsite expected to be vulnerable to coastal flooding based on coastal modelling for the timeframes of 2010, 2060 and 2120. The existing Port Hedland town centre within the West End (vulnerable to coastal flooding in all events)

Hazard: Existing Controls

- Formal controls to provide strategic mitigation of coastal inundation hazard are planning-based, including land-use zoning and finished floor levels, with well-established emergency management plans.
- The townsite's stormwater drainage network was identified as contributing to recovery after potential inundation events, with drainage pumps between Gilbert St and Wilson St.
- Foreshore walling near Richardson Street restricts inundation below 4.7m AHD.

Assets: Exposure of Coastal Assets to Inundation Impacts

Inundation Level (m AHD)	2.1 Port Hedland Townsite			2.2 Redbank-Wedgefield			2.3 Finucane-Boodarie		
	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)
3.2	0	0 / 0	0 / 0	0	0 / 0	4 / 0	0	0 / 0	0 / 0
3.3	0	0 / 0	0 / 0	0	0 / 0	4 / 0	0	0 / 0	0 / 0
3.4	0	0 / 0	1 / 0	0	0 / 0	4 / 0	0	0 / 0	0 / 0
3.5	0	0 / 0	1 / 0	0	0 / 0	5 / 0	0	0 / 0	0 / 0
3.6	0	0 / 0	0 / 0	0	0 / 0	5 / 0	0	0 / 0	0 / 0
3.7	0	0 / 0	0 / 0	0	0 / 0	5 / 0	0	0 / 0	0 / 0
3.8	0	0 / 0	1 / 0	0	0 / 0	6 / 0	0	0 / 0	0 / 0
3.9	0	0 / 0	1 / 0	0	0 / 0	6 / 0	0	0 / 0	0 / 0
4.0	0	0 / 0	1 / 0	1	0 / 0	7 / 0	0	0 / 0	0 / 0
4.1	0	0 / 0	1 / 0	1	0 / 0	8 / 0	0	0 / 0	0 / 0
4.2	0	0 / 0	1 / 0	1	0 / 0	9 / 0	0	0 / 0	0 / 0
4.3	0	0 / 0	2 / 0	1	0 / 0	9 / 0	0	0 / 0	0 / 0
4.4	6	0 / 0	4 / 0	2	0 / 0	10 / 0	0	0 / 0	0 / 0
4.5	14	0 / 0	5 / 0	2	0 / 0	11 / 0	0	0 / 0	0 / 0
4.6	24	0 / 0	6 / 0	2	0 / 1	11 / 0	0	0 / 0	0 / 0
4.7	68	11 / 41	9 / 0	3	0 / 1	12 / 0	0	0 / 0	0 / 0
4.8	73	14 / 42	9 / 0	3	0 / 1	13 / 0	0	0 / 0	0 / 0
4.9	81	17 / 42	11 / 0	3	0 / 1	13 / 0	0	0 / 0	0 / 0
5.0	85	20 / 42	13 / 0	3	0 / 1	13 / 0	0	0 / 0	0 / 0
5.1	90	23 / 42	14 / 0	13	0 / 2	14 / 0	0	0 / 0	0 / 0
5.2	93	26 / 42	14 / 0	17	0 / 9	14 / 0	0	0 / 0	0 / 0
5.3	100	31 / 42	14 / 0	28	0 / 12	14 / 0	0	0 / 0	0 / 0
5.4	110	35 / 42	15 / 0	39	0 / 14	15 / 0	0	0 / 0	0 / 0
5.5	122	40 / 42	15 / 0	52	0 / 16	15 / 0	0	0 / 0	0 / 0
5.6	135	42 / 42	15 / 1	61	0 / 26	15 / 0	0	0 / 0	0 / 0
5.7	143	44 / 42	15 / 1	76	0 / 31	16 / 0	0	0 / 0	0 / 0
5.8	154	45 / 42	16 / 1	81	0 / 34	16 / 0	0	0 / 0	0 / 0
5.9	162	46 / 42	16 / 1	95	0 / 36	16 / 0	0	0 / 0	0 / 0

High
Extreme
Extreme +0.9m

Other Assets Exposed:

2.1 Townsite:
High (~25yr ARI): 1 waste water treatement plant
Extreme (~100yr): 1 airport; 5km rail; 1 waste water treatment plant;
1 waste management site
Extreme +0.9M: 1 airport; 45 km railway track; 1 waste water treatment plant;
1 waste management site; 2 ha agricultural area

2.2 Redbank-Wedgefield
High (~25yr ARI): 1km railway track
Extreme (~100yr ARI): 6km railway track
Extreme +0.9M : 12km railway track; 1 waste management site

2.3 Finucaine-Boodarie*
High (~25yr ARI) : 20kms railway track
Extreme (~100yr ARI): 35kms railway track
Extreme +0.9m: 57kms railway track

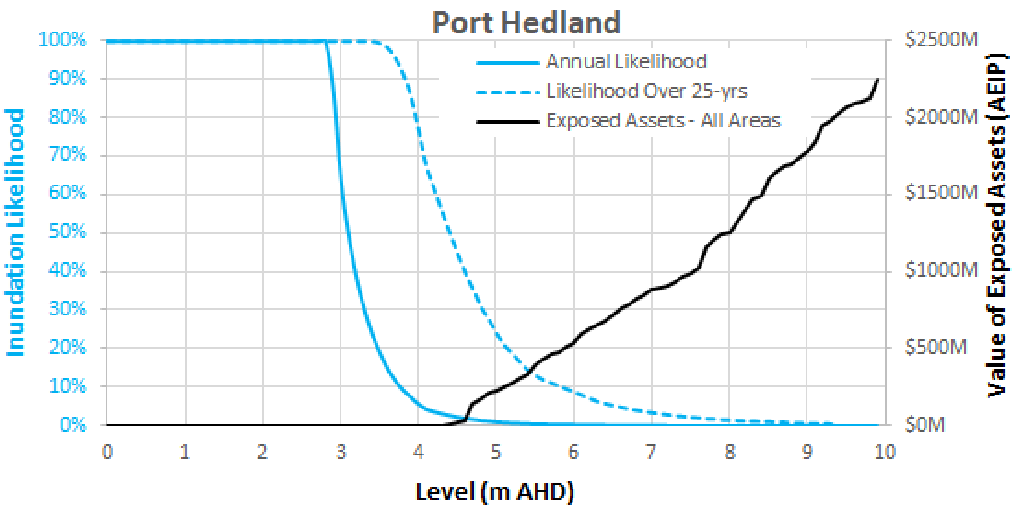
*No residential, commercial, industrial buildings or roads are exposed in area 2.3

2.1 Townsite
Mnimal exposure up to high water level scenario (1km of road); from 4.5m AHD residential buildings become exposed, increasing from 14 to 85 buildings at 5m AHD (extreme water level scenario) and 162 buildings at 5.9m AHD. A high number of commerical and industrial buildings are exposed from 4.7m (11 and 41 respectively) increasing to 20 commerical buildings and 42 industrial buildings at the extreme water level (5m AHD) and 46 commercial and 42 industrial buildings exposed at the extreme water level scenario +0.9m. A relatively large area of major road is also exposed from 4.2m with 16km flagged as exposed by the AEIP tool at the extreme +0.90m water level scenario (5.9m AHD).

2.2 Redbank-Wedgefield

Low exposure of residential buildings until the extreme water level scenario at ~5m AHD (3 residences exposed) increasing to 95 residences at 5.9m AHD (extreme +0.9m). No commercial buildings were identified as exposed but a relatively high number of buildings in this area are subject to impacts from 5.3m (12 buildings) increasing to 36 industrial buildings by 5.9m AHD. 4km of major road is exposed to inundation impacts at the present time increasing to 9km under the high water level scenario and up to 16km of major road for a water level of 5.9m.

Comparison of exposed assets and estimated inundation likelihood indicates assets identified via AEIP are affected by inundation above 4.5m AHD. This represents a low annual hazard (1-2%/year), with approximately 40% likelihood of exceedance of a 25 year period. Potential for extreme surge events due to tropical cyclones, and significant assets in the elevation range 5-7m AHD gives a high residual risk, although there is limited confidence in the estimation of extreme event likelihoods above 5.5m AHD. The asessment excludes wave driven inundation however the additional influence of waves is likely to be limited, due to flow pathways into low-lying areas of Port Hedland being inside Port Hedland Harbour.



Damage: Inundation Risk Ratings

Average Annual Damage Area	WL ARI	AEIP 4.2m AHD High	 5m AHD Extreme	 5.9m AHD Extreme+ 0.9m	 All WL
2.1: Port Hedland Townsite		$ 0K/yr	$ 91K/yr	$ 458K/yr	$ 1.5M/yr
2.2: Redbank-Wedgefield		$ 1K/yr	$ 9K/yr	$ 40K/yr	$ 445K/yr
2.3: Finucane-Boodarie		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
Total Damage		**$ 1K/yr**	**$ 100K/yr**	**$ 498K/yr**	**$ 2.0M/yr**

- Damage estimation is sensitive to the inundation scenario selected.
- Most of the 'average annual damage' occurs for buildings in 5.0-6.0 m AHD, including the area exposed to potential inundation within West End (Port Hedland townsite) and smaller impact at Redbank.
- Almost all average annual damage is associated with 'residual' events, above the 'extreme' water level scenario (~100yr ARI), typically above levels used for strategic or property level protection. This indicates sensitivity to very large storm events. However, there is low confidence in correctly estimating the frequency of events of this magnitude.
- Port Hedland is potentially subject to high inundation hazard, affecting a mix of commercial, residential, and industrial buildings.
- The analysis approach confirms previously identified inundation pathways, through Port Hedland Harbour, towards the south side of Port Hedland Townsite, potentially cutting off road access before affecting residents. The lowest road level of 4.2m AHD is inundated by a high-water level event (~25yr ARI), with opportunity for traffic interruption at lower levels due to wave action.

Planning Framework

Town of Port Hedland Local Planning Scheme LPS No.7 identifies a special control area for coastal hazards, with maps provided in Local Planning Policy LPP/07. The scheme is supported by a Coastal Vulnerability Study and a CHRMAP. Evaluation of Port Hedland's planning framework against Inundation Management Health Check criteria gave:

HC1	• Coastal inundation hazard has been identified by modelling, incorporating wave set-up. Modelling was provided for both inundation and rainfall runoff.
HC2	• The basis for mapping of inundation hazard is reported independently in Port Hedland CVS, using a 100yr ARI inundation level, with 0.9m SLR.
HC3	• LPP/07 is structured to support updating risk maps.
HC4	• LPP/07 outlines minimum floor levels, based on 0.5m above the 100-yr ARI inundation level.
HC5	• Adaptation is through revision and update of the policy (i.e., tied to development).
HC6	• The planning framework does not acknowledge the role of emergency management, which is active for Port Hedland through DFES.
HC7	• The special control area for coastal hazards (SCA7) does not have provisions related to building requirements or ABCB flood proofing guidance.
HC8	• A special control area for coastal hazards has been defined, supporting capacity to obtain targeted financial recompense to support strategic interventions or adaptation.

LIMITED Inundation Risk
at Coast

City of Karratha

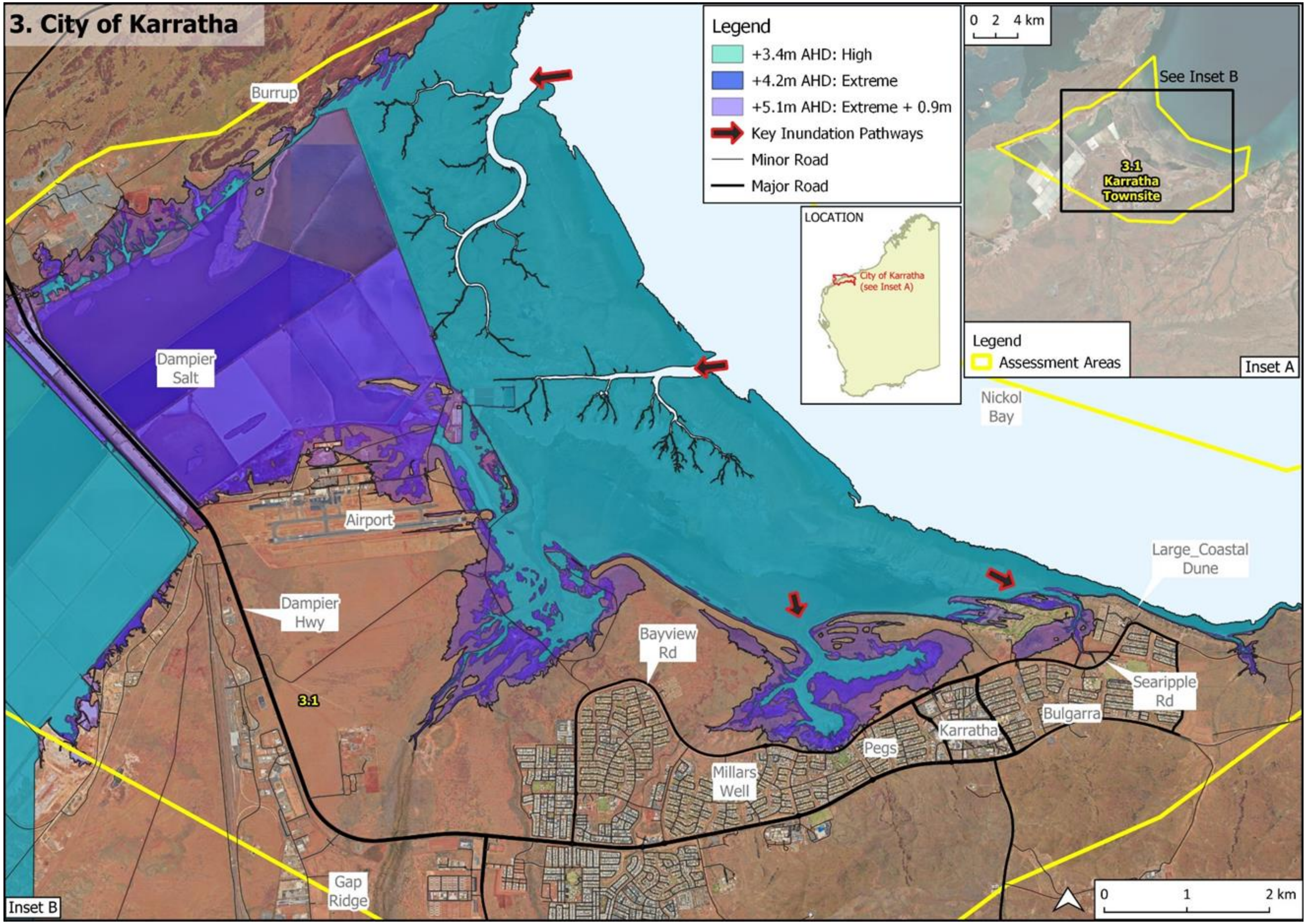
Focus

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

Actions

Management at Foreshore | Targeted Mitigation | Emergency Plan

Seashore Engineering


3. City of Karratha
Legend
+3.4m AHD: High
+4.2m AHD: Extreme
+5.1m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road
LOCATION
City of Karratha (see Inset A)
0 2 4 km
See Inset B
3.1 Karratha Townsite
Legend
Assessment Areas
Inset A
Burrup
Dampier Salt
Airport
Dampier Hwy
Nickol Bay
Large_Coastal Dune
Bayview Rd
Searipple Rd
Bulgarra
Karratha
Pegs
Millars Well
3.1
Gap Ridge
0 1 2 km
Inset B

3. KARRATHA

Site Overview:

The authors wish to acknowledge the Ngarluma people as the native title holders of the lands and waters in and around of the City of Karratha. Karratha is the largest city in Pilbara region, adjoining the port of Dampier. It was established in 1968 to accommodate iron ore processing and from the 1980s, this expanded to include oil and gas operations and processing of North West Shelf Venture. In 2021/22 it is estimated the region produced an estimated $16.281 billion from iron ore and oil and gas mining and processing through four industrial ports and a growing industrial sector supported by 232ha[1] of developed industrial land. The City has a vibrant and diverse population of 22,716 people, which is supported by a high level of amenity and services. The mining sector is the largest employer with 4,755 local jobs.

Areas at risk from inundation:

One inundation exposure area was considered for the Karratha 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	3.4m AHD High	4.2m AHD Extreme	5.1m AHD Extreme + 0.9m
3.1 Karratha Townsite		1.8km²	15.3km²	23.8km²

Morphology: Tidal Flats; Fringing Mangrove; Rock Control; Coastal Dunes

- Four coast types; tidal flats to the west and north of the townsite (Western Nickol Bay & West Karratha), and a rocky shore on the eastern edge of the Townsite (East Karratha). Further east is Nickol River Delta
- Fringing mangrove swamps and tidal flats are prevalent, particularly at the mouth of the Nickol River
- East Karratha is landward of a high, largely continuous coastal dune with underlying rock that provides protection to inundation. This is breached by an ephemeral creek channel to the east, at Mulataga.
- Karratha coast is located within the lee of Burrup Peninsula, with partial shelter provided by Legendre, Hally and Delambre Islands. Rock formations along the Burrup and east of Nickol River effectively confine Nickol Bay, which has a shallow seabed gradient, declining to the northeast. The bay alignment has been theorized to provide greater susceptibility to storms from the northeast.
- Sediment supply to Karratha coast is apparently limited, with Nickol River providing a relatively low input due to its small catchment.
- Structural modification along Karratha coast is mainly due to Dampier Salt works, including extensive bunding across the western flats and dredging of a bitterns channel. A small boat ramp with a rock armour breakwater is located east of Karratha.

Climate: Macrotidal; Tropical Storms

- Hot summers with occasional heavy rain and mild winters with intermittent rainfall.
- Tides are semi diurnal, with a highest astronomic tide of 5.10m CD. The tidal sequence is strongly affected by monthly spring-neap cycle and a bi-annual cycle, with peaks near March and September equinoxes.
- Afternoon west-north-westerly sea breezes blow regularly throughout the year, producing choppy seas along the coast. Local variations in wave direction are apparent in Dampier Archipelago and Nickol Bay. Wind velocity influences both the height and energy of waves. Along Dampier coastline, wind generated waves are variable, but generally small being less than 1.3m in height. Although higher waves can be generated in Nickol Bay, the shallow seabed limits waves reaching Karratha shore during normal tidal conditions, with higher waves possible during extreme storms.
- Karratha is located in Wind Region D (AS1170.2), being subject to severe tropical cyclones.
- Storm events are accompanied by larger wave activity with the strongest winds and highest waves generally occurring during tropical cyclones.
- Cyclone season runs from December to April peaking in February. Since 1910, 48 cyclones caused wind gusts exceeding 90km/h in Karratha region – on average this is about one every two years.

[1] Areas were calculated at 0.1m increments with HAT for Karratha taken at 3m AHD in this study.

Development Record: Resource Service centre

- Karratha is situated on the traditional lands of the Ngarluma people.
- Karratha is located at the south-central end of an area of relatively flat land adjacent to Nickol Bay, settled since the 1860s.
- The present-day townsite was established in 1968 in response to growth of the iron-ore industry and need for a new regional centre due to shortage of land in Dampier.
- Karratha's economic base includes iron ore operations, sea-salt mining, ammonia export operations, liquified natural gas facilities and ammonia / ammonium nitrate production. Karratha provides a retail hub for surrounding towns of Dampier, Wickham and Roebourne.
- Karratha has grown rapidly in recent years, mainly to accommodate an expanding resources sector. Developments have expanded the townsite west with Bayton West development and proposed Madigan and Gap Ridge North developments. South of the main townsite is Karratha Light Industrial Area (LIA) and northwest is Karratha Airport. Significant infrastructure includes Dampier-Paraburdoo railway line, Dampier Hwy and North West Coastal Hwy.

Coastal Inundation History: Rare Storm Events; Tidally Modulated

There are no measurements of water level from Karratha.

- Water level observations from King Bay (Dampier) tide gauge are available from 1982 onwards, except 2010-2013. The gauge is managed by Pilbara Ports Authority. Water level processes evident in the record include tides, storm surges (e.g. tropical cyclones), seasonal and inter-annual mean sea level variations. Water levels are shown to Chart Datum (CD), which is 2.77m below AHD (Australian Height Datum, which approximately matches mean sea level).
- Inundation hazard for Karratha has been inferred from the Dampier record, using a factor based on Canute-3 modelling.
- There has been relatively low occurrence of high-water level events associated with storm surge in the record, with only two events exceeding the highest astronomical tide of +5.10m CD (2.43m AHD). These occurred during severe cyclones which tracked west of Karratha and coincided with high tides, with +5.81m CD (3.04m AHD) recorded on 21/03/1999 in TC Vance and on 30/03/2006 in TC Glenda.
- Coincidence of storms with low or neap tides restricted water levels to below HAT during passage of TC Orson (1989), TC Bobby (1995) and TC Olivia (1996), which tracked within 150km west of Dampier with central pressure less than 940hPa.
- Overall, the townsite has experienced high water levels but relatively low impacts due to protection from the coastal dune and its underlying rock.

Hazard: Summary of Previous Coastal Inundation Hazard Assessments

Karratha Coastal Vulnerability Study (JDA 2012)

- Potential for coastal inundation is a significant constraint for future expansion and development of Karratha.
- Karratha townsite is landward of a high, largely continuous coastal dune that provides some protection to inundation. With sea level rise, the tidal flat fronting the dune system will progressively experience inundation, with formation of a tidal creek network and likely formation of a coastal lagoon behind the coastal dune. As sea level increases, erosion of the coastal dune will likely occur, potentially decreasing the protection it provides.

Karratha Flood Study (GEMS 2012)

- The 100-yr ARI flood extent indicates that a significant proportion of the townsite is subject to some degree of inundation.
- Nickol River tidal flats are impacted by storm surge.
- Most of the existing townsite is above the 100yr ARI flood level.
- Areas which may be affected are properties along Balmoral Rd between Gawthorne Drive and Warambie Rd, which are subject to some inundation as a result of storm surge.

Hazard: Existing Controls

Strategic mitigation of coastal inundation hazard is informally provided by the coastal road (Bayview Rd and Searipple Rd). This is not a formal protective work but was developed by constructing a roadway that matches the minimum land development level identified in development approval policy, through Karratha Town Planning Scheme and Karratha Coastal Hazard Risk Management and Adaptation Plan.
Existing mitigation of coastal inundation risk is primarily through property level protection, allowing land fill or stilt housing for properties up to 2.0m below the mapped 500-yr ARI storm surge inundation level (approximately 5.8-7.8m AHD range). These levels include wave effects and are consequently higher than inundation risk levels.

Assets: Exposure of Coastal Assets to Inundation Impacts

Inundation Level (m AHD)	3.1 Karratha Townsite Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)
2.5	0	0 / 1	0 / 0
2.6	0	0 / 1	0 / 0
2.7	0	0 / 1	0 / 0
2.8	0	0 / 1	0 / 0
2.9	0	0 / 1	0 / 0
3.0	0	0 / 1	0 / 0
3.1	0	0 / 1	0 / 0
3.2	0	0 / 1	0 / 0
3.3	0	0 / 1	0 / 0
3.4	0	0 / 2	0 / 0
3.5	0	0 / 2	0 / 0
3.6	0	0 / 2	0 / 0
3.7	0	0 / 2	0 / 0
3.8	0	0 / 2	0 / 0
3.9	0	0 / 2	0 / 0
4.0	0	0 / 2	0 / 0
4.1	0	0 / 2	0 / 0
4.2	0	0 / 2	0 / 0
4.3	0	0 / 2	0 / 0
4.4	0	0 / 2	0 / 1
4.5	0	0 / 2	0 / 1
4.6	0	0 / 2	0 / 1
4.7	0	0 / 2	7 / 1
4.8	0	0 / 2	7 / 1
4.9	0	0 / 2	7 / 1
5.0	0	0 / 2	7 / 1
5.1	0	0 / 2	7 / 1

Other Assets Exposed:
High: 1 airport
Extreme: 1 airport
Extreme +0.9m: 1 airport

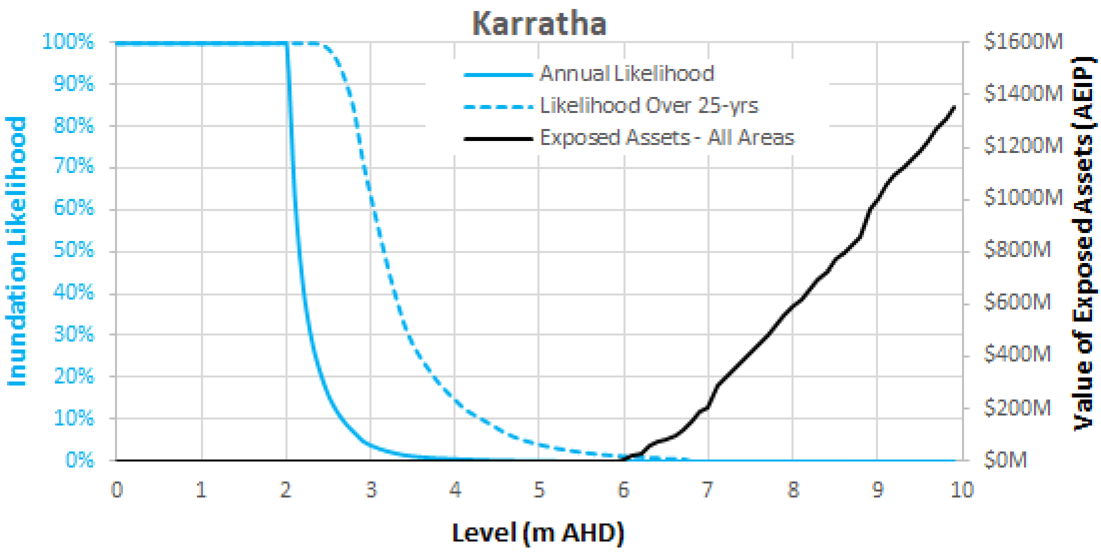
3.1 Karratha Townsite

- Karratha Airport and Dampier Salt are key assets exposed to inundation within the townsite area considered. However, they have been excluded from the Damage Assessment reported following a ground truthing exercise that confirmed no buildings were impacted at relevant levels.
- Exposure is initially predicted at a water level of approximately 2.5m AHD (1 Industrial building) increasing to 2 industrial buildings at a water level of 3.4m AHD which corresponds to an extreme water level scenario for the townsite.
- No roads are exposed to inundation impacts until ~ 4.4m AHD (1km Arterial) with exposure of 7km of major roads upwards of 4.7m AHD. AEIP analysis undertaken does not identify any residential buildings with likely exposure to inundation impacts for Karratha townsite.
- First exposure of residential buildings to inundation occurs at 6.0m AHD, well above the estimated extreme water level +0.9m

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

Comparison of exposed assets and estimated inundation likelihood indicates most assets identified via AEIP are above levels likely to be affected by coastal inundation. This assessment excludes Dampier Salt assets identified at lower land levels within the facility boundaries. Other assets are typically above 6m AHD, which which has less than 2% likelihood of exceedance of a 25 year period, although there is low confidence in the estimation of extreme event likelihoods above 4.5m AHD.

The assessment excludes wave driven inundation. There is some potential for additional influence of wave action associated with storms from the northeast, as Nickol Bay is open to this direction.



Damage: Inundation Risk Ratings

Average Annual Damage		AEIP			
	WL	3.4m AHD	4.2m AHD	5.1m AHD	All Water Levels
Area	ARI	High	Extreme	Extreme+ 0.9m	
3.1: Karratha Townsite		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 5K/yr
Total Damage		**$ 0K/yr**	**$ 0K/yr**	**$ 0K/yr**	**$ 5K/yr**

Inundation likelihood estimates derived from tide gauge observations are substantially below modelled inundation levels. Assets in Karratha Townsite have low exposure to inundation because townsite planning considered inundation hazard using the Karratha Kelly Line (10’ above HAT, which is ~5.7m AHD). However, recent land development has extended seaward, using an estimated 100yr ARI level, and allowing pre-development fill. This approach potentially defers significant risk until projected sea level rise occurs but increases residual risk and raises the importance of land retention structures.

Planning Framework

The City of Karratha has a Local Planning Policy for Storm Surge Risk (DP19), covering areas identified as susceptible to coastal inundation within a 1 in 500-year ARI coastal inundation event. The policy was published in 2016. Evaluation of Karratha’s planning framework against the Inundation Management Health Check criteria gave:

HC1
- Interactions between coastal inundation and runoff flooding risks are identified.

HC2
- Allowance for sea level rise is not clearly reported, and there is no requirement or provisions for adaptation.

HC3
- DP19 is structured to support updating risk maps, but these are independent from the study used to develop them (i.e. provided without a basis for derivation).

HC4
- DP19 allows strategic risk mitigation, including storm surge barriers and evacuation planning, at the direction of the City.
- DP19 allows property level protection through fill up to 0.5m (conditionally to 1.0m) and use of stilt housing to provide a finished floor level above the 500-year ARI level.

HC5
- Adaptation is through revision and update of the policy (i.e. tied to development).

HC6
- The planning framework acknowledges the role of emergency management, but does not explicitly identify policy interactions.

HC7
- A selection of building requirements are outlined, but are not related to ABCB guidance.

HC8
- A special control area has not been defined, with a whole of townsite policy applied due to widespread runoff flooding risk. Lack of an SCA limits capacity to obtain targeted financial recompense to support strategic interventions or adaptation.

HIGH Inundation Risk
at Coast

Shire of Ashburton: Onslow

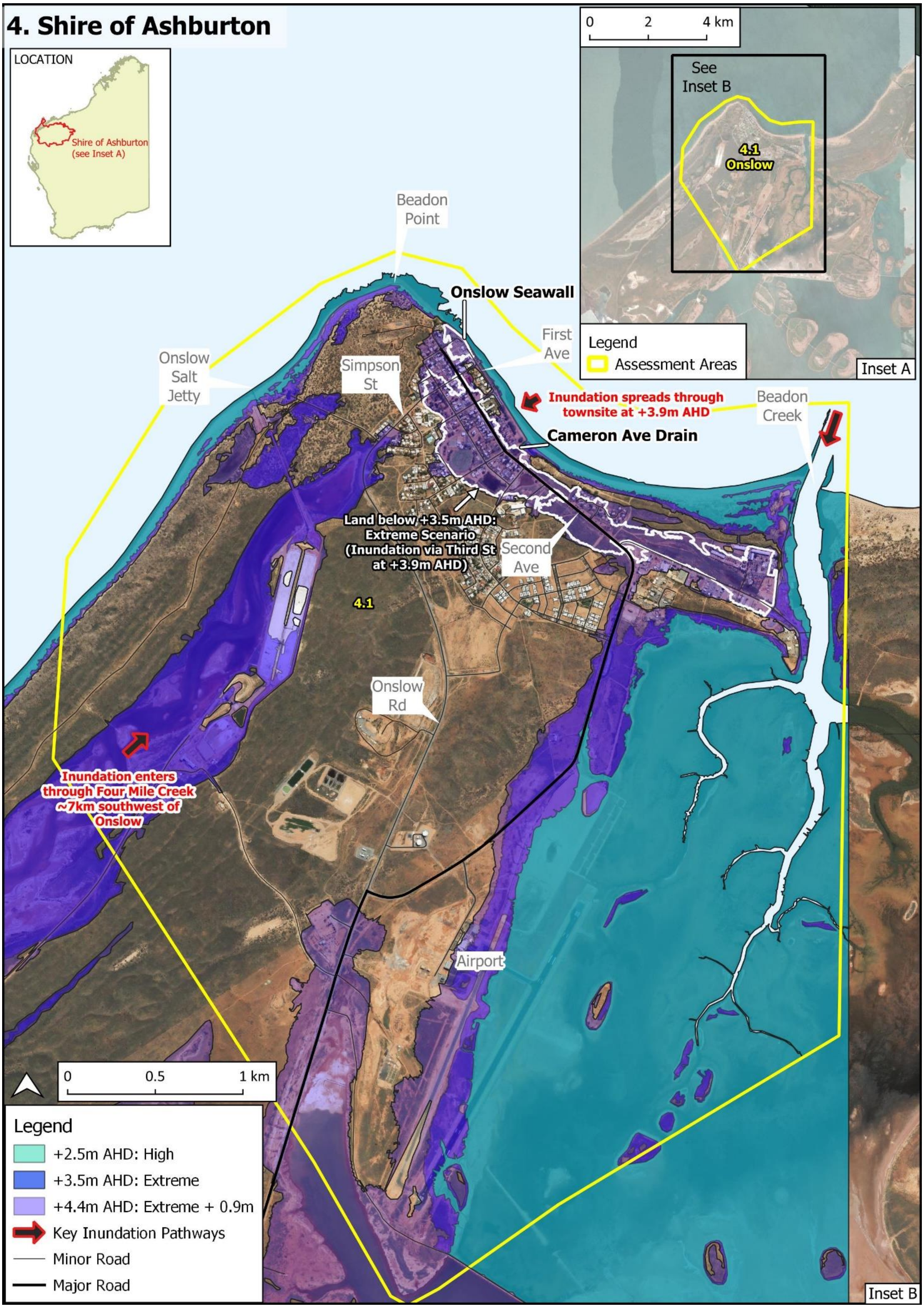
Focus

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

Actions

- Targeted Mitigation
- WL Review (CHRMAP)
- Damage Based Assessment
- WL Sensitivity Review
- Emergency Plan

Seashore Engineering


4. Shire of Ashburton
LOCATION
Shire of Ashburton (see Inset A)
0 2 4 km
See Inset B
4.1 Onslow
Legend
Assessment Areas
Inset A
Beadon Point
Onslow Seawall
First Ave
Onslow Salt Jetty
Simpson St
Inundation spreads through townsite at +3.9m AHD
Beadon Creek
Cameron Ave Drain
Land below +3.5m AHD: Extreme Scenario (Inundation via Third St at +3.9m AHD)
Second Ave
4.1
Onslow Rd
Inundation enters through Four Mile Creek ~7km southwest of Onslow
Airport
0 0.5 1 km
Legend
+2.5m AHD: High
+3.5m AHD: Extreme
+4.4m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road
Inset B

4. ASHBURTON

Site overview:

The authors wish to acknowledge the Thalanyii people (Onslow) which is the coastal region pertaining to this study but also the Eastern Curuma people (Tom Price), the Kurrama people (Pannawonica) and the Yinhawangka people (Paraburdoo) as the native title holders of the lands and waters of the Ashburton region. The Shire provides a diverse range of economic activities adding $38.57 billion to WA's Gross Domestic Product (GDP) in 2021/22 and boasts a unique lifestyle with national parks, pristine coastline, and a diverse population and cultural history. Onslow, the coastal town, is located near the mouth of the Ashburton River and is the oldest town in Ashburton region and is the focus of this study. The total population of the Shire is over 7,300 with almost 900 residents in the coastal town of Onslow.

Areas at risk from inundation:

One inundation exposure area has been assessed for the Shire of Ashburton encompassing Onslow townsite, adjacent to Beadon Bay. 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	2.5m AHD High	3.5m AHD Extreme	4.4m AHD Extreme + 0.9m
4.1 Onslow		1.3km^2	7.3km^2	17.9km^2

Morphology: Mesotidal; Coastal Floodplain; Low Relief; Tide Dominated

- Onslow Townsite is located between the Ashburton and Cane Rivers, to the west and east respectively and is dominated by an expansive area of mudflats which act as an overflow pathway for the river systems during extreme runoff events.
- The townsite is located on a coastal floodplain, which is eastward and downdrift from a major sediment supply from Ashburton River. This ongoing, albeit irregular sediment supply is sufficient to facilitate vertical growth of coastal dunes, with occasional severe storm erosion and dune over wash.
- Relict coastal limestone features controlling shoreline position have fixed position and capacity, providing a generally narrow coastal dune structure, with any excess material bypassing the low-lying coastal headlands. A wider dune field of up to 800m width has developed on Sunset Beach (also called Onslow Back Beach).

Climate: Mesotidal; Tropical cyclones

- 3m tidal range (LAT to HAT)
- Arid sub-tropical climate. Prevailing conditions are very dry, enhancing the influence of thermally driven winds, particularly southerly breezes, which are frequent year-round.
- Onslow is located in Wind Region D (AS1170.2), being subject to severe tropical cyclones. Typically, the region experiences occasional (1-2 per year) tropical cyclones during summer months as well as the northern tail of mid-latitude storms in winter, including tropical-temperate interaction from northwest cloud bands.
- The most extreme onshore winds generally occur from the northeast as TCs pass either to the north or just prior to landfall to the west (e.g., TC Vance in March 1999).

Development Record: Regional Service Hub

Onslow is situated on the traditional lands of the Thalanyji people.

- The colonial townsite was established in 1883 supporting pastoral activities and resource exploration, with maritime facilities located inside the Ashburton River Mouth. Subsequently, it has supported fishing and salt production and more recently mining and oil and gas activities.
- Facilities were relocated from 1894 following repeated flooding of the area and movement of the river channel with the townsite itself moved in the 1920s. Onslow Sea jetty was destroyed during initial construction in 1897, rebuilt and then later abandoned in favour of a jetty at Beadon Point.
- The existing Onslow townsite is located between Beadon Point and Beadon Creek. Dredging works and construction of a training wall in 1968 provided a mooring area for fishing vessels in the creek entrance, managed by DoT and intermittently dredged, with recent expansion to develop a supply base for offshore resource operations.
- Concern regarding risk of the frontal dune breaching from inundation resulted in construction of a seawall in front of the town. This structure was damaged during TC Vance in 1999, with an upgraded 900 m seawall completed in 2002. This

[1] Areas were calculated at 0.1m increments with HAT for Ashburton taken at 1.6m AHD in this study.

structure protects against dune breaching that previously occurred but does not completely block inundation hazard, with parts of the town below the estimated 100-year storm water level.

- Due to the development of the ANSIA and Chevron's Wheatstone Project (circa 2013-2015), the town is primarily a service town highly dependent on the commodities market with a large proportion of transient residents.
- The Beadon Creek entrance channel was deepened, and the training wall has been upgraded in 2019.

Coastal Inundation History: Rare Storm Events; Tidally Modulated

Water level data is available for over 35 years (1985-2022) recorded at Beadon Creek tide gauge. Water levels substantially above HAT of 3.0 m CD (1.51m AHD) only occur during exceptional events, requiring a TC to pass near and to the west of Onslow. Significant extreme water levels have caused flooding in the Onslow townsite but were not captured in the water level record:

1880: "cyclone passed near Yammadery Creek, between Onslow and Fortescue River, tidal surge of 8m above tidal mark"

1934: "The storm surge inundated the town and drove sea water through buildings."

1956: "A near record tide pounded the jetty. A roadway and aboriginal camp were washed away. Buildings were awash and frail buildings blown away."

1958: "Two cyclones crossed near Onslow within two weeks. The second cyclone on the 15th caused extensive damage. Half the jetty was washed away, and the storm surge broke through the foreshore wall flooding the town." "Ocean broke through the foreshore and ran through the town."

1961: "A severe cyclone made landfall at Onslow. Hurricane force winds demolished several buildings and storm surge inundated the town with 1.8 meters water." "2.5 m storm surge above highest tide to be expected in the area." "Reliable eyewitness estimate. Submerged cars and refrigerators on a jetty normally 0.9 m above highest tide level."

In recent times the most significant water level events for Onslow townsite were:

TC Vance, March 1999 - 5.1m CD (3.6 m AHD)

- Tracked 80km West of Onslow with wind speeds of 182 km/hr recorded at Onslow amongst highest gusts ever recorded on mainland.
- Water level of 8.09m CD reached around Locker Point, west of Onslow.
- Occurred coincident with annual peak tides, combined with a sustained regional positive surge signal to generate elevated water levels across the whole NW Shelf.
- Surveyed wrack lines at Onslow estimate WL of 5.1m above CD which correspond to roughly 2m above HAT.
- Sustained property damage with storm surge causing widespread inundation to the lower parts of town and waves severely damaged the seawall which projects the townsite.

TC Tina, Jan 1990 - 3.4m CD (1.9 m AHD)

- Tracked within 150-200km of Onslow and moved rapidly down the coast. Resulted in highest recorded tide gauge level recognizing. Flooding of low-lying foreshore adjacent to Second Avenue.

TC Veronica, March 2019 - 3.3m CD (1.9 m AHD)

- A water level of 3.31m CD occurred during annual maximum tide and relatively small forerunner surge when TC Veronica was positioned offshore of Port Hedland. A slightly lower water level of 3.15m CD occurred during TC Olwyn (Mar 2015), which generated the highest surge since baseline but combined with a lower tide than TC Veronica.

Hazard: Existing Coastal Inundation Hazard Assessment Summary

Overview of previous study findings:

- Inundation through either coastal flooding or runoff is a significant hazard across the low-lying floodplains within the Shire of Ashburton.
- Major events have previously caused extensive damage to coastal infrastructure and on two occasions caused relocation of Onslow townsite.
- Potential severity of extreme events is suggested by wrack lines up to +8m AHD that have been dated at 700 years before present.

CHRMAP (Cardno 2017)

- Identified the threat of steadily rising sea levels, combined with storm events - ocean storm surge, local rainfall-induced flooding and rising water tables will affect the viability of low-lying areas of the town.

Hazard: Existing Controls

Strategic management of coastal inundation hazard for Onslow has been strongly tied to interactions between coastal hazards and runoff flooding. Construction of a seawall to limit inundation hazard was tied to installation of a drainage network, pumping system, and evacuation warning system.

Use of property level protection has been incorporated into town planning, with a tension between achieving minimum floor levels for habitation and maximum fill levels to ensure sufficient runoff storage volume. Minimum floor levels (+5mAHD for 'dune ridge' and +4m AHD for remaining storm surge hazard area) were recommended by the Department of Marine Harbours (1988) increasing from the previous +3m AHD contour with subsequent modelling of inundation hazard. Minimum floor levels were established after the town was initially established and are above extensive low-lying portions of the town, including the road network.

Assets: Exposure of Coastal Assets to Inundation Impacts

Inundation Level (m AHD)	4.1 Onslow Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)
2.0	0	0 / 0	0 / 0
2.1	0	0 / 0	0 / 0
2.2	0	0 / 0	0 / 1
2.3	3	0 / 0	0 / 1
2.4	8	0 / 0	0 / 1
2.5	14	0 / 0	0 / 1
2.6	19	0 / 0	0 / 1
2.7	25	0 / 0	0 / 1
2.8	30	0 / 0	0 / 1
2.9	35	1 / 0	0 / 2
3.0	39	2 / 0	0 / 2
3.1	42	3 / 0	0 / 2
3.2	44	3 / 0	0 / 2
3.3	45	7 / 0	0 / 2
3.4	47	10 / 0	0 / 2
3.5	48	14 / 0	0 / 2
3.6	55	16 / 0	0 / 2
3.7	62	17 / 0	0 / 2
3.8	72	19 / 0	0 / 4
3.9	81	21 / 0	0 / 6
4.0	83	22 / 0	0 / 6
4.1	88	24 / 0	0 / 6
4.2	93	26 / 0	0 / 7
4.3	97	27 / 0	0 / 7
4.4	100	30 / 0	0 / 7

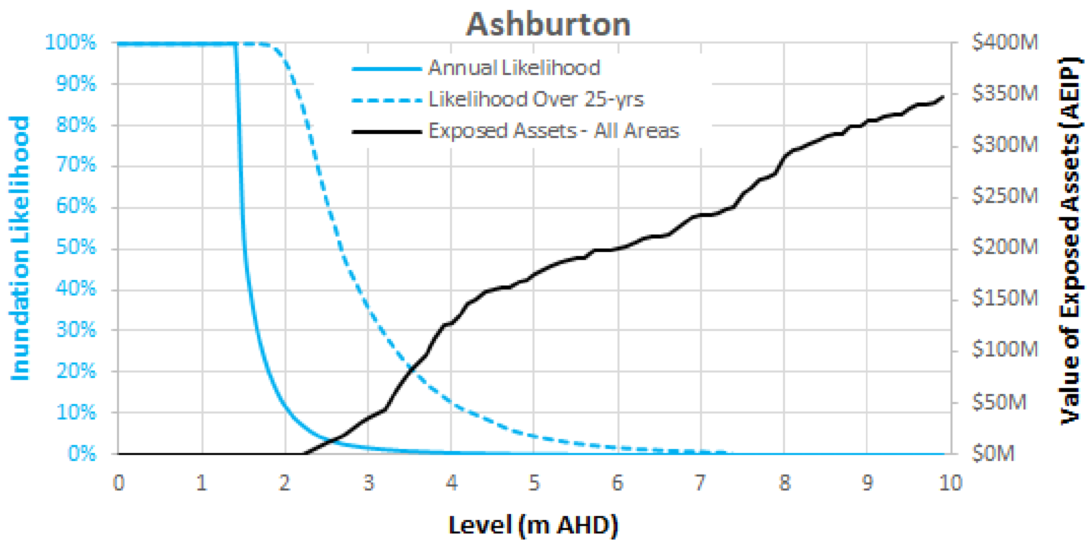
Other Assets Exposed:

Extreme (~100yr ARI): 1 airport; 1 port
Extreme +0.9m: 1 airport; 1 port; 1 ambulance station; 1 nursing home; 1 school; 1HA agricultural land

- Inundation of assets within low lying areas of Onslow (i.e. residential buildings from +2.3m AHD) occurs via Third Street at approximately +3.9m AHD, when the seawall and foreshore level along First Avernue is breached. This is 0.4m above the extreme scenario of +3.5m AHD.
- A flow path through 4-Mile Creek (approximately 7km South of Onslow) potentially reaches low lying areas adjacent to Seaview Drive around 3.5m AHD and Onslow Salt facilities around 4.2m AHD. It is expected that significant damping of the ocean water level will occur along this pathway, due to its shallow and broad structure.
- There are residential properties (81) and commercial properties (21) with Port infrastructure at risk of inundation impacts at the +3.9m AHD level. Exposure across residential and commercial building categories then increases relatively progressively between 3.9m and 4.4m AHD (extreme scenario + 0.9m).
- Exposure of the airport is identified at 2.5m AHD. This is a result of the airport extension, including reclamation works, being conducted after the topographic data was collected. Ground truthing estimated that the airport buildings and runways may become impacted by inundation above 4m AHD.

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

- AEIP indicated approximately $100M of assets are located below +3.9m AHD, which highlights the importance of the existing inundation protection measures provided by the foreshore levels along First Avenue and the Cameron Street Drain. The liklihood of these assets being impacted has a relatively low annual risk, estimated at around 15% likelihood of exceedance over a 25 year period.
- Potential for extreme surge events due to tropical cyclones, and significant assets in the elevation range 4-7m AHD gives a high residual risk, although there is limited confidence in the estimation of extreme event likelihoods above 4m AHD.
- The assessment excludes wave driven inundation. Influence of waves is likely to be limited to the coastal fringe of Onslow townsite.



Damage: Inundation Risk Ratings

Average Annual Damage		AEIP			
	WL	**2.5m AHD**	**3.5m AHD**	**4.4m AHD**	**All Water Levels**
Area	**ARI**	**High**	**Extreme**	**Extreme+ 0.9m**	
4.1: Onslow		$ 0K/yr	$ 0K/yr	$ 188K/yr	$ 511K/yr
Total Damage		**$ 0K/yr**	**$ 0K/yr**	**$ 188K/yr**	**$ 511K/yr**

- Inundation of assets within low lying areas of Onslow (i.e. from +2.3m AHD) occurs via Third Street at approximately +3.9m AHD. Inundation likelihood applied to these assets in damage estimates is subsequent based on a water level exceedance of +3.9m AHD.
- Total damage for Onslow townsite using the AEIP approach is due to impacts on commercial and residential buildings, with the highest contribution to projected damage rates is provided from inundation levels of 3.9-6m AHD.
- Inundation pathways through Beadon Creek may affect the airport and associated infrastructure (presently at around +4.0m AHD), however no value for the airport has been assigned in AEIP.
- Inundation likelihood estimates derived for the damage assessment from tide gauge observations are below modelled inundation levels, which include allowances for wave action.

Planning Framework

Shire of Ashburton Local Planning Scheme LPS No.7 identifies a special control area for coastal hazards, with supporting maps provided. The scheme is supported by a Coastal Vulnerability Study and a CHRMAP. Evaluation of Ashburton's planning framework, for Onslow, against Inundation Management Health Check criteria gave:

HC1	• Coastal inundation hazard has been identified by modelling, incorporating wave set-up. Modelling was provided for both inundation and rainfall runoff.
HC2	• A basis for mapping of inundation hazard is reported independently in Onslow CVS, using a 100yr ARI inundation level, with 0.9m SLR.
HC3	• LPS No.7 is structured to support updating risk maps. Information regarding inundation mapping and definition of the special control area is not consistent between the scheme and the CVS, which shows two different SCA outlines.
HC4	• LPS No.7 Appendix 12 outlines minimum floor levels, with varying levels based upon building use.
HC5	• The SCA identifies time-based thresholds for adaptation of properties. For other areas, adaptation is through revision and update of the policy and hazard assessment, but otherwise tied to development approval.
HC6	• The planning framework acknowledges the role of emergency management, with a direction in 2017 for coastal erosion and flooding risks to be incorporated into emergency response plans. This has not been confirmed.
HC7	• The special control area for coastal hazards has a requirement for storage, warehousing, and electrical fittings to be above 5.9m AHD. There is no reference to ABCB flood proofing guidance.
HC8	• A special control area for coastal hazards has been defined, supporting capacity to obtain targeted financial recompense to support strategic interventions or adaptation.

MODERATE Inundation Risk
at coast

Shire of Exmouth

Focus

Adaptation Priority

Management at Foreshore

Targeted Mitigation

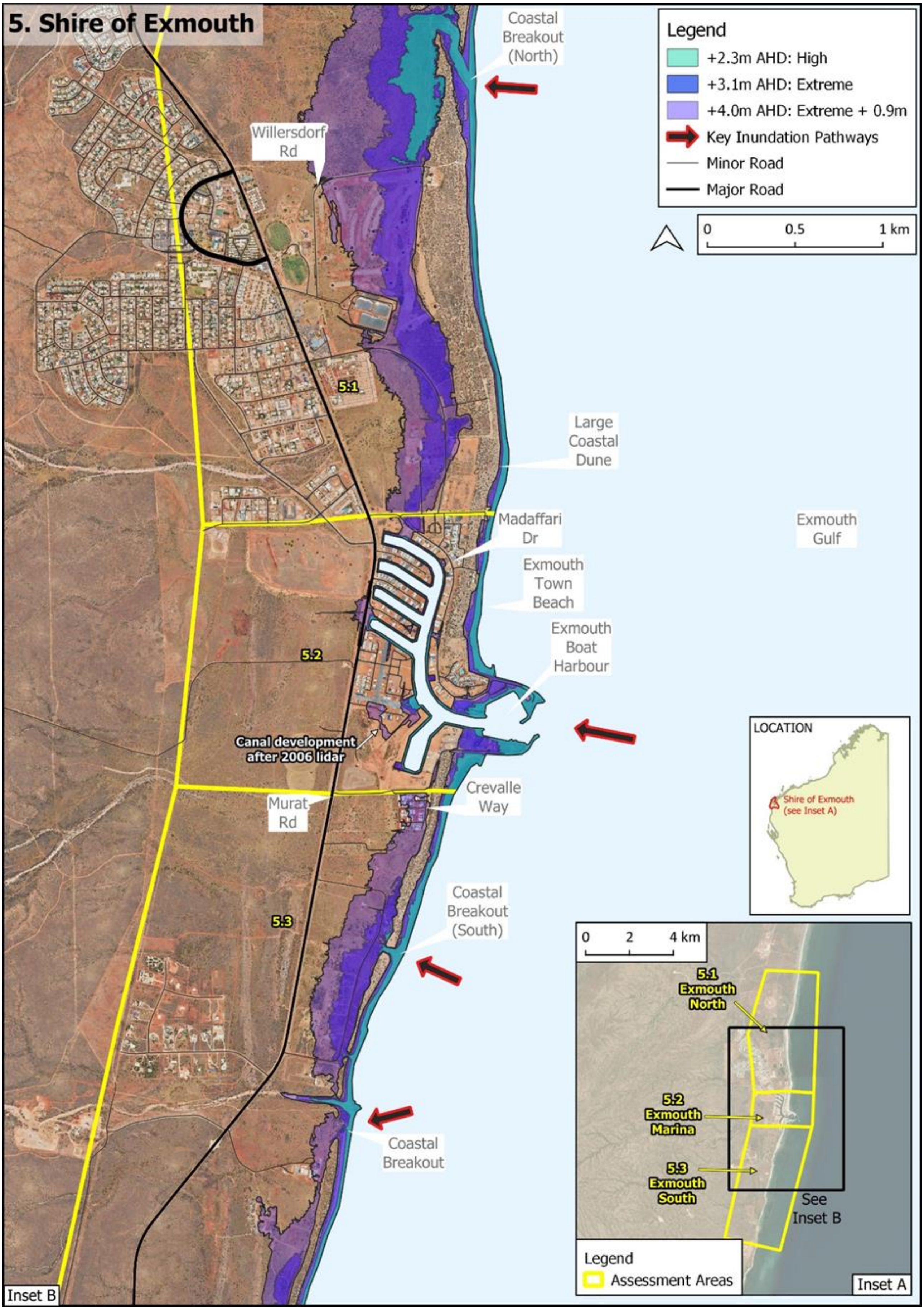
Actions

Management at Foreshore

Targeted Mitigation

WL Review (CHRMAP)

Seashore Engineering


5. Shire of Exmouth
Coastal Breakout (North)
Willersdorf Rd
Legend
+2.3m AHD: High
+3.1m AHD: Extreme
+4.0m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road
0
0.5
1 km
5.1
Large Coastal Dune
Madaffari Dr
Exmouth Gulf
Exmouth Town Beach
Exmouth Boat Harbour
5.2
Canal development after 2006 lidar
Crevalle Way
Murat Rd
LOCATION
Shire of Exmouth (see Inset A)
Coastal Breakout (South)
5.3
0
2
4 km
5.1 Exmouth North
5.2 Exmouth Marina
5.3 Exmouth South
See Inset B
Coastal Breakout
Legend
Assessment Areas
Inset A
Inset B

5. EXMOUTH

Site overview:
The authors wish to acknowledge the Biayungu, Thalanyji and the Yinikurtura people as the native title holders of the lands and waters of the Exmouth region. The Shire of Exmouth is located on the Gulf Coast of northwest WA supporting a national and international tourist industry that in 2020 generated an estimated $110 million for the WA economy. In 2021/22 Exmouth had a reported population of 3,074, with people largely concentrated in Exmouth townsite. As the northern gateway to the Ningaloo coast world heritage area and adjacent Cape Range National Park, the townsite is a tourism hub which experiences high visitor numbers year-round, particularly during the peak tourist season between March-August.

Areas at risk from inundation:
Three inundation exposure area have been assessed for the Shire of Exmouth with a focus on the Exmouth townsite. 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	2.3m AHD High	3.1m AHD Extreme	4m AHD Extreme + 0.9m
5.1 Exmouth North		0.3km²	1.7km²	3km²
5.2 Exmouth Marina		0.1km²	0.2km²	0.3km²
5.3 Exmouth South		0.1km²	0.4km²	0.9km²

Morphology: Sandy beaches with Rock Control; Barrier Dunes; Flood Basin.

- Exmouth is located on the western side of Exmouth Gulf, in relatively shallow and sheltered waters.
- Exmouth coastal zone is characterised by a broad, shallow rock platform overlain by a coastal dune barrier system, with flood basins to landward (Area 5.1).
- The dune system provides an almost continuous barrier along Exmouth foreshore, supported by alongshore sediment transport by winds and waves.
- The coastal dune system acts as a buffer to extreme erosion and storm surge inundation events caused by occasional tropical cyclones.
- Local sediment transport has been significant altered by construction of Exmouth Marina, which has an ongoing sand bypassing work program at the marina.

Climate: Mesotidal; Relatively Low Wave Energy; Sheltered

- Hot summers with periodic heavy rain and mild winters with occasional rainfall.
- Semi-diurnal, mesotidal conditions with tidal range of 2.9m (LAT to HAT).
- Wave action largely generated by wind waves inside Exmouth Gulf. Small swell wave entry from north. Extreme waves generated during tropical cyclones.
- Tropical cyclone season occurs from November to April, with systems typically passing west of Exmouth. Incidence of cyclonic impacts to Exmouth is irregular, with a TC travelling within 300km on average once per year and within 100km once every two years.

[1] Areas were calculated at 0.1m increments with HAT for Exmouth taken at 1.5m AHD in this study.

Development Record: Defence (historical) & Harbour

The Shire of Exmouth is situated on the lands of the Baiyungu, Thalanyji and Yinigurdira People. The traditional name for the coastal land of the Exmouth cape, and the waters surrounding the Ningaloo Reef is Ningaloo. It was given to the region by the West Thalanyji-Yinigudara people, and it means either 'deep water' or 'land jutting out to sea'.

- **1960's to early 1990's:** Exmouth was a strategic military base, including occupation by United States of America personnel. The civilian population of the town largely focused on activities related to service of the base.
- **Early 1990s:** following base decommissioning, townsite grew as a fishing and tourism destination.
- **1995-1996:** Plans for a harbour on the coastline to support fishing, eco-tourism and offshore supply services. Construction of Harbour in 1996 and subsequent sand management modified behaviour of the adjacent coast, particularly along Town Beach foreshore. Sand management used to reduce disruption of alongshore transport.
- **1996-present:** Ongoing growth of Exmouth townsite with substantially increased tourism, expansion of residential numbers, including development of Exmouth Marina Village canal estate, and development of light industrial operations.

Coastal Inundation History: Rare Storm Events; Tidally Modulated

Water levels have been measured by Department of Transport at Exmouth Jetty (1989-1993), and in the Boat Harbour from 1997 onwards. Tropical cyclones (TC) are the most severe weather systems experienced in the Exmouth region, with capacity to generate extreme winds, waves, surge and rainfall. Most significant water level events in recent records for Exmouth are:

TC Vance, March 1999 – 4.89m CD (3.48m AHD)

- Most memorable direct cyclone impact to the Exmouth coastline, passing approximately 25km east of Exmouth as a category 5 cyclone before making landfall in the southern part of the Gulf.
- TC Vance generated extreme waves and water levels roughly 2.0m above highest astronomical tide levels which caused severe erosion of the beachfront and inundation around Exmouth Marina

TC Olwyn, March 2015 - 3.37m CD (1.96m AHD)

- Severe Tropical Cyclone *Olwyn* was the most significant tropical cyclone to affect the Gascoyne coast in decades, tracking close to the coast from Exmouth to Shark Bay as a category three tropical cyclone. It moved south-southwest and passed just to the west of Exmouth on 12 March. A storm water level of about 3.37m CD was recorded at Exmouth. Minor to moderate damage to homes and infrastructure were reported.

TC Narelle, Jan 2013 - 3.23m CD (1.82m AHD)

- Narelle tracked in a southwest direction and was located around 470 (km) to the north northwest of Exmouth from 13 January before it weakened below tropical cyclone strength on 14 January, finally dissipating well offshore to the west of Perth.
- Though the tropical cyclone never directly impacted the mainland, it produced a tidal residual of 0.84m at Exmouth on 13 January, causing some inundation of low-lying areas but no major impact overall.

Hazard: Existing Coastal Inundation Hazard Assessment Summary

CHRMAP (Seashore & LandInsights 2023)

- Coastal inundation hazard has been evaluated, considering projected sea level rise to +1.0m, using a combination of tide gauge analysis and parametric tropical cyclone modelling.
- Coastal inundation provides a relatively limited hazard for Exmouth, with most areas exposed to coastal inundation already being identified as subject to runoff flooding at higher levels. However, relative impact of coastal inundation will increase in frequency due to projected sea level rise.
- Inundation of the flood basin behind the northern breakout presently occurs with approximately 10-year ARI water level. Increased inundation frequency with sea level rise will change the character of the breakout:
- Greater wave action across the nearshore rock platform will increase alongshore sediment transport and provide a greater tendency for closure at the breakout mouth.
- Higher coastal inundation events give a greater capacity for breaching and scour as floodwaters withdraw. Large inundation events may bring in coastal sediment and cause salinisation across part of the flood basin.
- For sea level rise above 0.4m, tidal ingress will occur. This will permanently change vegetation in the flood basin and eventually develop a tidal channel network.

Hazard: Existing Controls

Runoff flooding hazard has historically provided a focus for flood management, with coastal inundation identified as a secondary threat, typically occurring at lower elevations. Consequently, existing flood mitigation, through site identification, emergency management and minimum fill levels, provide effective controls to coastal inundation.

Assets: Exposure of Coastal Assets to Inundation Impacts

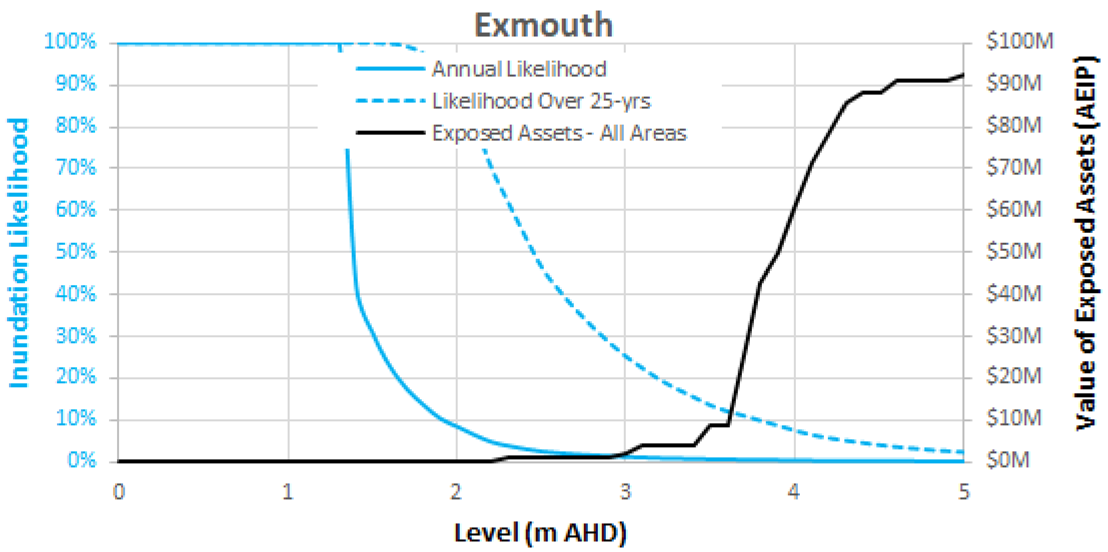
Inundation Level (m AHD)	5.1 Exmouth North			5.2 Exmouth Marina			5.3 Exmouth South		
	Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/ Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)
2.2	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
2.3	0	0 / 0	0 / 0	0	0 / 0	0 / 0	1	0 / 0	0 / 0
2.4	0	0 / 0	0 / 0	0	0 / 0	0 / 0	1	0 / 0	0 / 0
2.5	0	0 / 0	0 / 0	0	0 / 0	0 / 0	1	0 / 0	0 / 0
2.6	0	0 / 0	0 / 0	0	0 / 0	0 / 0	1	0 / 0	0 / 0
2.7	0	0 / 0	0 / 0	0	0 / 0	0 / 0	1	0 / 0	0 / 0
2.8	0	0 / 0	0 / 0	0	0 / 0	0 / 0	1	0 / 0	0 / 0
2.9	0	0 / 0	0 / 0	0	0 / 0	0 / 0	1	0 / 0	0 / 0
3.0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	2	0 / 0	0 / 0
3.1	0	0 / 0	0 / 0	0	0 / 0	0 / 0	4	0 / 0	0 / 0
3.2	0	0 / 0	0 / 0	0	0 / 0	0 / 0	4	0 / 0	0 / 0
3.3	0	0 / 0	0 / 0	0	0 / 0	0 / 0	4	0 / 0	0 / 0
3.4	0	0 / 0	0 / 0	0	0 / 0	0 / 0	4	0 / 0	0 / 0
3.5	0	0 / 0	0 / 0	0	0 / 0	0 / 0	5	1 / 0	0 / 0
3.6	0	0 / 0	0 / 0	0	0 / 0	0 / 1	5	1 / 0	0 / 0
3.7	0	0 / 0	0 / 0	0	0 / 0	0 / 1	8	7 / 0	0 / 0
3.8	0	0 / 0	0 / 0	0	0 / 0	0 / 1	10	13 / 0	0 / 0
3.9	0	0 / 0	0 / 0	0	0 / 0	0 / 1	15	14 / 0	0 / 0
4.0	0	0 / 0	0 / 0	0	0 / 0	0 / 1	16	18 / 0	0 / 0

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

Other Assets Exposed:
5.1 Exmouth North
Extreme +0.9m: 1 wastewater treatment plant

Overall, inundation exposure across the 3 areas of consideration for Exmouth is low:

- **5.1 Exmouth North**: No exposure is predicted across the 4 categories (residential, commercial, industrial buildings and roads)
- **5.2 Exmouth Marina & Town Beach**: No commercial or residential buildings are predicted to be impacted up to 4m AHD and only 1km of arterial road becomes exposed to potential inundation impacts at a water level of 3.6m AHD.
- **5.3 Exmouth South**: 1 residential building at Crevelle Way is exposed to impacts at an inundation level of 2.3m (high) increasing to 4 buildings under at the extreme water level scenario. No other assets are exposed in this area until an inundation level of 3.5m is reached, when commercial buildings at Neale Cove will be impacted (18 buildings at extreme water level scenario +0.9m)



Comparison of exposed assets and estimated inundation likelihood indicates most assets are above 3.5m AHD, which is above an 1% annual likelihood of inundation. This provides an underestimate of inundation exposure within Exmouth Boat Harbour, which has assets below 3.0mAHD, and exaggerated exposure in the marina canals, due to intersection of the 50-m AEIP grid with inundation hazard lines within the marina waterways. A substantial asset threshold occurs at 5.25m AHD, which is the defined fill level for Exmouth Marina Village. For the inundation likelihoods identified, this has almost 1% likelihood of occurrence over the next 25 years.

Damage: Inundation Risk Ratings

Average Annual Damage		AEIP			
	WL	2.3m AHD	3.1m AHD	4m AHD	All Water Levels
Area	ARI	High	Extreme	Extreme+ 0.9m	
5.1: Exmouth North		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 3K/yr
5.2: Exmouth Marina		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 34K/yr
5.3: Exmouth South		$ 0K/yr	$ 4K/yr	$ 15K/yr	$ 93K/yr
Total Damage		**$ 0K/yr**	**$ 4K/yr**	**$ 15K/yr**	**$ 131K/yr**

Analysis of inundation hazard generally indicated 'low' damage, resulting from development of the townsite upstream of the coastal floodplain, and infilling of Exmouth Marina Village to a level above 5.25m AHD. Floodplain breakouts provide potential ingress points for coastal inundation. Most damage to assets due to coastal inundation is likely within Exmouth Boat Harbour, which has a low ground level.

Planning Framework

The significance of the Ningaloo coastal region has been acknowledged through development of State Planning Policy 6.3 – Ningaloo Coast (SPP 6.3), which provides objectives for management of the Ningaloo region, including Exmouth.

The Shire of Exmouth Local Planning Strategy acknowledges the importance of managing coastal hazards, through both SPP 2.6 (Coastal Planning Policy) and SPP 6.3. This is further supported in the Exmouth region by the *Ningaloo Coast Regional Strategy* (2004). Despite acknowledgement of coastal hazards, there is limited identification of coastal inundation, as runoff flood risk occurs in the same locations, to generally higher levels. A special control area for Exmouth floodplain (SCA5) is identified in Exmouth Local Planning Scheme 4.

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

HC1
- Interactions between coastal inundation and runoff flooding risks are identified.

HC2
- There is no defined scenario for coastal inundation hazard, with runoff flooding levels generally above coastal inundation levels at the 100-year ARI recurrence used for town planning. Allowance for sea level rise is not clearly reported, and there is no requirement or provisions for adaptation.

HC3
- Information regarding coastal inundation hazard is not reported in the Local Planning Strategy or LPS4.

HC4
- Exmouth Local Planning Strategy identifies that opportunities for growth of Exmouth town site may include undertaking flood management and mitigation works.
- Minimum floor levels are recommended.

HC5
- The need for potential adaptive management along Exmouth coast is identified in the Local Planning Strategy, acknowledging SPP 2.6. Adaptation pathways are not described explicitly.

HC6
- The planning framework acknowledges the role of emergency management and has incorporated provisions supporting access evacuation in the Local Planning Strategy.

HC7
- Exmouth Local Planning Strategy and LPS4 acknowledge the role of ABCB guidance for buildings.

HC8
- A special control area for Exmouth Floodplain (SCA5) encompasses the area subject to coastal inundation hazard, except for Exmouth Boat Harbour. Definition of SCA5 based on runoff flooding, without additional reference to its role to mitigate coastal inundation may impede SCA use to support strategic coastal interventions or adaptation.

EXTREME Inundation Risk
at coast

Shire of Carnarvon

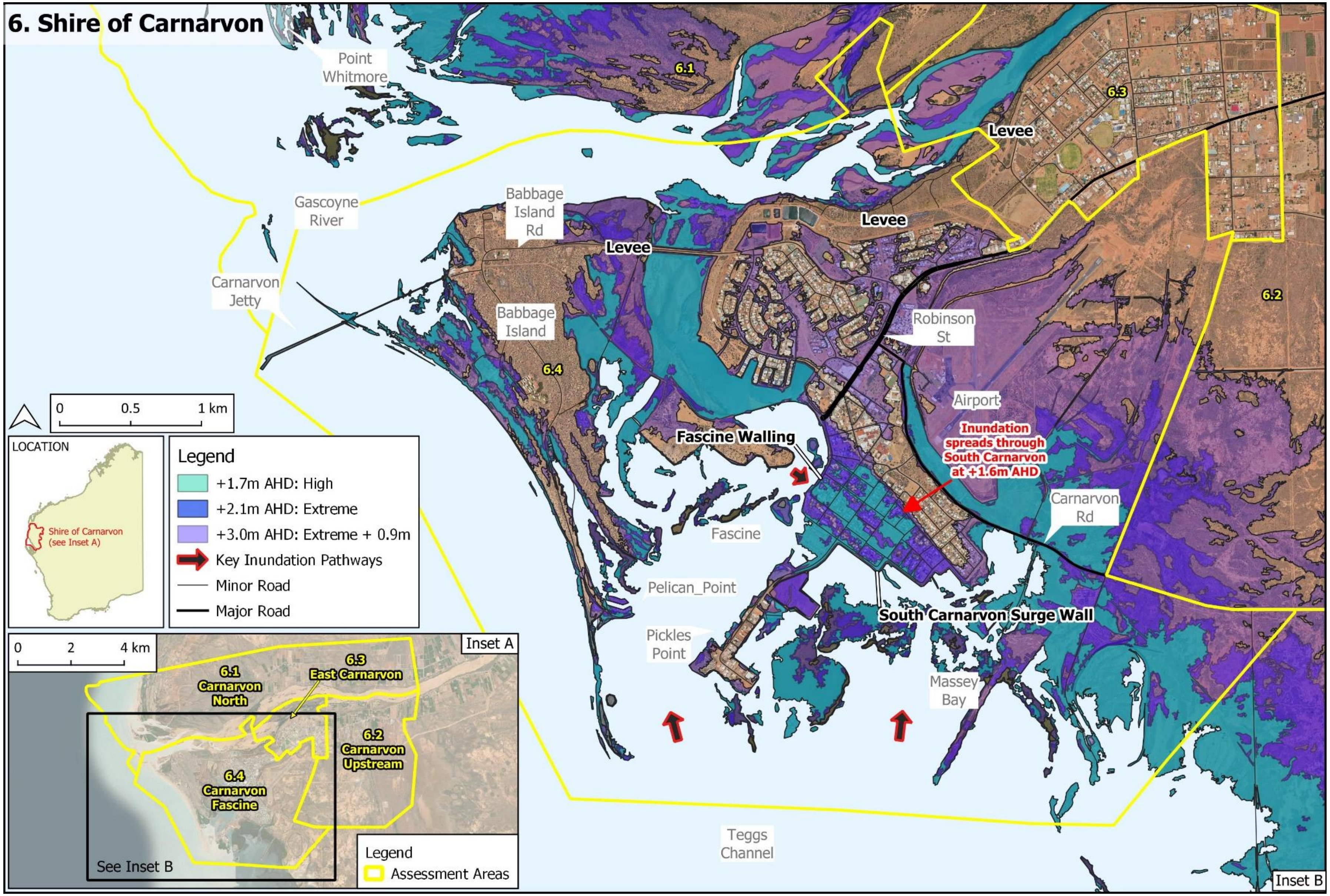
Focus

Active Management | Adaptation Priority | Targeted Mitigation | Emergency Management

Actions

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

Seashore Engineering


6. Shire of Carnarvon
Point Whitmore
6.1
6.3
Levee
Levee
Levee
Gascoyne River
Babbage Island Rd
Carnarvon Jetty
Babbage Island
6.4
Robinson St
6.2
Airport
Fascine Walling
Inundation spreads through South Carnarvon at +1.6m AHD
Carnarvon Rd
Fascine
Pelican_Point
South Carnarvon Surge Wall
Pickles Point
Massey Bay
Teggs Channel
0 0.5 1 km
LOCATION
Shire of Carnarvon (see Inset A)
Legend
+1.7m 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
6.1 Carnarvon North
6.3 East Carnarvon
6.2 Carnarvon Upstream
6.4 Carnarvon Fascine
See Inset B
Legend
Assessment Areas
Inset B

6. CARNARVON

Site overview:

The authors wish to acknowledge the Yinggarda people as the native title holders of the lands and waters of the Shire of Carnarvon. Carnarvon is the main townsite for the Shire of Carnarvon and the main regional centre for the Gascoyne, with a population of over 5,000. It is located in the northern part of Shark Bay and south of Ningaloo coast. Carnarvon townsite acts as a service centre for the region's industry including mining, fishing, tourism and agriculture (fruit & vegetables, cattle, goats, sheep, wool). Carnarvon townsite is located on the low-lying delta of Gascoyne River and has been previously identified as subject to both flood hazard from the river and coastal inundation associated with tropical cyclones.

Areas at risk from inundation:

Four inundation exposure area have been assessed for the Shire of Carnarvon. 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	2.1m AHD Extreme	3m AHD Extreme + 0.9m
6.1 Carnarvon North		5km²	8.4km²	15.3km²
6.2 Carnarvon Upstream		0km²	0.4km²	1.9km²
6.3 East Carnarvon		0.4km²	0.5km²	0.7km²
6.4 Carnarvon Fascine		4.1km²	6.2km²	10.8km²

Morphology: Tidal creeks; Supratidal and Intertidal Flats; Delta Plain

- Carnarvon is located on Gascoyne River delta.
- The river mouth has a complex structure, with three deltas. The modern position of the mouth is the northernmost delta, with two residual deltas acting as drainage paths for smaller catchment areas including Boodalia and Brown channels.
- The main area of inundation hazard is Carnarvon Fascine area (area 6.4), south of Gascoyne River mouth from Babbage Island in the west to Massey Bay in the east.
- The barrier is an active chenier spit and dune ridge with washover fans encroaching tidal flats and tidal creeks. Bare sand has been subjected to overwash during storms. The backshore deltaic environment includes cheniers, beach ridges, supratidal and intertidal flats, tidal creeks, runoff channels, palaeochannels and shallow basin swamps.

Climate: Mesotidal; Relatively Low Energy; Locally Generated Wind Waves

- Carnarvon has a transitional climate, being toward the southern fringe of arid sub-tropical conditions and the northern limit of extra-tropical weather systems. This produces moderated influences from both tropical and mid-latitude weather systems.
- Mixed, mainly semi-diurnal tidal regime, with tidal range of 2.0m from LAT to HAT.
- Sea levels exhibit transitional behaviour, with varying influence of semi-diurnal and diurnal tides, interacting with the annual mean sea level cycle. Consequently, although the largest daily tide range is in June and December, there is opportunity for high water levels from January through to June.
- Carnarvon is at the western fringe of Wind Region D (AS1170.2), which means it is potentially subject to intense tropical cyclones, although it has a history of relatively infrequent storm impact.
- Carnarvon coast is strongly protected from southwest ocean swells by the presence of rock peninsulas and islands, including Bernier and Dorre Islands to the west of Carnarvon.
- Carnarvon experiences a relatively benign ambient wave climate, driven largely by locally generated waves across Shark Bay; Prevailing winds are south-southwest, which correspond with the longest available fetch across Shark Bay.

Development Record: Regional Centre for Horticulture; Mining; Tourism

Carnarvon's traditional owners are the Aboriginal Yinggarda people, who named this area, Gwoonwardu, meaning 'neck of water'.

- **1876 – early 1900s**: Town site established in 1883 with town jetty constructed between 1897 and 1904, servicing state ships and livestock exports. Extensive flooding of Gascoyne River in the early 1900s, with the river overflowing its banks.
- **1910-1925:** timber walling was constructed along the South Arm of the Gascoyne which separated Babbage and Whitlock Islands from the mainland.

[1] Areas were calculated at 0.1m increments with HAT for Carnarvon taken at 1.1m AHD in this study.

- **1976:** Construction of a fishing boat harbour and related industrial precinct east of Pickles Point. Artificial channel cut through tidal flats, with dredged spoil used to raise the surrounding land.
- **1986:** Gascoyne south arm was closed at its northern end using a levee to reduce flooding to town following the flood strategy developed for Carnarvon.
- **1995**: The Fascine Development Plan was prepared in 1995 following initial coastal response studies. Some project objectives of the Fascine Development Plan have been achieved, including construction of two stages of the Northwater precinct land development and dredging of a boating basin south of Whitlock Island, with the dredged material raising an area on the island.

Coastal Inundation History: Rare Storm Events; Tidally Modulated

Over 45yr WL record (1966-2023); however, movement of the tide gauge from Carnarvon Jetty to Carnarvon Boat Harbour when basin was dredged in 1979[2], changed the record quality and complicates comparison of historic extreme water levels.
Cyclone impact causing wind gusts more than 90 km/h in the vicinity of Carnarvon occurs about once every five years on average. This is less than half the frequency for communities along the Pilbara coast reflecting the decreased risk southwards along the west coast. However, the occurrence of tropical cyclones is not evenly distributed in time. The most significant water level events recorded for Carnarvon include:

TC Glynis, Feb. 1970 - 2.59m[3] CD (1.63m AHD)

- Tracked parallel to coast reaching peak intensity of 970hPa on 1 February 100km of NW cape.
- Lost intensity as it tracked south passing 220km W of Carnarvon. Due to the offshore position, wind speeds on land during passage were relatively modest with 37km/hr at Carnarvon.
- Highest ever water level recorded at Carnarvon tide gauge on 2nd February.
- At Carnarvon, the shelf wave travelled near to the critical speed for surge amplification with the tidal residual peaking at 1.4m during a relatively modest high tide of 1.3m.

TC Vanessa in 1976 - 2.55m CD (1.59m AHD) & TC Hazel in 1979 - 2.72m CD (1.76m AHD)

- Reports of extreme water levels associated with TC Vanessa and TC Hazel describe inundation occurred at low lying areas in the Fascine, Yacht Club, Harbour Road and around the intersection of Brown Street and West end. While similar reports are absent for TC Glynis, given its slightly higher water level, it is possible to infer that similar flooding was experience during this event.

Hazard: Existing Coastal Inundation Hazard Assessment Summary

GEMS (2009)

- A detailed storm surge study for Carnarvon, including cyclonic storm surge modelling
- The GEMS study identified areas affected by cyclonic inundation, coastal development setbacks, stability of Babbage Island spit and strategies or works to minimise risk to future development.
- The study found that the variable level of existing walling is an inundation threat the settlement; and the incomplete structure of the South Carnarvon surge wall reduces its effectiveness as a barrier.
- The study incorporates recommendations for consideration of proposals within areas subject to inundation.

CHRMAP (in progress 2024)

The CHRMAP for Carnarvon is currently underway and due for completion in 2024.

Hazard: Existing Controls

- Runoff flooding hazard has historically provided a focus for flood management, with coastal inundation identified as a secondary threat, typically occurring at lower elevations only. Flood mitigation and emergency management activities are consequently used for coastal inundation hazard, particularly for the northern side of Carnarvon, as there are levee banks on the Gascoyne River and elevated land levels.
- Strategic controls for coastal inundation have been progressively developed for the west and south side of Carnarvon townsite, including the South Arm barrage, built in the 1980s, South Carnarvon surge wall, built in 2007 and installation of sheetpile walling along Carnarvon Fascine foreshore, completed in 2013.
- The Fascine Levee along Olivia Terrace provides protection up to ~2m AHD

[2] Tide gauge was moved after recorded water levels associated with TC Glynis in Feb. 1979
[3] To present datum

Assets: Exposure of Coastal Assets to Inundation Impacts

Inundation Level (m AHD)	6.1 Carnarvon North			6.2 Carnarvon Upstream			6.3 East Carnarvon			6.4 Carnarvon Fascine		
	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	0	0 / 0	0 / 0	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	0 / 0	0 / 1
1.5	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	4	0 / 0	0 / 1
1.6	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	69	0 / 0	0 / 1
1.7	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	105	0 / 0	0 / 1
1.8	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	144	1 / 0	0 / 1
1.9	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	204	1 / 0	0 / 1
2.0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	238	1 / 0	0 / 1
2.1	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	268	1 / 0	0 / 1
2.2	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	290	1 / 0	0 / 2
2.3	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	306	3 / 0	0 / 2
2.4	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	307	4 / 0	0 / 3
2.5	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	311	5 / 0	0 / 3
2.6	0	0 / 0	0 / 0	0	0 / 0	0 / 1	0	0 / 0	0 / 0	351	23 / 0	2 / 4
2.7	0	0 / 0	0 / 0	0	0 / 0	0 / 1	0	0 / 0	0 / 0	378	25 / 0	2 / 4
2.8	0	0 / 0	0 / 0	0	0 / 0	0 / 1	0	0 / 0	0 / 0	411	26 / 0	2 / 4
2.9	0	0 / 0	0 / 0	0	0 / 0	0 / 1	0	0 / 0	0 / 0	475	26 / 0	2 / 4
3.0	0	0 / 0	0 / 0	0	0 / 0	0 / 2	0	0 / 0	0 / 0	530	29 / 0	3 / 4

High (~25yr ARI)

Extreme (~100yr ARI)

Extreme +0.9m

Other Assets Exposed:

6.4 Carnarvon Fascine

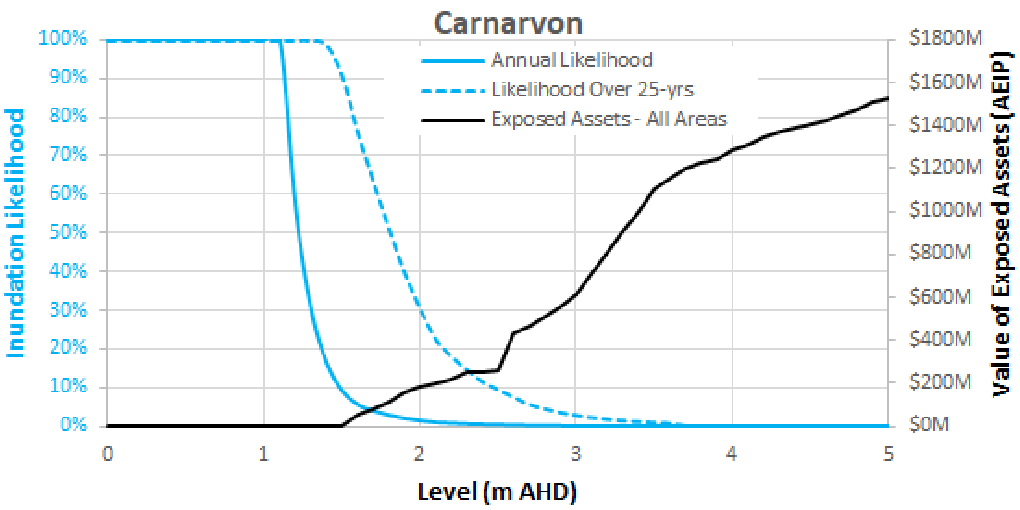
High: 1 airport; 1km rail track

Extreme: 1 airport; 1km rail track; 1 HA agricultural land; 1 power station; 1 school

100yr+0.9m: 1 airport; 5km rail track; 1 HA agricultural land; 1 power station; 3 schools

- Interrogation of NEXIS database using inundation contours indicates that exposure commences at approximately 1.4m AHD for the Carnarvon Fascine area (1 residential building impacted); increasing to 530 for the extreme water level scenario +0.9m. Commercial buildings begin to be exposed within the Fascine precinct at 1.8m AHD (1 building) increasing to 3 at 2.3m AHD and 29 at 3m AHD. Within the Fascine area both arterial and main roads are exposed from 1.4m and 2.2m AHD respectively.
- For a high water level scenario (~25yr ARI) the Fascine area to the northeast of Whitlock Island will be exposed to inundation impacts including the residential areas at Yardi Quay.
- The 1.7m AHD water level projects inundation of low-lying areas east of Olivia Terrace along the South Carnarvon side of the Fascine as well as low lying wetland areas in Massey Bay. A primary inundation pathway is identified through Massey Bay to the South of the Carnarvon Road.
- Inundation will proceed through a pathway along Carnarvon Road towards Robinson Street with the low-lying land adjacent to the airport impacted at 1.7m AHD and airport infrastructure exposed to inundation by 3m AHD. At an inundation level of 3m AHD low lying land to the west of Carnarvon Road around the hospital and to the east of Robinson Street will be exposed to inundation impacts.

Comparison of exposed assets identified via AEIP and estimated inundation likelihood indicates substantial presence of assets at levels potentially affected by coastal inundation. The most significant area of exposure is South Carnarvon, which includes many houses with ground levels below 2.0m AHD.



An asset exposure threshold around +2.6m AHD has developed following previous identification of coastal inundation hazard at +2.4m AHD for the extreme water level scenario (~1% AEP) level. This threshold has approximately 10% likelihood of being reached within a 25-year period.
Extreme inundation levels, up to 3.0m AHD, would create additional areas of coastal inundation hazard for residences. Urban drainage reserves adjacent to Bibra Way and Babbage Island Road provide potential inflow paths. A wide area around and including Carnarvon Airport is potentially susceptible to extreme inundation, which would arrive via Massey Bay.

Damage: Inundation Risk Ratings

Average Annual Damage		AEIP			
	WL	1.7m AHD	2.1m AHD	3m AHD	All Water Levels
Area	ARI	High	Extreme	Extreme+ 0.9m	
6.1: Carnarvon North		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
6.2: Carnarvon Upstream		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
6.3: East Carnarvon		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
6.4: Carnarvon Fascine		$ 43K/yr	$ 375K/yr	$ 906K/yr	$ 1.2M/yr
Total Damage		**$ 43K/yr**	**$ 375K/yr**	**$ 906K/yr**	**$ 1.2M/yr**

- Damage primarily from South Carnarvon within the Carnarvon Fascine segment, with inundation through a low point in the South Carnarvon surge wall via Carnarvon Yacht Club.
- Has high average annual damage from inundation up to extreme (~100 year ARI) levels, with widespread inundation commencing at +1.6m AHD which is around a 25yr ARI.
- Most of the ‘average annual damage’ occurs for buildings set between +1.6m AHD to +3.5m AHD.

Planning Framework

The significance of the Ningaloo coastal region has been acknowledged through development of State Planning Policy 6.3 – Ningaloo Coast (SPP 6.3), which provides objectives for management of the Ningaloo region, including Carnarvon.

The Shire of Carnarvon Local Planning Strategy acknowledges the importance of managing coastal hazards, through both SPP 2.6 (Coastal Planning Policy) and SPP 6.3. This is further supported in the Carnarvon region by the *Ningaloo Coast Regional Strategy* (2004). Despite acknowledgement of coastal hazards, there is limited inclusion of coastal inundation in the Shire’s policies, with ‘flood prone’ areas only identified as those areas susceptible to flooding by the Gascoyne River. A special control area for river flooding (SCA3) is identified in Local Planning Scheme 13.

Evaluation of Carnarvon’s planning framework against the Inundation Management Health Check criteria gave:

- HC1 • Interactions between coastal inundation and runoff flooding risks are not identified.
- HC2 • Carnarvon town planning requires consideration of 100-year ARI hazard events, including inundation and flooding. Allowance for sea level rise is not clearly reported, and there is no substantive requirement or provisions for adaptation.
- HC3 • Information noting coastal inundation hazard is provided with mapping of ‘flood prone’ areas that does not include areas susceptible to coastal inundation. Ningaloo Coastal Regional Strategy notes a level of 3.0m AHD represents a 100-year ARI level combining coastal inundation and river flooding for Carnarvon townsite and notes an extreme coastal inundation scenario may reach 4.0m AHD, but this hazard is not mapped.
- HC4 • Ningaloo Coastal Regional Strategy provides direction towards incorporation of property level protection measures in future development, including minimum floor levels and flood proofing.
- HC5 • Adaptation is not described explicitly, although requirements for coastal developments to meet SPP 2.6 are outlined in Local Planning Scheme 13.
- HC6 • The planning framework acknowledges the general role of emergency management but does not explicitly identify policy interactions or emergency management during inundation events.
- HC7 • Potential for development approvals to require flood proofing are identified in Ningaloo Coastal Regional Strategy but are not related to ABCB guidance (which was released later).
- HC8 • A special control area for coastal hazards has not been defined, with a whole of townsite policy applied due to widespread runoff flooding risk. Lack of an SCA limits capacity to obtain targeted financial recompense to support strategic interventions or adaptation.

MODERATE Inundation Risk
at coast

Shire of Shark Bay: Denham

Focus

Adaptation Priority

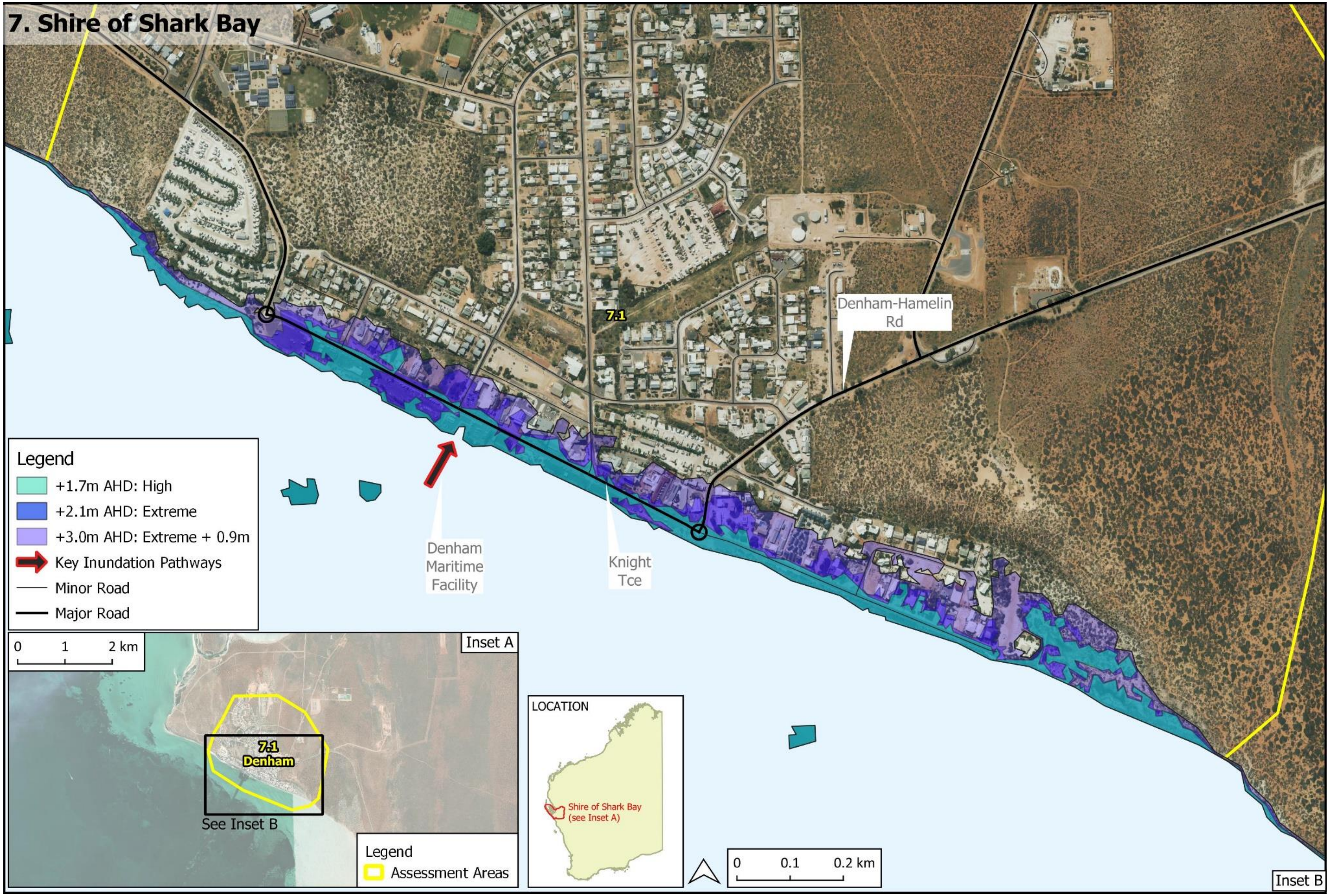
Management at Foreshore

Actions

Management at Foreshore

WL Review (CHRMAP)

Seashore Engineering


7. Shire of Shark Bay
7.1
Denham-Hamelin Rd
Denham Maritime Facility
Knight Tce
Legend
+1.7m AHD: High
+2.1m AHD: Extreme
+3.0m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road
0 1 2 km
Inset A
7.1
Denham
See Inset B
Legend
Assessment Areas
LOCATION
Shire of Shark Bay (see Inset A)
0 0.1 0.2 km
Inset B

7. SHARK BAY

Site overview:

The authors wish to acknowledge the Malgana people, the Nhanda people and the Yingkarta people as the native title holders of the lands and waters in and around the Shark Bay region. The Shire of Shark Bay is located approximately 800 km north of Perth on Western Australia's Gascyone Coast with a population of just over 1000 people. Denham townsite is a hub for tourism, commercial and recreation activities. While it's resident population is just over 700 the townsite also experiences high visitor numbers throughout the year as a gateway to Shark Bay World Heritage Area including the world renowned dolphin interaction experience at Monkey Mia.

Areas at risk from inundation:

One inundation exposure area has been assessed for the Shire of Shark Bay in the area around the Denham townsite. 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	2.1m AHD Extreme	3m AHD Extreme + 0.9m
7.1 Denham		0.3km²	0.4km²	0.6km²

Morphology: Storm ridge and tidal flat system; low dunes; engineered foreshore

- Denham is the main coastal townsite for the Shire of Shark Bay, located on Peron Peninsula in Henri Freycinet Harbour
- It is relatively protected from open ocean conditions and with the exception of dredged channel, the nearshore bathymetry adjacent to the town is shallower than -3m AHD up to 2km offshore, with significant areas exposed under regular low tides.
- The townsite itself is centered around the foreshore area and accompanying main street (Knight Terrace), which comprises new and old developments primarily under 5m AHD.
- The low-lying foreshore area is part of a storm ridge and tidal flat system and is reported to be the original settlement location.
- There is a scarp extending steeply upwards from around the 4m AHD contour. This appears to be the Quaternary rock layers, which may resist erosion. This is particularly the case seaward of Denham Seaside Caravan Park, and to the west around to the public lookout, where the scarp is quite close to the existing shore.
- Engineering of the coastal interface along much of Denham foreshore has altered natural evolution of the local geomorphology.

Climate: Micotidal; Relatively Low Energy; Fetch-limited Wind Waves

- Shark Bay is located within a climatically transitional zone on the Western Australian coastline, experiencing mid-latitude and tropical weather systems.
- Microtidal, falling within the shift from diurnal to semi-diurnal tidal dominance (moving north) with Highest Astronomical Tide (HAT) of approximately 1.7m CD (0.9m AHD).
- Denham is in Wind Region C (AS1170.2), which means it is potentially subject to moderately intense tropical cyclones, although it has a history of relatively infrequent storm impact,
- Most winds come from the southern sector, with almost 45% of winds from south-southwest through to south-southeast.
- Waves approaching Denham are predominantly wind-driven, both from the ambient southerly sea breezes as well as during storms/cyclones. These wind-generated waves are both fetch and depth limited.
- Shallow sand bars extending offshore limit energy reaching the foreshore. Therefore, most waves approaching Denham are likely to be less than 0.5m. Larger waves are only expected in the nearshore during extreme events.

Development Record: Pastoralism; Tourism; Fishing

- Shark Bay is the traditional country of three Aboriginal language groups: Malgana, Nhanda and Yingkarta. The Malgana name for Shark Bay is Gutharraguda, which means 'two bays' or 'two waters'. The Shark Bay area is significant to Aboriginal people and there are about 130 registered Aboriginal heritage sites in the Shark Bay area including quarries, rock shelters, burial sites and large scatters of discarded shells, bone and other food-related artefacts known as middens.

[1] Areas were calculated at 0.1m increments with HAT for Shark Bay taken at 1.1m AHD in this study.

- Shark Bay was first settled by Europeans in the 1850s and was important for industries such as guano mining, pearling and pastoralism.
- In several areas throughout the LGA, pastoralism was combined with tourism operation folowing collapse of the wool market in the 1990s.
- The present townsite planning is based on historic and ongoing foreshore reclamation. Denham foreshore has been reclaimed seaward of Knight Terrace since the 1898 alignment between Page Street to Durlacher Street, with some reclamation east of the present harbour associated with the placement of dredged material from the harbour.
- The earliest reclamation was attributed to the pearling technique of dredging and dumping the shells on the shore.
- From 1978 onwards, capital and maintenance dredging for the harbour has been placed either on the foreshore (or on the terrace northwest of the channel
- Reclamation allows for foreshore use and development with the narrow reclaimed foreshore area seaward of Knight Terrace zoned for recreation and public purposes.
- The central foreshore has been hardened through construction of a revetment which was upgraded in 2016.

Coastal Inundation History: Rare Storm Events

No long term tide gauge for Denham although short periods of water level measurements have been recorded within Shark Bay at Denham and Monkey Mia, and irregular measurement to support Shark Bay Salt operations. Denham townsite is located in an area prone to tropical cyclones, however, direct impact of cyclones for the Gascoyne coastline are less frequent than further north, occurring on average once every two to three years. Anecdotal significant water level events for Shark Bay include:

Unnamed TC, Feb. 1921:

- A storm surge pushed sea water 2.9 m above the highest tide mark at Denham, resulting in 20 cm of water in the Post Office. The whole town was inundated and from 3:30 pm until midnight on the 20th, the population had to shelter in the School and Police Station.

Unnamed TC, Feb. 1937:

- Some Denham houses were under about 2 m of water and residents had to row to safety. Waves broke to the steps of the Dirk Hartog Island homestead and the 10 tonne cutter Dirk Hartog was driven over 100 m up the beach. Huge seas combined with a 4.3 m tide to alter the coastline for several kilometres and cover 14 km of the road from Hamelin Pool to Denham.

TC Hazel, March 1979:

- A storm surge at Denham flooded buildings forcing people to evacuate. TC Hazel developed a high storm surge due to the path of the cyclone parallel to the coast, compared with an equivalent theoretical system approaching the coast at a perpendicular angle

TC Herbie, May 1988:

- A 2 m storm surge flooded the Denham foreshore as the extratropical low storm accelerated and deepened, and crossed the coast near the town of Denham on 20 May 1988.

Hazard: Existing Coastal Inundation Hazard Assessment Summary

CHRMAP (Water Technology 2019)

- Inundation assessment investigated the 500-year ARI inundation event for the different planning timeframes: Present Day, 2030, 2050 and 2118.
- Investigations were based on an event with a predicted level of 3.3m AHD in the present day, and 4.2 m AHD by 2118.
- 140 coastal assets were identified as having at some level of risk in the present day, due to the low likelihood of the 500-year ARI inundation event occurring (0.2%), the resulting risk classification is low for all assets except critical utilities.
- Water Technology identified that no appropriate locally measured water level or wave data with which to calibrate the models developed for this study was obtained.

Hazard: Existing Controls

The Shire of Shark Bay manages coastal inundation hazard through property level protection, requiring a minimum finished floor level of 4.2m AHD. Foreshore walling is around 2.0m AHD, effectively providing erosion protection only, although it may be adequate to resist smaller storm surge events.

Assets: Exposure of Coastal Assets to Inundation Impacts

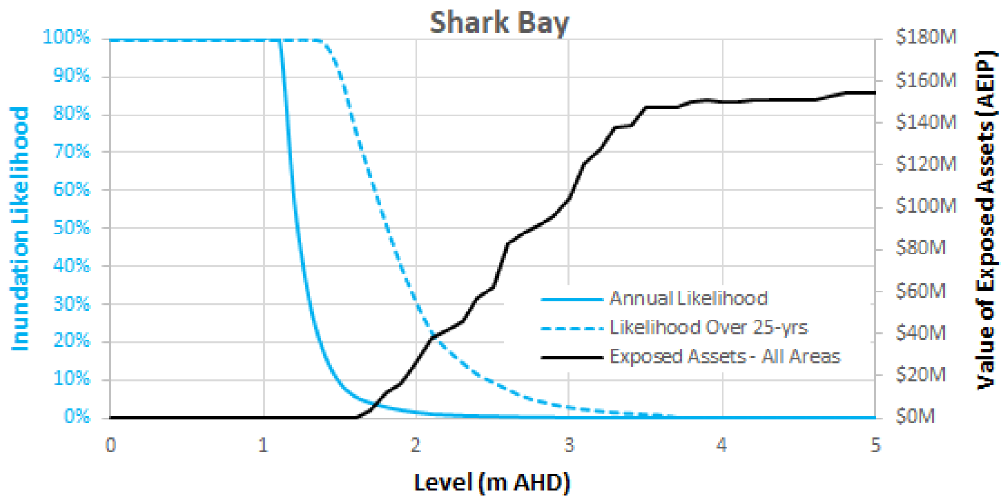
Inundation Level (m AHD)	7.1 Denham Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)
1.3	0	0 / 0	0 / 1
1.4	0	0 / 0	0 / 1
1.5	0	0 / 0	0 / 1
1.6	0	0 / 0	0 / 1
1.7	3	0 / 0	0 / 1
1.8	10	0 / 0	0 / 1
1.9	14	0 / 0	0 / 1
2.0	17	1 / 0	0 / 1
2.1	19	3 / 0	0 / 2
2.2	22	3 / 0	0 / 2
2.3	25	3 / 0	0 / 2
2.4	30	4 / 0	0 / 2
2.5	32	5 / 0	0 / 2
2.6	38	8 / 0	0 / 2
2.7	42	8 / 0	0 / 2
2.8	45	8 / 0	0 / 2
2.9	48	8 / 0	0 / 2
3.0	55	8 / 0	0 / 2

Other Assets Exposed: N/A

- Exposure is initially predicted at a water level of 1.3m AHD for the Denham townsite (1km of road impacted) with residential buildings first exposed at approximately 1.7m AHD (High water level scenario ~25 ARI).
- This increases to 19 residential buildings at the extreme water level with 3 commerical buildings also potentially exposed along with 2km of road.
- At the extreme +0.9m inundation level or 3m AHD it is projected that 55 residential buildings and 8 commerical buildings will be impacted.
- Application of the AEIP tool does not identify any major roads, services or utilites exposed to inundation impacts up to a water level of 3m AHD corresponding to the extreme +0.9m inundation level.

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

Asset exposure commences at approximately 2.1m AHD, which has an estimated inundation likelihood of 1%, and approximately 20% likelihood of occurring in the next 25 years. Other assets identified using AEIP are effectively distributed up to 3.4m AHD, which has slightly less than 1% likelihood of occurrence in the next 25 years. Notably, this does not include effects of waves, which can extend to higher levels.



Damage: Inundation Risk Ratings

Average Annual Damage Area	WL ARI	AEIP 1.7m AHD High	2.1m AHD Extreme	3m AHD Extreme+ 0.9m	All Water Levels
7.1: Denham		$ 0K/yr	$ 24K/yr	$ 104K/yr	$ 145K/yr
Total Damage		**$ 0K/yr**	**$ 24K/yr**	**$ 104K/yr**	**$ 145K/yr**

Inundation likelihood estimates derived from tide gauge observations are substantially below modelled inundation levels for Denham CHRMAP, which include wave setup and are noted as based on preliminary modelling. Landforms, such as the storm ridge and tidal flat on which the original townsite was constructed, including the reclaimed foreshore of Knight Terrace are low-lying and will be prone to increased inundation and consequently shore retreat with projected sea level rise.

Planning Framework

The Shire of Shark Bay Local Planning Scheme No 4 identifies the significance of coastal inundation at Denham. Evaluation of the Shire planning framework against the Inundation Management Health Check criteria gave:

HC1	• Although interaction between coastal inundation and waves have been identified in the CHRMAP, this information is neither separable nor complete.
HC2	• Denham town planning requires consideration of 500-year ARI coastal inundation hazard, with allowance for 0.9m sea level rise. Development applications may be required to incorporate adaptation planning.
HC3	• Information describing coastal inundation hazard is included in Denham CHRMAP, including mapping of the 500-year ARI sea level with a range of sea level rise scenarios. This information is consistent with LPS No.4, but inconsistent with the Local Planning Strategy, which is from 2013.
HC4	• LPS No.4 identifies minimum floor levels for habitable areas.
HC5	• Adaptation is not described explicitly in LPS No.4, although it is noted that coastal developments should have due regard for SPP 2.6 and may require adaptation planning to be identified.
HC6	• The planning framework does not identify policy interactions with emergency management for inundation.
HC7	• There is no guidance regarding flood proofing or building requirements in areas subject to inundation hazard. Due regard is noted for the Building Code of Australia for commercial and tourism zones, but this does not stipulate flood proofing.
HC8	• A special control area for coastal hazards has not been defined, with a whole of townsite policy applied due to widespread hazard. Lack of an SCA potentially limits capacity to obtain targeted financial recompense to support strategic interventions or adaptation.

MODERATE Inundation Risk
at coast

City of Greater Geraldton

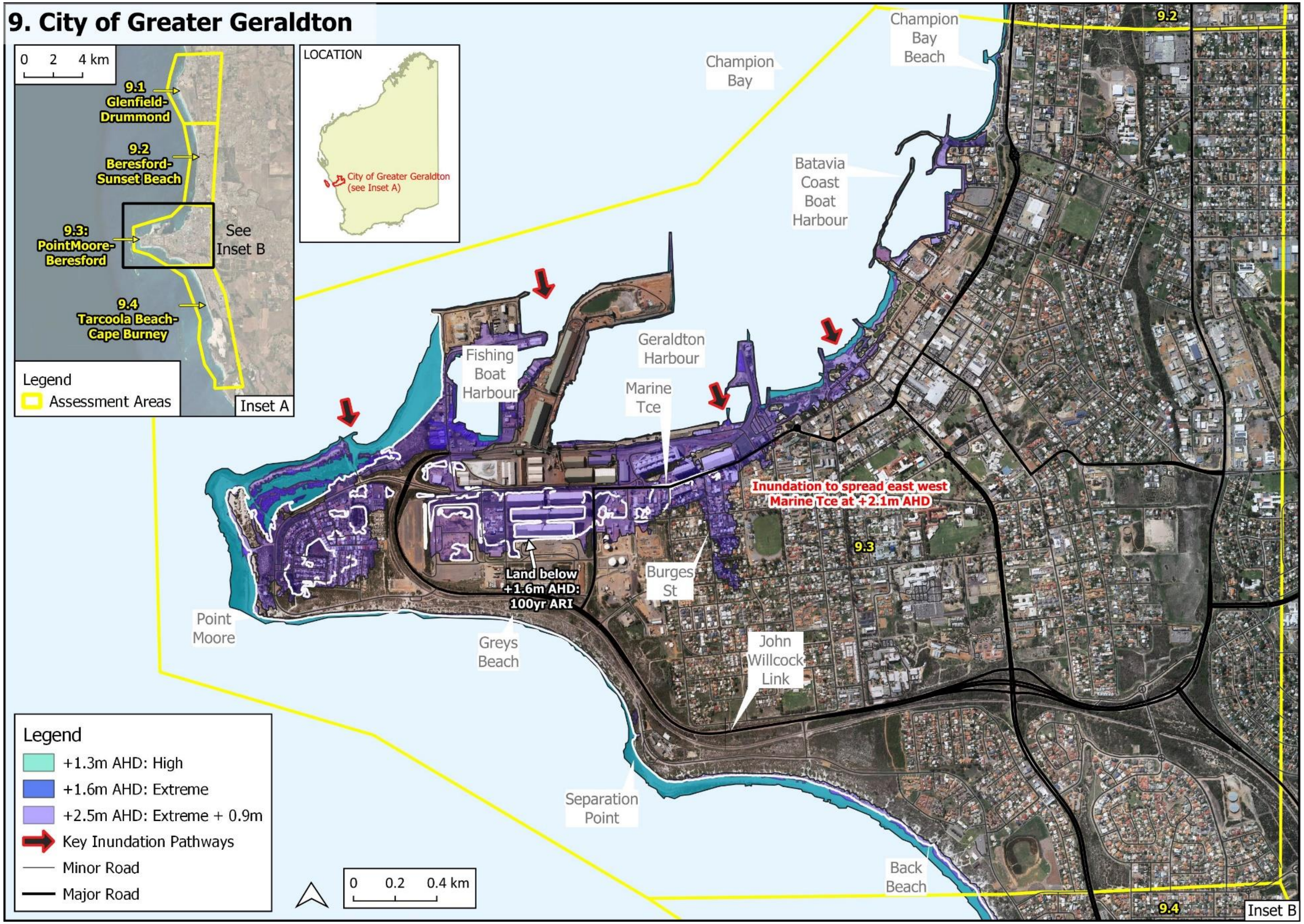
Focus

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

Actions

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

Seashore Engineering


9. City of Greater Geraldton
0 2 4 km
9.1 Glenfield-Drummond
9.2 Beresford-Sunset Beach
9.3: PointMoore-Beresford
9.4 Tarcoola Beach-Cape Burney
See Inset B
Legend
Assessment Areas
Inset A
LOCATION
City of Greater Geraldton (see Inset A)
Champion Bay Beach
Champion Bay
Batavia Coast Boat Harbour
Fishing Boat Harbour
Geraldton Harbour
Marine Tce
Inundation to spread east west Marine Tce at +2.1m AHD
9.3
9.2
Land below +1.6m AHD: 100yr ARI
Burges St
Point Moore
Greys Beach
John Willcock Link
Separation Point
Back Beach
9.4
Inset B
Legend
+1.3m AHD: High
+1.6m AHD: Extreme
+2.5m AHD: Extreme + 0.9m
Key Inundation Pathways
Minor Road
Major Road
0 0.2 0.4 km

9. GERALDTON

Site Overview:
The authors wish to acknowledge the Yamatji people as the native title holders of the lands and waters in and around the City of Geraldton. The City is home to 32,000 residents and serves as the main centre for the Midwest region of WA, with a trade focus through Geraldton Port. The City and the Midwest are recognized as having the most diversified economy in the state through industries including mining, fishing, aquaculture, agriculture, manufacturing, construction, retail and tourism. Known as an extensive host of water sports, Geraldton lends itself to some of the most spectacular kite surfing, windsurfing, fishing and diving conditions and is the gateway to the Houtman Abrolhos Islands. The Geraldton population was 41,198 with mining, construction, manufacturing, and transport and warehousing the top industries.

Areas at risk from inundation:
Inundation exposure has been considered across four areas for Geraldton 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	1.6m AHD Extreme	2.5m AHD Extreme + 0.9m
9.1 Glenfield-Drummond		0km²	0.1km²	0.2km²
9.2 Beresford-Sunset Beach		0km²	0.1km²	0.2km²
9.3 PointMoore-Beresford		0.3km²	0.4km²	1.5km²
9.4 Tacoola Beach-Cape Burney		0.2km²	0.2km²	0.4km²

Estimated inundation levels do not include wave effects, and it is noted that high waves and water levels are often coincident.

Morphology: Wave Dominated; Reef Tombola; Mixed Relief

- Geraldton town centre is located on Point Moore, in the lee of a high relief segment of several nearly parallel, discontinuous, reef chains marking the position of previous shorelines (including Champion Reef).
- Coastal topography is strongly influenced by barrier dune development, with moderate transgressive movement via blowouts.
- Low points have developed where there is significant wind sheltering, limited sand supply or through river channel incision (i.e. Chapman River mouth). This has resulted in a large area of relatively low land, generally below 2.5m AHD, on the north side of Point Moore, occupied by the Port and industrial area, Geraldton CBD and West End caravan park.
- Geraldton has multiple features potentially introducing coastal instability, especially under scenarios for sea level rise, that may affect inundation hazard. These include salient/tombolo migration and fluctuations, sand spit and beach width fluctuations, mobility of foredune plains, foredune and primary dune activity/scarping and modifications to the rate of sediment supply from seagrass beds.

Climate: Micotidal; Mixed Storm Types; Semi Arid

- Transitional climate zone
- Mainly diurnal tides that are microtidal with a tidal range of range of 1.2 m (CD) from LAT to HAT (0.65m AHD).
- Position in the Midwest region exposes it to the influence of both mid-latitude storm systems and tropical storms, but the City is distant from most storm paths. This limits potential surge generation, except during anomalous events, such as low-latitude westerly storms, or southward travelling tropical cyclones.
- Geraldton is in Wind region B2 (AS1170.2), which means it is rarely subject to tropical cyclones and these have typically declined in intensity.
- The land-sea breeze cycle dominates the prevailing winds of the region, particularly over summer, with moderate easterly winds in the morning and stronger (up to 15 m/s) southerly to south-southwesterly sea breezes commencing around noon and weakening during the night.

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

Development Record: Regional Port

- Geraldton is located on the traditional lands of various localised Aboriginal language groups which are collectively known as Yamatji and include the Amangu people, Naaguja people, Wadjarri people, Nanda people, Badimia people and additionally the region includes the Western Desert people known as the Martu people.
- For thousands of years, Champion Bay (Jambinu) provided a sheltered location and rich fishing ground for Yamaji people.
- Point Moore defines the southern end of Champion Bay, with Geraldton Port constructed on its north, originally positioned to take advantage of shelter from southwest swell and sea breezes provided by the reefs and foreland.
- Geraldton townsite was initially established to support shipping for mining and grazing. The town substantially developed around the port facilities, with the CBD developing adjacent to the port, and subsequent growth extending outwards.
- The Geraldton coastline has been heavily modified over the last 100 year with the port main breakwater built the 1920s, followed by further development of the port and construction of the Fishing Boat Harbour and Batavia Coast Marina. These developments have changed the natural sediment transport processes in Champion Bay as well as interrupting the predominant northerly longshore sediment drift.
- In recent years the coast to the north of the Port, particularly has been heavily engineered to respond to coastal erosion impacts. This has included modification of structures at Champion Bay beach, construction of detached breakwater, groyne, sections of revetment along the Beresford shoreline and construction of GSC groynes at Sunset Beach and Drummond Cove.

Coastal Inundation History: Occasional storm events; ~1 TC per 5 years

- Tidal record for Geraldton commenced in 1966
- Relative timing of tide, mean sea level and extra-tropical surge controls the potential for high water levels which occurs in May-June in Geraldton.
- Timing of high tides and mean sea level in this region is generally out of phase with the tropical cyclone season.
- The relatively narrow shelf and west facing shore of the Midwest reduces the significance of both tides and tropical cyclone induced surges relative to the Northwest.

The largest observed coastal inundation events at Geraldton are:

TC Seroja, April 2021 – 2.42m CD (1.88m AHD)

- TC Seroja is one of the strongest cyclones to impact the west coast of WA in modern history causing widespread damage
- Localised and shallow inundation occurred at Pages Beach parkland, Francis Street boast ramp and low lying areas in the Port of Geraldton

Boxing Day Tsunami 2004 – 2.38m CD (1.84m AHD)

- A tsunami generated by the Sumatra earthquake propagated to the Western Australian coast. This created dramatic short-period water level oscillations of up to 2.2m range, which decayed over 4-5 days
- This produced the highest water level recorded at Geraldton tide gauge up to that date, later exceeded by TC Seroja
- Local inundation was observed, with considerable debris washed up along Geraldton beaches
- A fishing boat was sunk, floating jetties were damaged and several small boats were jammed under jetties or catwalks

Unnamed TC, March 1956 - 2.1m CD (1.56m AHD)

- Shipping was battered in Geraldton Harbour overnight. The grain freighter Cape St. David was smashed against her berth, with her hull badly damaged and some boats were left high and dry 80 m from the water line.
- Inundation of the foreshore Shepheard's Hotel (now Ocean Centre Hotel).

Hazard: Existing Coastal Inundation Hazard Assessment Summary

Inundation & Coastal Processes Studies: Point Moore, Cape Burney, Town Beach (M P Rogers 2018)

- Cyclone storm surge modelling to determine the potential inundation caused by severe cyclones.
- Analysis of available water level records to determine the potential inundation caused by non-cyclonic events.
- Inundation Mapping Plans show areas that could be inundated by different events for each of the timeframes outlined.

Geraldton CBD Flood and Inundation Study (Cardno 2020)

- Inundation hazards assessment considered a range of processes including rain, storm tide (including wave set-up and overtopping) and tsunami.
- Three design events (i.e. 20yr ARI or 5%AEP, 100yr ARI or 1%AEP and 500yr ARI or 0.2%AEP) and three timeframes (i.e. 2030, 2070 and 2110) with allowance for mean sea level rise.
- The most significant coastal inundation hazards are attributed to storm tide & rainfall events and wave overtopping.
- Residential areas in West End become inundated during the 20yr ARI event, with depths increasing to approximately 2m in the 500yr ARI.

Summary of Previous Assessments:

- Reasonable definition of low ARI events.
- Significant management of runoff flooding risk
- Probabilistic definition of TCs is probably conservative – single evaluation used for multiple studies.
- West End one of the first locations in WA where leasehold application was used as a tool to limit exposure to coastal erosion and inundation impacts.
- Application to convert to freehold in 2007 rejected based on inundation risk, with detailed modelling study identifying Point Moore subject to inundation for events with less than 20-year ARI recurrence.
- Previous attempts to characterise inundation hazard have resulted in highly variable estimates, due to combination of method biases and data periods used.
- The importance of individual events is illustrated by the difference between Damara (2007) and Cardno (2021) assessments, with 16 of the top 25 water level events occurring between 2005 and 2018 (25% of the record duration), and only four between 1976 and 2004 (50% of the record duration)

Hazard: Existing Controls

The main feature limiting inundation hazard for Geraldton is the presence of coastal dunes, supported by dune management. These limit the extent of wave run-up, with energetic waves commonly occurring at the same time as high sea levels.

Construction of a rail line for Geraldton Port in the 1870s provided a barrier to inundation of low-lying areas for Geraldton CBD, which was removed around 2000 as part of foreshore enhancement works. The Port and Batavia Coast Marina provide an informal control to inundation of the CBD, with their breakwaters providing significant damping of incident waves.

Low-lying areas of Geraldton townsite have previously been identified as prone to rainfall flooding. Existing flood management, including land-use zoning for industrial or leasehold purposes, stormwater management (pumping) and emergency management are consequently effective for coastal inundation hazard. Until 2015, perceived risk to CBD was considered tolerable for non-habitable buildings, with ground levels above the estimated present-day 100-yr ARI coastal inundation event.

At Point Moore, Lease agreements for Point Moore residents have managed retreat conditions specified based on erosion and inundation triggers.

Assets: Exposure of Coastal Assets to Inundation Impacts

Inundation Level (m AHD)	9.1 Glenfield-Drummond			9.2 Beresford-Sunset Beach			9.3 PointMoore-Beresford			9.4 Tacoola Beach-Cape Burney		
	Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/ Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/ Arterial (km)
1.0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.1	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.2	0	0 / 0	0 / 0	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	0	0 / 0	0 / 0
1.4	0	0 / 0	0 / 0	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	0	0 / 0	0 / 0
1.6	0	0 / 0	0 / 0	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	0	0 / 0	0 / 0
1.8	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.9	0	0 / 0	0 / 0	1	0 / 0	0 / 0	0	0 / 1	0 / 0	0	0 / 0	0 / 0
2.0	0	0 / 0	0 / 0	1	0 / 0	0 / 0	59	0 / 1	0 / 0	0	0 / 0	0 / 0
2.1	0	0 / 0	0 / 0	1	0 / 0	0 / 0	80	1 / 21	0 / 2	0	0 / 0	0 / 0
2.2	0	0 / 0	0 / 0	1	0 / 0	0 / 0	82	2 / 21	0 / 2	0	0 / 0	0 / 0
2.3	0	0 / 0	0 / 0	1	0 / 0	0 / 0	98	6 / 21	1 / 2	0	0 / 0	0 / 0
2.4	0	0 / 0	0 / 0	2	0 / 0	0 / 0	116	6 / 21	1 / 2	0	0 / 0	0 / 0
2.5	0	0 / 0	0 / 0	2	0 / 0	0 / 0	144	8 / 21	1 / 2	0	0 / 0	0 / 0

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

Other Assets Exposed:
9.3 Point Moore to Beresford
Extreme +0.9m : 6km railway track

- No exposure to built buildings recorded at a high water level scenario across the 4 areas considered (not including wave action)
- Residential and commercial buildings are initally exposed in the Point Moore-Beresford area at a water level of 2.1m AHD increasing at 2.5m AHD (extreme+0.9m – shaded in purple above).
- Overall exposure to inundation impacts is low/non-existant in all areas except Point Moore-Beresford and here, the majority of buildings exposed are residential, followed by industrial/commercial under the extreme + 0.9m water level scenario.
- Inundation pathways have been identified at Pages Beach Playground area (1.3m AHD) moving inland through a pathway at Marine Terrace to the Beeliar Village caravan park (2.5m AHD)
- Fishing Boat Harbour crossing Bogle road into the industrial buildings and cooperative bulk handling area adjacent to Marine Terrace.
- Within the Geraldton harbour area a likely inundation pathway will occur at the inner harbour adjacent to Ian Bogle Rd, moving landward toward the Geraldton CBH facility, crossing Marine Terrace and proceeding towards the commercial buildings adjacent to Pollard and Cunningham street.
- A preliminary entry point under the 1.3m inundation level was identified at the midpoint of Town Beach between groyne 1 and 2 and in line with Cathedral Street impacting foreshore infrastructure around the Geraldton water park and Dome café as well as the Yacht Club, Playground and Multi user centre and crossing further landward past Foreshore Drive and Marine Terrace under an inundation level of 1.6m and 2.5m AHD respectively
- The most northerly portion of Town Beach is exposed to inundation impacts under a high water level of 1.3m with likely impacts to foreshore facilities around the Jaffle Shack; while at Batavia Coast Harbour and Champion Bay Beach, residential properties will be exposed at an inundation level of 2.5m AHD extreme + 0.9m)

Assets identified with AEIP occur from 1.9m AHD, with a substantial increase in assets above 2.5m AHD. Comparison with estimated inundation likelihood indicates limited interaction, with an estimated 5% likelihood of coastal inundation impact over a 25 year period. Notably, this does not include effects of waves, which can extend to higher levels.

Substantial increase in asset exposure around 2.5m AHD indicates high senstivity to an inundation difference of around 0.7m. This difference could be developed through event scenarios or statistics, inclusion of wave processes, or allowance for sea level rise. This explains the significant difference in hazard identification between this evaluation and Geraldton CHRMAP.

Damage: Inundation Risk Ratings

Average Annual Damage		AEIP			
	WL	1.3m AHD	1.6m AHD	2.5m AHD	All WL
Area	ARI	High	Extreme	Extreme+ 0.9m	
9.1: Glenfield-Drummond		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
9.2: Beresford-Sunset Beach		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
9.3: PointMoore-Beresford		$ 0K/yr	$ 0K/yr	$ 16K/yr	$ 25K/yr
9.4: Tacoola Beach-Cape Burney		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
Total Damage		**$ 0K/yr**	**$ 0K/yr**	**$ 16K/yr**	**$ 25K/yr**

- Based on inundation levels up to an extreme water level scenario (1.6m AHD) no assets are identified by the AEIP database as exposed to inundation impacts across any of the 4 areas considered for Geraldton LGA. Notably, this does not include wave processes.
- Geraldton CBD has high value commercial buildings around 2.5-2.7m AHD. The contribution of these assets to residual risk (in this case above the ~100-yr ARI) is sensitive to inundation scenarios selected, as demonstrated by the difference between Phase 1 results and this assessment.
- All damage identified occurs in Point Moore-Beresford assessment area.
- The analysis approach confirms inundation pathways, through narrow pathways, into larger areas of low land.
- It is noted the 'bath-tub' approach used does not capture effects of wave runup and overtopping identified in more detailed modelling, and a refined analysis may be required to assess priority for mitigation actions at a City scale.
- Most projected damage is associated with residual risk, indicating sensitivity to very large storm events and in the longer term, potential influence of projected sea level rise.

Planning Framework

The City of Greater Geraldton Local Planning Strategy and Local Planning Scheme No. 1 were both published in 2015. The Strategy identifies potential for increasing impact of coastal hazards due to sea level rise, including erosion and inundation and outlines development of Geraldton CHRMAP. However, there is otherwise limited inclusion of coastal inundation in the City's policies, with 'flood prone' areas only identified as those areas susceptible to flooding by the Chapman River and Greenough River. A special control area for river flooding (SCA6) is identified in Local Planning Scheme No. 1.

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

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

HC2
- Geraldton Local Planning Strategy requires consideration of 100-year ARI for river flooding, with no stated requirement for coastal inundation. Coastal vulnerability studies evaluated conditions up to 500-year ARI, with 0.9m sea level rise, with the CHRMAP identifying short-term inundation hazard.

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

HC4
- Inundation mitigation measures are not identified in Geraldton planning framework, with a recommendation to determine minimum floor levels in the CHRMAP. Minimum floor levels for the CBD have been calculated by Cardno (2020).

HC5
- Design Finished Floor levels have been identified for the CBD inundation risk; Managed Retreat Leases have been implemented for the Point Moore inundation risk.
- These cover 80% (144 of 178) of the assets identified in the exposure tables above.

HC6
- The planning framework does not acknowledge the role of emergency management for coastal hazards. The CHRMAP recommends developing and implementing an evacuation plan.

HC7
- A set of building design recommendations are outlined in the CHRMAP, but these are not related to ABCB guidance.

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

LIMITED Inundation Risk
at coast

Shire of Coorow

Focus

Adaptation Priority

Management at Foreshore

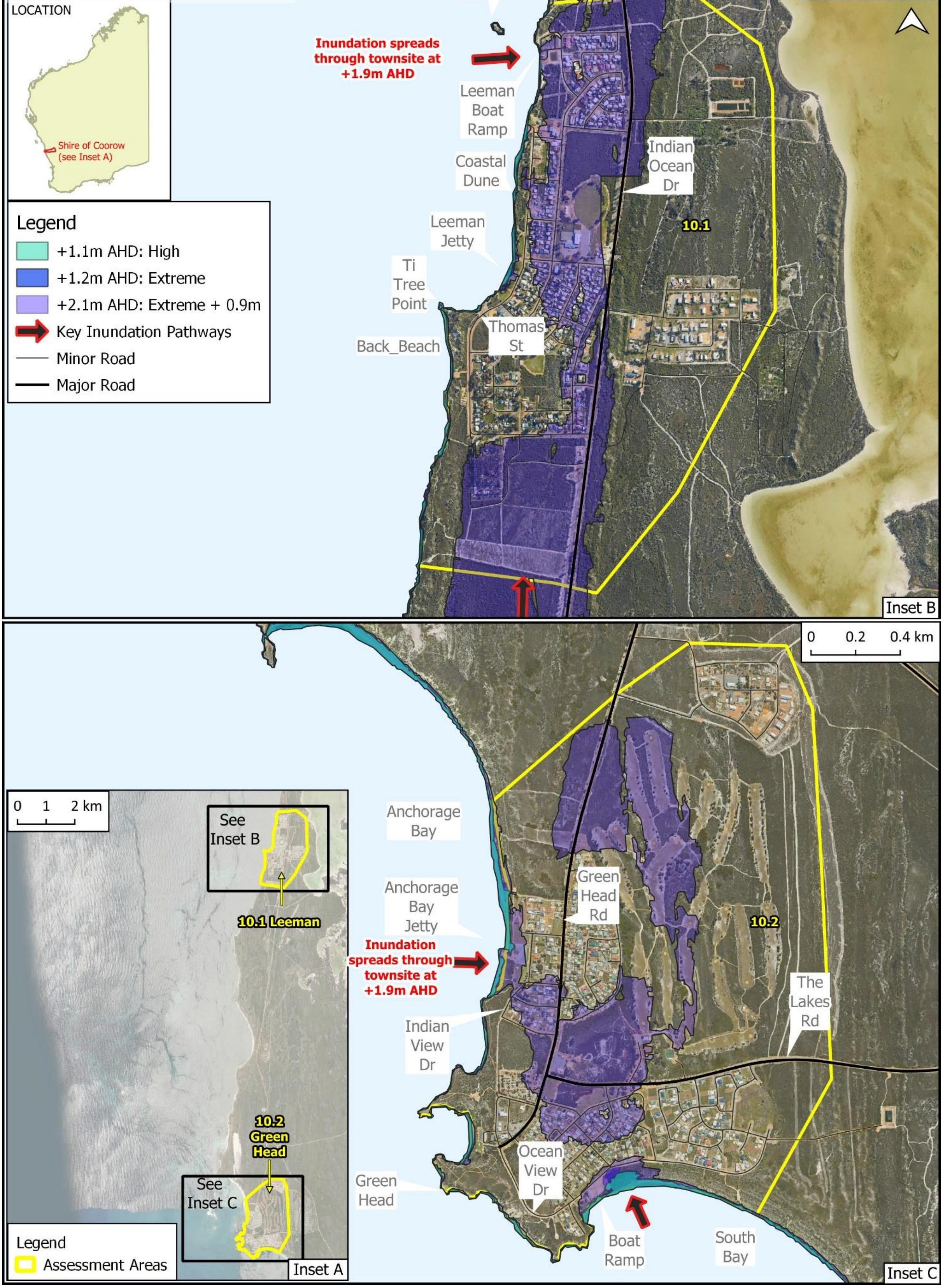
Actions

Management at Foreshore

WL Review (CHRMAP)

Seashore Engineering

10. Shire of Coorow



10. COOROW

Site overview:

The authors wish to acknowledge the Amangu people, Badymia people and the Yued people as the native title holders of the lands and waters in and around Shire of Coorow. The Shire of Coorow is located in the Midwest region of WA, roughly 270km north of Perth and 130km south of Geraldton. The largest settlements are the coastal town of Leeman and the nearby settlement of Green Head with a population of 1,055. The Shire of Coorow covers an area of 4,189sqkm and has diverse local industries including agriculture, floriculture, lobster and fishing and an emerging tourism industry.

Areas at risk from inundation:

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

REGION	WL ARI	1.1m AHD High	1.2m AHD Extreme	2.1m AHD Extreme + 0.9m
10.1 Leeman		0km²	0km²	2.2km²
10.2 Green Head		0.1km²	0.1km²	0.9km²

Morphology: Perched Sandy Beaches; Rocky Cliffs and Headlands; Parabolic Dunes

10.1 Leeman

- Shallowly indented arcuate shoreline facing WNW.
- Sandy beaches are largely sheltered, narrow and perched on rock platforms and pavement between headland outcrops and have a sheltered, flat or segmented morphology.
- Perched parabolic dunes with 25 to 75% vegetation cover overlying coastal limestone.
- Foredunes abutting the small beaches have been cliffed by erosion. Access tracks along the coast and to the small, sheltered beaches are common.

10.2 Greenhead

- Small reflective beaches are located at the head of deeply indented W and SW facing embayments around Green Head. Anchorage Bay forms a WSW facing embayment between Green Head and Point Louise.
- Its beaches are reflective and are sheltered by the Fairweather Reef approximately 1km offshore of the bay centre.
- Long walled episodic transgressive dunes and smaller blowouts overlying limestone outcrops have contributed to formation of Green Head tombolo.
- Similarly, nested parabolic dunes sourced in Anchorage Bay, extend northwards landward of Point Louise.
- Urban development occupies most of the barrier in the vicinity of Green Head.
- Close to shore, the frontal dune ridge has greater than 75% cover where not disturbed by access tracks. The foredune and frontal dunes in Anchorage Bay have 25 to 75% vegetation cover with numerous small blowouts present.

Climate: Temperate; Microtidal; Mid Latitude Storms

- Temperate-zone coast subject to a Mediterranean climate.
- Affected by a variety of weather systems commonly including anticyclonic high pressure systems, extra-tropical cyclones, mid-latitude depressions, strong seabreezes and occasional dissipating tropical cyclones.
- Microtidal with a tidal range at Leeman of 1.2m LAT to HAT.
- Leeman and Green Head are in Wind region B2 (AS1170.2), which means they are rarely subject to tropical cyclones.
- Mid-latitude storm events are the most common source of extreme winds, generally occurring between May and September.
- These storm systems commonly provide winds from the westerly half, often swinging from the northwest through to the southwest, with the peak winds speeds dependent upon the system location, path and thermal structure.
- Direct impact of tropical cyclones along the Midwest coast is infrequent, causing strong winds on average, once every five to ten years. Tropical cyclones may produce strong winds and waves in any direction due to their intense radial structure, but most commonly are passing southwards offshore, and hence produce northeast winds, swinging through to northwest, westerly and southwest winds.
- The relatively narrow shelf and west facing shore of the Midwest reduce the significance of tropical cyclone induced surges compared to the northwest.

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

Development Record: Local Fisheries; Tourism

- Green Head and Leeman are located on the traditional lands of the Yued people.
- The area between Green Head and Jurien Bay is home to the largest number of midden deposits in Southwest Australia.
- Development at Leeman and Green Head was initially associated with fishermen's huts, with increasing development following establishment of the Midwest rock lobster industry, including informal shacks.
- Leeman townsite was formally established in 1961, with subdivision occurring.
- Increased growth of the two sites occurred following establishment of a coastal road in 2004, with completion of Indian Ocean Drive in 2010 increasing accessibility, residential population and tourist activities.
- Both Leeman and Greenhead have boat ramps and small maritime facilities with a service jetty.

Coastal Inundation History:

No tide gauge within the Coorow area; nearest station at Jurien Bay in Shire of Gingin has records for almost 30 years from 1991-2020. Highest water levels recorded at Jurien Bay over the last 30 years were:

EX TC Manga, May 2020 – 2.01m CD (1.13m AHD)
EX TC, May 2003 – 1.89m CD (1.01m AHD)
Mid Latitude Depression, July 1995 – 1.77m CD (0.89m AHD)

- No locally relevant descriptions of inundation impacts are available. Assets within the townsites considered are above the reported inundation levels. Possible inundation around the South Bay boat ramp area and Oceanic Drive at Greenhead.
- It is likely that wave impacts will be a more pressing concern at a site-specific scale for Leeman in particular. These will typically be managed through maintenance of an adequate foreshore reserve.

Hazard: Existing Coastal Inundation Hazard Assessment Summary

- No previous assessments have been identified.

Hazard: Existing Controls

Existing controls for coastal inundation in the Shire of Coorow are limited to planning requirements for development approval. For Leeman and Green Head, foreshore reserves have been defined, with exclusions for boating access.

Assets: Exposure of Coastal Assets to Inundation Impacts

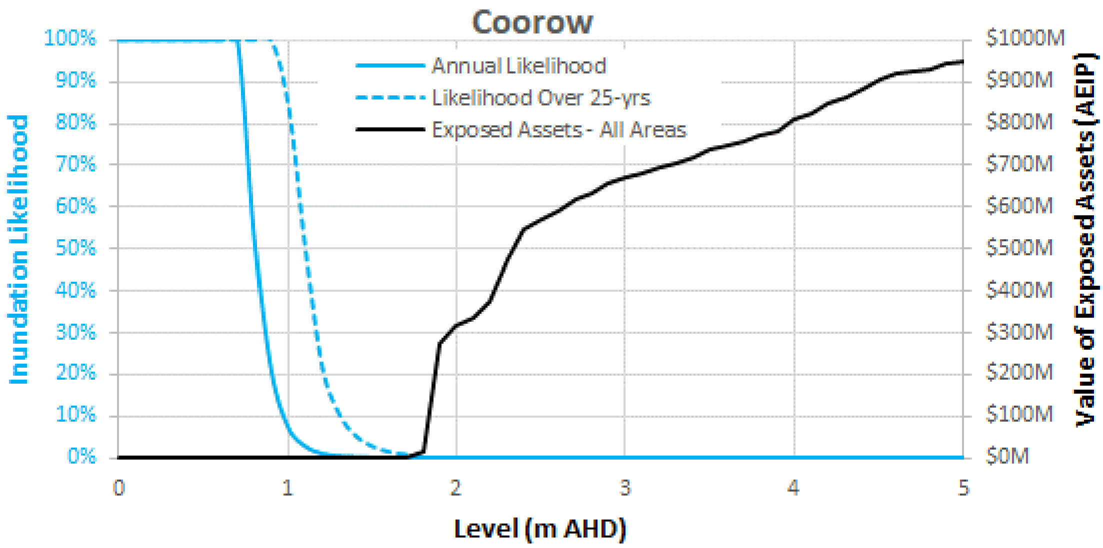
Inundation Level (m AHD)	10.1 Leeman			10.2 Green Head		
	Residential Buildings	Commercial /Industrial Buildings	Roads Major/Arterial (km)	Residential Buildings	Commercial /Industrial Buildings	Roads Major/ Arteri (km)
0.8	0	0 / 0	0 / 0	0	0 / 0	0 / 0
0.9	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.0	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.1	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.2	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.3	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.4	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.5	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.6	0	0 / 0	0 / 0	0	0 / 0	0 / 0
1.7	0	0 / 0	0 / 1	0	0 / 0	0 / 0
1.8	13	0 / 0	0 / 4	0	0 / 0	0 / 0
1.9	175	0 / 0	0 / 5	53	0 / 0	0 / 1
2.0	196	0 / 0	0 / 5	66	0 / 0	0 / 1
2.1	203	0 / 0	0 / 5	74	0 / 0	0 / 2

Other Assets Exposed:
10.1 Leeman
Extreme +0.9m: 2 airport landing grounds; 1 ambulance station

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

Comparison of exposed assets and estimated inundation likelihood indicates assets identified via AEIP are above the levels most likely to be affected by coastal inundation. Notably, this does not include effects of waves, which can extend to higher levels.

Substantial increase in asset exposure from 1.8m AHD indicates high senstivity to an inundation difference of around 0.7m. This difference could be developed through event scenarios or statistics, inclusion of wave processes, or allowance for sea level rise.



Damage: Inundation Risk Ratings

Average Annual Damage		AEIP			
	WL	1.1m AHD	1.2m AHD	2.1m AHD	All WL
Area	ARI	High	Extreme	Extreme+ 0.9m	
10.1: Leeman		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
10.2: Green Head		$ 0K/yr	$ 0K/yr	$ 0K/yr	$ 0K/yr
Total Damage		**$ 0K/yr**	**$ 0K/yr**	**$ 0K/yr**	**$ 0K/yr**

As indicated by separation of identified asset exposure and inundation likelihood, Leeman and Green Head have no effective inundation hazard. The potential influence of wave action is considered likely to be mitigated by existing foreshore reserves.

Planning Framework

Coorow Local Planning Scheme No 3 acknowledges need to consider coastal inundation and requirement for appropriate foreshore reserves as part of the development approval process, with SPP 2.6 acknowledged in the Local Planning Strategy. The Shire does not presently have a CHRMAP, with the Local Government Coastal Planning Study: Mid-West Region (2015) and Leeman to Green Head Coastal Strategy (2018) identifying development of a CHRMAP is a future need.

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

HC1	• Coastal inundation is identified as a consideration for development approval.
HC2	• Inundation scenarios have not been defined.
HC3	• There is no information on inundation hazard.
HC4	• There is no information regarding mitigation of inundation hazard.
HC5	• Pathways for adaptation are not identified.
HC6	• The planning framework does not acknowledge the role of emergency management for coastal hazards.
HC7	• There is no guidance regarding building design for areas prone to inundation.
HC8	• A special control area for coastal hazards has not been defined.