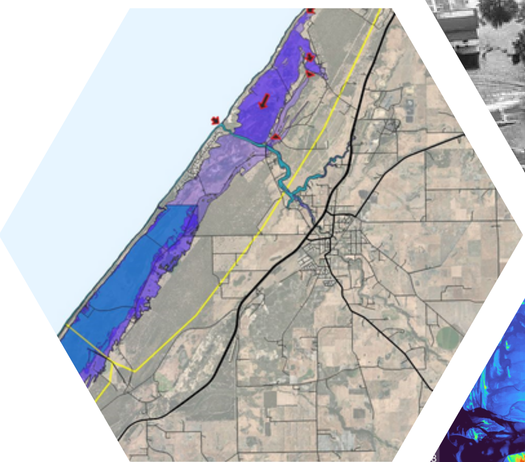
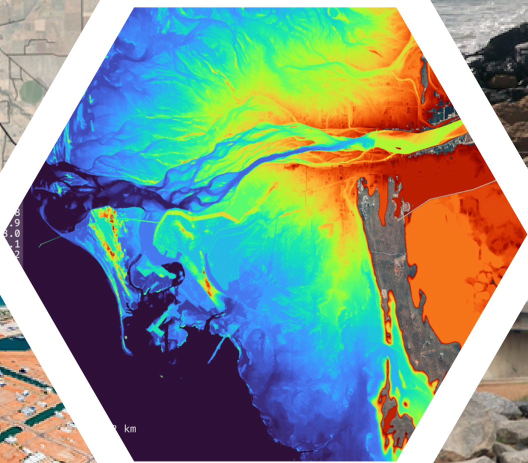
Seashore Engineering

A Statewide Coastal Inundation Assessment for WA





Prepared for:

coastwa

GOVERNMENT OF WESTERN AUSTRALIA

Department of **Planning, Lands and Heritage**
Department of **Transport**

Executive Summary

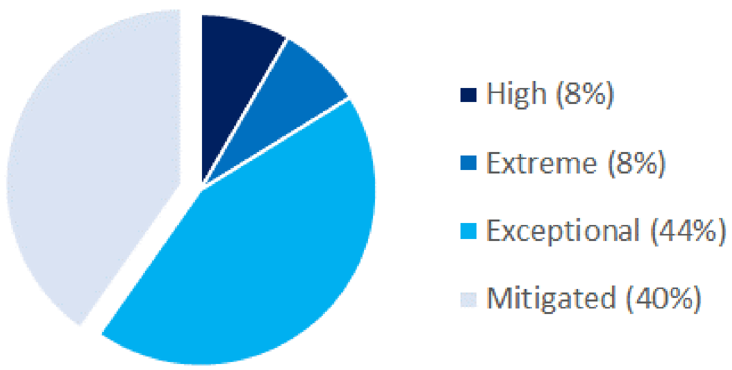
WA Government is working towards a whole of state approach for management of coastal hazards. This assessment focuses on coastal inundation, which occurs when high ocean water levels adversely impact on assets or values that are usually outside the influence of the sea. The assessment aims to evaluate potential scale and extent of coastal inundation in WA over the short to medium term at present and into the next 25 years. The assessment is intended to assist Government develop a strategic approach to challenges presented by inundation hazards.

This evaluation has been undertaken on behalf of the WA Department of Transport, with input from the Department of Planning, Lands and Heritage. The Statewide inundation assessment comprises two stages: stage 1 focuses on the identification of 'at risk' sites and a pilot hazard assessment. Stage 2 (this report) presents a more detailed evaluation of the 23 at-risk sites identified in Stage 1.

Development of a whole of State approach has focused on identifying sites with potential for inundation impact to private or public assets within the next 25 years. It is recognised that hazard is expected to increase over time, with projected sea level rise, requiring future adaptation. Following initial screening, 23 sites were identified for detailed evaluation, including:

- Characterisation of inundation likelihood using tide gauge information.
- Topographic analysis to identify pathways and extent of coastal inundation.
- Identifying existing assets and their estimated values, using the National Exposure Information System (NEXIS) database via Australian Exposure Information Portal (AEIP).
- Applying damage functions, to assess potential costs of inundation.
- Review of State and local planning frameworks, in the context of readiness to apply integrated and adaptive management to coastal inundation.
- Identification of directions for improved local assessment and decision-making.

Site summaries were produced for the at-risk sites to provide an overview of findings for each of the focus Local Government Areas. Evaluation of inundation hazard and asset exposure has identified the scale and extent of coastal inundation pressures across WA. This highlights that inundation impacts, while infrequent at most sites, can be substantial, with $10M-$100M damage possible at individual townsites, mainly affecting residential dwellings. Most of the identified risk is associated with exceptional events, above typical standards of protection (100-500yr ARI). Considering annualised risk, with estimated damage multiplied by likelihood, then 44% of risk is associated with exceptional events, and 40% of risk is mitigated by existing inundation protection measures (Figure 6-1).



Distribution of Annualised Average Damage

Considered for all sites, this represents the proportion of annualised damage (estimated damage times likelihood) associated with high (up to ~25yr ARI), extreme (~25-100yr ARI) or exceptional (above ~100yr ARI) events.

	HIGH	EXTREME	EXTREME +0.9M
DAMAGE WITH SSB*	$25M AUD*	$133M AUD*	$4,100M AUD*
DAMAGE WITHOUT SSB**	$48M AUD**	$288M AUD**	$4,100M AUD**
# SITES IMPACTED**	10 sites**	15 sites**	20 sites**
# SITES OVER $1M AUD**	Carnarvon Bunbury Busselton	Broome Port Hedland Ashburton Carnarvon Shark Bay Mandurah Harvey Bunbury Busselton	All except Karratha, Northampton, Esperance

*with the protection provided by Bunbury Storm Surge Barrier (SSB)
** without protection provided by Bunbury Storm Surge Barrier (SSB)

Potential Damage from Inundation at Event Scenarios for WA
This is the estimated damage that would be developed if all locations experienced events at equivalent level (high, extreme, or extreme +0.9m).

	HIGH	EXTREME	EXTREME +0.9M	ALL WATER LEVELS
DAMAGE WITH SSB*	$2.0M/yr*	$3.9M/yr*	$11.1M/yr*	$14.4M/yr*
DAMAGE WITHOUT SSB**	$5.9M/yr**	$10.3M/yr**	$20.7M/yr**	$24.1M/yr**
# SITES IMPACTED**	10 sites**	15 sites**	19 sites**	20 sites**
# SITES OVER $1M AUD**	Busselton $4.4M/yr Bunbury $1.4M/yr	Busselton $5.6M/yr Bunbury $3.8M/yr	Bunbury $9.3M/yr Busselton $8.5M/yr	Bunbury $9.7M/yr Busselton $8.9M/yr Port Hedland $2.0M/yr Carnarvon $1.2M/yr

*with the protection provided by Bunbury Storm Surge Barrier (SSB)
** without protection provided by Bunbury Storm Surge Barrier (SSB)

Average Annual Damage from Inundation for WA
Calculated by multiplying damage and event likelihood across a range of inundation events.

Findings from the evaluation include:

1. Financial impact from inundation has been estimated as an average of $11M/yr damage, combined for all 23 coastal LGs. However, this will mostly occur as infrequent major events, say once every 10-30 years, with correspondingly higher damage.
2. The most significant sites for inundation management are at Bunbury and Busselton, which are actively managing existing risk through use of protective structures, mitigating an estimated $9.7M/yr damage, although subsequent development has introduced substantial risk associated with exceptional events.
3. Much of the annualised average damage (~73%) has been assessed to occur during exceptional events (above levels typically used for design). Almost all this risk is from potential events overwhelming existing defences at Bunbury and Busselton, which could produce devastating damage in the order of $100M to $1000M. Potential impacts at other sites is generally smaller, but still in the potential range of $10M to $100M for Carnarvon, Port Hedland, Fremantle, Mandurah, Shire of Murray, Broome, or Lancelin.
4. There is an immediate need to review Busselton's inundation protection in detail. It is noted that City of Busselton are presently undertaking detailed investigations.
5. Frequent exposure of built assets to inundation occurs across low elevation coastal areas of Geographe Bay, between Busselton and Australind. Other sites with high frequency of inundation exposure include Carnarvon, due to low elevation, and Cervantes, where there is inadequate foreshore reserve to mitigate waves. At most other sites exposure to inundation commences with extreme events (around 100yr ARI) with significant damage generally developed only by exceptional events.
6. Existing tools used for inundation assessment typically do not incorporate risk associated with exceptional events, which can and do occur. It is implicitly assumed that emergency management provides adequate mitigation of inundation impacts during exceptional events. However, emergency management actions largely focus on human safety, rather than financial impacts. Asset loss or damage during exceptional events is typically considered a natural disaster, which may be eligible for relief funding or insurance.
7. Inundation risk is substantially associated with private residences. Since 2014, this financial risk cannot be offset by standard insurance policies. Consequently, financial impact will be on private landowners.

A key conclusion of this assessment is:

> **Relative exposure to exceptional events should be a key driver for inundation management decision making, rather than assuming risk above mitigation thresholds is tolerable.**

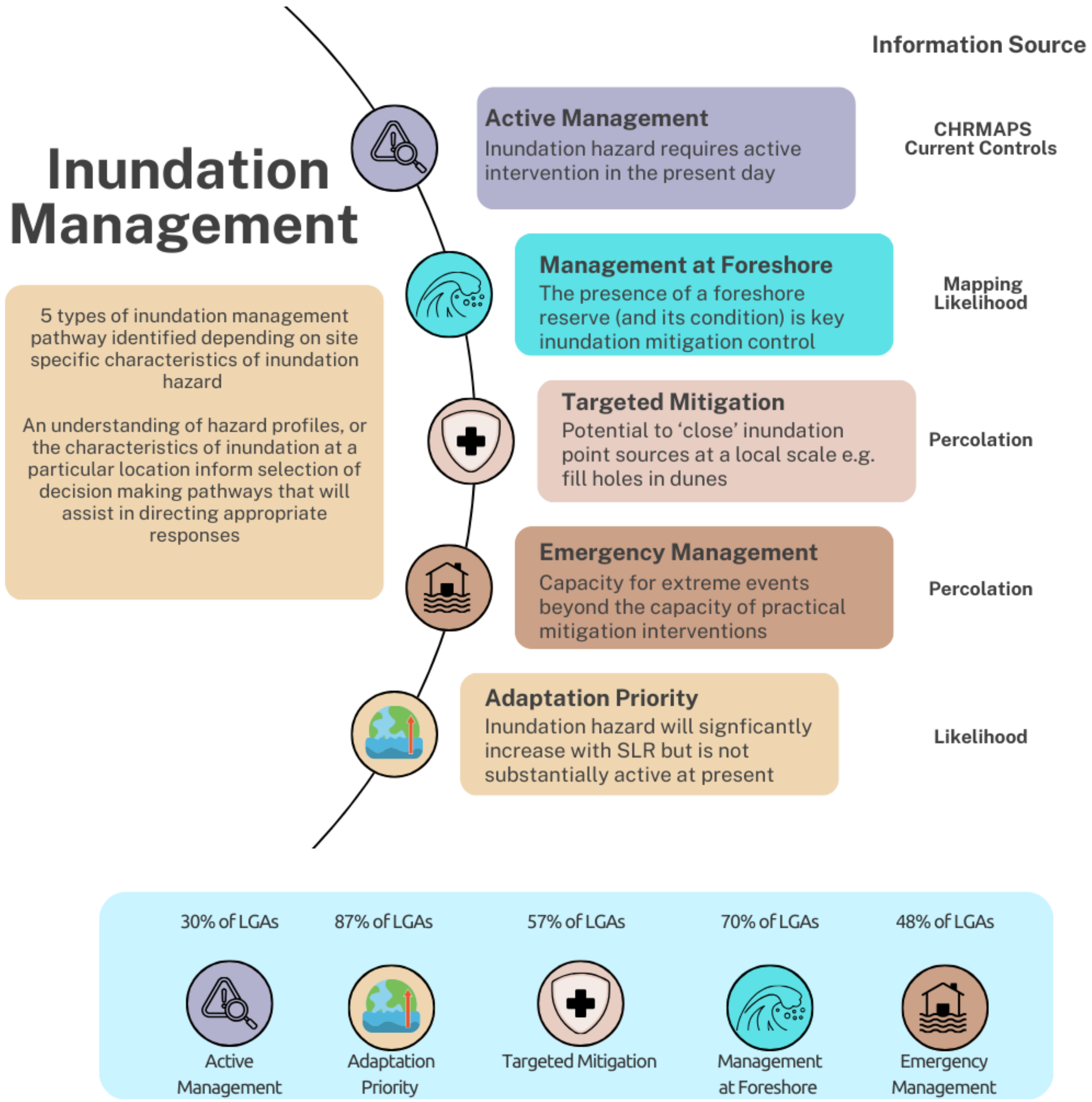
It is highlighted the existing planning approach in SPP2.6, to preferentially avoid coastal hazard with a long-term forecast, remains international best practice, supported by risk-based evaluation through CHRMAP. However, tools used to delineate zones of hazard avoidance are not well-suited to identification of inundation mitigation actions in developed sites, where it is impractical to avoid the hazard. In these locations, there is increased need to use refined inundation decision-making. This need will increase in the longer term, under projected sea level rise.

Coastal inundation susceptibility, based on estimated damage scale, immediacy, and sensitivity, has been used to guide recommended decision-making and actions at individual LGs.

Coastal Inundation Susceptibility and Decision-Making
These are indicative only.

	Coastal Inundation Susceptibility Rating				
	0	**1**	**2**	**3**	**4**
Inundation Susceptibility	Negligible	Limited	Moderate	High	Extreme
Decision-making timeframes	>25 years	>25 years	5–25 years	1–5 years	Active
Hazard Assessment	N/A	CHRMAP Hazard Lines		Damage Based Hazard Assessment	
Actions to be Taken	N/A	N/A	Review WL Likelihood	Review Sensitivity	Economic Review
Management Plans	Regional Coastal Management Plan only			Assess need for Plans	Inundation Plan
Basis for Classification	Above Design Storm WLs	Future Inundation Risk	Low Inundation Risk	Moderate Inundation Risk	High Risk / Active Management
LGs		Coorow Esperance Karratha Northampton Rockingham	Augusta-MR Dandaragan Exmouth Fremantle Geraldton Gingin Mandurah Murray Shark Bay	Albany Ashburton Broome Capel Harvey Port Hedland	Bunbury Busselton Carnarvon

In all locations, it is appropriate to consider all aspects of coastal inundation. However, existing townsite layouts and management suggest different areas of focus for inundation management, not mutually exclusive, broadly classed into active management, management at the foreshore, targeted mitigation, emergency management and adaptation priority.



Focal Areas for Inundation Management

Assessment of inundation hazard using high resolution elevation data supported identification of 13 sites appropriate for targeted assessment. This involves evaluation of a local inundation pathway, to determine whether targeted works may cost-effectively alleviate inundation risk.

Locations for Targeted Assessment

Local Government	Location	Description	High WL	Extreme WL
Port Hedland	West End	Central Port Hedland, along the Esplanade from +4.7m AHD.	+4.2m AHD	+5.0m AHD
Ashburton	Onslow *	Arriving through Third St at +3.9m AHD.	+2.5m AHD	+3.5m AHD
Exmouth	South of Exmouth Marina	Along Crevalle Way at +3.5m AHD via a coastal breakout ~700m to the south.	+2.3m AHD	+3.1m AHD
Carnarvon	South Carnarvon *	Arriving through Yacht Club at +1.6m AHD.	+1.7m AHD	+2.1m AHD
Gingin	Lancelin	Inundation to low lying areas depends on dune breaching.	+1.0m AHD	+1.2m AHD
Fremantle	North Fremantle	Arriving along Johannah St at +1.1m AHD.	+1.2m AHD	+1.4m AHD
Rockingham	Palm Beach	Arriving across Esplanade near Fisher St at +1.9m AHD.	+1.2m AHD	+1.4m AHD
Mandurah	Manjar Bay	Along Ormsby Tce and Cooper St, from +1.4-1.5m AHD.	+1.2m AHD	+1.4m AHD
Bunbury	Bunbury *	Arriving at Bunbury CBD at +1.3m AHD. Mitigated by storm surge barrier to +2.16m AHD.	+1.6m AHD	+1.9m AHD
Capel	Peppermint Grove Beach *	Arriving at +1.2m AHD via Stirling Wetland. Mitigated by Vasse-Wonnerup storm surge barriers to ~+1.5-2.0m AHD.	+1.7m AHD	+2.0m AHD
Busselton	Multiple sites *	Pathways through coastal dunes, estuaries, and agricultural drains at a range of levels.	+1.8m AHD	+2.1m AHD
Albany	Behind Middleton Beach	Arrival at +1.6m AHD via inlet at Emu Point.	+1.1m AHD	+1.3m AHD
Esperance	The Esplanade	Arrival at +2.3m AHD north of Taylor St Jetty.	+1.3m AHD	+1.5m AHD

* These sites have existing inundation mitigation structures.

Planning Framework Review

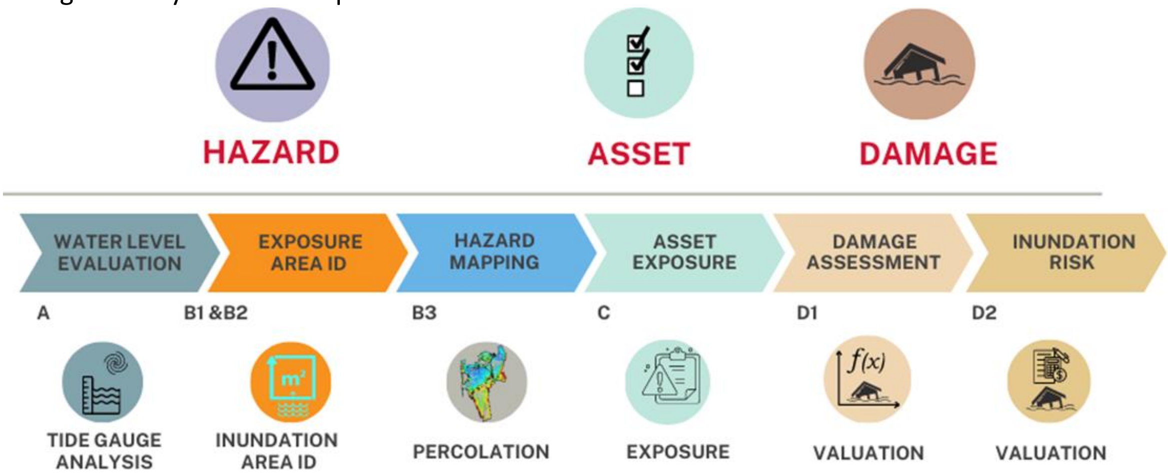
Review of planning frameworks indicated that LGs have evolved a range of approaches for coastal inundation management and adaptation. These extend outside the conventional planning model recommended by DPLH, which utilises Special Control Areas for special provisions.

A 'Planning Framework Health Check' was undertaken for each LGA, specifically to evaluate how existing LG planning frameworks could support whole-of-system coastal inundation management, including adaptation. Overall, there is wide variability, suggesting appropriate pathways for refinement will be distinct for each LG. At present, LG planning frameworks do not support use of the full range of coastal inundation management tools. This doesn't align with LG's expressed interest in having a choice of approaches, able to be effective and fit-for-purpose across a range of scales. Recommended actions include:

- More consistent use of agreed methodologies and inundation scenarios.
- A focus of avoiding inconsistency and ambiguity within planning documents.
- Consideration of a wider range of mitigation options to improve cost-effectiveness of managing coastal inundation.
- Improved recognition of the role of building design and emergency management for coastal inundation is required, including their effect to offset inundation criteria.

Coastal Inundation Assessment Method

A hazard-asset-damage evaluation method for inundation assessment has been developed to ensure consistency across the State. This method is consistent with the national framework for management of Natural Hazards, and was derived through evaluation of available datasets, governance, and policy settings. Use of the Australian Exposure Information Portal (Geoscience Australia) provided a significantly accelerated process for evaluation of assets at risk and their valuation.



Although the strategic method applied for this assessment was simplified, it offers several opportunities for improvement of detailed inundation assessments typically undertaken to support CHRMAP. These include:

1. Use of the percolation assessment, or equivalent, provides a clear first pass evaluation of the identification of hazard onset and pathways than use of hazard lines commonly presented in CHRMAP.
2. Incorporation of shapefile functionality into the spatial intersection of assets exposure and hazard facilitates better linking of detailed coastal hazard assessment, derived through numerical modelling.
3. Identification of incremental damage estimates supports simplified financial justification for mitigation works, by submitting amended shapefiles to AEIP for valuation.

It is recommended that liaison with Geoscience Australia be undertaken, to identify opportunities for local-scale refinement of exposure information. This may include:

1. More direct transfer of valuation and asset information from LGs to Geoscience Australia.
2. Development of higher-resolution positioning of assets at selected coastal locations.
3. Refinement of damage functions, to better incorporate local building information and hazard characteristics (e.g. water levels, waves and currents).

Table of Contents

List of Figures

List of Tables

Limitations of this Report

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Document Control

Index	Author	Date	Review	Date	Comment
Rev A	M.Eliot	02.11.2023			
Rev B					
Rev 0	M.Eliot	30.11.2023	DoT	07.12.2023	
Rev 1	M.Eliot	14.12.2023			

1 Introduction

The Western Australian (WA) Government is working towards a whole of state approach for management of coastal hazards, identifying amplitude and extent of hazards, assets at risk, potential management pathways and challenges to implementation of good practice. This understanding will help develop an overarching WA Government strategy for technical investigations, policy review and financing. Identified coastal hazards include erosion, inundation, and mobility of coastal landforms, with a strategic assessment of coastal erosion previously completed [1].

This assessment focuses on coastal inundation, which occurs when high ocean water levels adversely impact on assets or values that are usually outside the influence of the sea. State Coastal Planning Policy SPP2.6 [2] recommends that, where possible, coastal development avoid inundation hazard, by considering severe events, over longer time frames, including allowance for projected sea level rise. However, as many townsites were developed prior to this policy, a number have active or emerging inundation risk.

The assessment aim is to evaluate potential scale and extent of coastal inundation in WA over the short to medium term and builds upon findings of an initial study to assess available information and its feasibility to support strategic assessment [7]. This is intended to assist Government develop a strategic approach to challenges presented by inundation hazards. Development of a whole of State approach has focused on identifying sites with potential for inundation impact to private or public assets within the next 25 years. It is recognised that hazard is expected to increase over time, with projected sea level rise, requiring future adaptation. For each site, assessment has included:

- Characterisation of inundation likelihood using tide gauge information.
- Analysis of high-resolution topography to estimate pathways and extent of coastal inundation, using 0.1m vertical intervals.
- Identifying existing assets and their estimated values, extracted from the National Exposure Information System (NEXIS) database [3] via Australian Exposure Information Portal (AEIP) [4].
- Applying depth-related damage functions, to assess financial implications of potential inundation events [5].
- Review of planning frameworks.

This method is consistent with the national framework for management of Natural Hazards [6], and was derived through evaluation of available datasets, governance, and policy settings [7].

Information developed for this evaluation is strategic, with on-ground implementation of coastal inundation management, typically led by Local Government, requiring interpretation and in many cases substantial further refinement. More detailed investigations with implementation plans, such as Coastal Hazard Risk Management and Adaptation Planning (CHRMAP) [8] and site-specific inundation studies [9] required at a local scale as part of comprehensive CHRMAP.

This evaluation has been undertaken on behalf of the WA Department of Transport, with input from the Department of Planning, Lands and Heritage.

1.1 Coastal Inundation Assessment for WA

The Western Australian Government has recognised that development of large-scale mitigation infrastructure can take 10-20 years from identification of need to implementation, and typically requires targeted financing. To support this process, a proactive approach is preferred, strategically assessing future needs, and commencing preliminary investigations ahead of the hazard becoming intolerable. **The WA Government has therefore committed to undertake a strategic, Statewide Assessment to identify pathways for improved coastal inundation management**.

The first phase of the Statewide Assessment [7] involved:

- **Evaluation of existing inundation management in WA, and comparison with National and international practice**. This indicated transferring from threshold-based inundation criteria to risk management is widely occurring in global flood management practice, supported at a national level by a natural hazard assessment framework, that includes exposure and damage across the full range of hazard events. These frameworks are not presently widely used in WA, with limited recognition of hazard uncertainty and residual risk (hazard above protection thresholds).
- **Examination of governance, policy, and information sources for coastal inundation management in WA**. This indicated that coastal inundation management tools of planning, building approvals and emergency management are separate and distinct, limiting the application of integrated management.
- **Collation and evaluation of completed CHRMAP to assess consistency and ability to provide a basis for strategic analysis.** This identified that while CHRMAP provide a substantive body of work relevant to coastal inundation management, it is generally tailored for local relevance, and not to provide a consistent basis to support Statewide strategic evaluation.
- **Liaison with Local Government to identify capacity and practices to manage existing and future inundation hazard**. Local governments (LG) indicated that existing knowledge had been substantially developed through CHRMAP, with most acknowledging an increased need for inundation management would result from projected sea level rise, requiring additional knowledge, staff resources and funding. LGs generally identified a willingness to apply a wider range of management techniques.
- **Preliminary identification of townsites potentially subject to coastal inundation impacts within the next 25 years**. Using existing estimates of inundation levels and on-line visualisation tools, 23 townsites were identified as having potential for coastal inundation hazard. Limitations of both inundation estimates and mapping were identified.
- **Development of a method for strategic evaluation of coastal inundation hazard across WA, considering information constraints**. The method developed incorporates high resolution topography, the NEXIS database and depth-related damage functions to evaluate a probabilistic estimate of potential damage associated with coastal inundation. It was noted that this method provides a preliminary evaluation but can be extended to provide a more nuanced approach appropriate for local assessment and decision-making.

The capacity to apply a more uniform approach, and further refine pathways for improved coastal inundation management were taken forward into Phase 2 of the Statewide Assessment.

Phase 2 of the coastal inundation assessment has involved:

1. Application of refined inundation hazard assessment, following Phase 1:
   - Identification of areas potentially subject to inundation.
   - Characterising how inundation hazard affects each LG, supporting comparison of relative impacts across the State.
   - Identification of infrastructure value that may be affected by coastal inundation, accounting for relative event likelihood and inundation across a range of possible levels.
   - Presenting results as inundation summaries for individual LG (Appendix A).
2. Review of planning framework readiness to apply integrated and adaptive management to coastal inundation. This assessed:
   - State Government policy and guidance.
   - LG planning and coastal management documents.
3. Identification of directions for improved local assessment and decision-making including the:
   - Summary of available LG practices.
   - Description of supplementary tools and datasets.
4. Identification of potential for better alignment with national disaster risk management practices and available information.
5. Development of actionable recommendations for stakeholders across a wide range of key areas, including inundation risk management, policy and governance, and longer-term resilience.

2 Coastal Inundation Context for WA

Coastal inundation is a hazard occurring when ocean water levels rise above critical thresholds to threaten human life or cause detrimental impact to human property (see **Box 1**).

Occurrence of extreme coastal inundation affecting WA is reported from oral histories [10,11] and evidenced by stratigraphic records [12,13]. Post-colonial records are limited, with many parts of the State remaining substantially undeveloped until growth phases in the 1960s and 2000s, providing limited observations of ocean water levels or inundation impacts.

Historically, coastal inundation in WA is an infrequent hazard, but capable of creating substantial impacts. The severity of observed impacts has determined that coastal inundation has played a significant role in WA town planning, including:

- Repeated damage to the townsite of Cossack from 1881 to 1925, leading to its abandonment.
- Cyclone impacts requiring relocation of Onslow in 1925.
- Significant damage to Port Hedland in 1939, leading to restriction of townsite development and the inland establishment of South Hedland in the 1960s.
- A series of tropical cyclones affecting Carnarvon from 1976-1981, resulting in closure of the Gascoyne South Arm, and progressive works along the town foreshore to restrict inundation and flooding impacts.
- Installation of significant mitigative works across Bunbury, following river flooding in 1964 and coastal inundation during TC Alby in 1978.
- Identification of minimum floor levels through Busselton following coastal inundation during TC Alby in 1978 (see **Box 1**).

Due to the significance of these impacts and the challenges of retroactive mitigation, by 1973 WA had adopted an approach to preferentially avoid coastal hazards, with a general setback policy for coastal erosion [14] and targeted assessments for coastal inundation [15]. This tended to result in a geographic separation of critical hazards:

- In the southwest, inundation hazard was typically included inside the area of erosion hazard.
- In the northwest, where severe tropical cyclones occur, inundation hazard typically defines a much greater area than erosion hazard.

The infrequent and episodic nature of coastal inundation tended to downplay its significance compared to wave overtopping and erosion, which more evidently display evolving hazard through progressive coastal change. To address this, WA Policy for inundation was shifted to a probabilistic basis using Annual Recurrence Intervals (see **Box 2**), with target likelihood changing from maximum tolerable exposure (e.g. requiring building floor levels to be above 100-yr ARI), through to definition of a potential hazard zone, using 500-yr ARI.

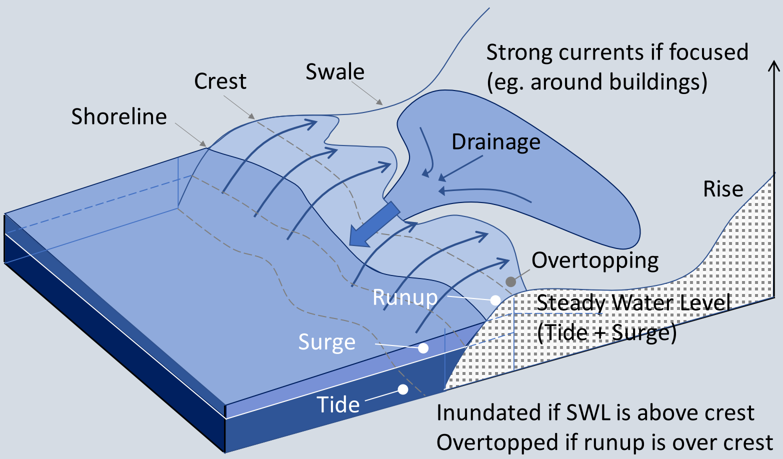
Inundation has remained one of the main coastal hazards to be considered when identifying potential for land development [2]. However, movement towards application of risk management frameworks has potential to downplay significance of coastal inundation, through limited consideration of risk above design event thresholds and due to perceived tolerance of assets to short-term inundation (discussed in more detail in Section 5.1).

Box 1: Coastal Inundation Terminology

High ocean water levels potentially create a series of impacts:

- At moderate-high levels, there is potential to cause beach and dune **erosion**, as the upper part of the beach experiences atypical waves and currents.
- When sea level is high, it may enable wave **overtopping**, which is water passing over coastal barriers such as dunes or seawalls. This potentially impacts on structures, vehicles, or people along or behind the barrier. Overtopping is typically a near-coast issue, which can be managed by effective shore protection, including drainage systems.
- For extremely high sea levels, direct coastal **inundation** occurs when sea level is above, around or through coastal barriers. Under these conditions the volume of water able to move landward is orders of magnitude greater than via overtopping, severely limiting effectiveness of drainage systems.

This assessment focuses on coastal inundation processes, excluding interactions with stream flow and rainfall runoff flooding. Coastal inundation encompasses all conditions where a substantial volume of seawater travels over normally dry land, including effects of individual waves. This typically excludes the effects of wind-blown sea spray, although under certain rare conditions, this can be focused enough to cause flooding.



Processes of Inundation, Overtopping and Drainage

Wave Overtopping at Mindarie
Photo: City of Wanneroo

Inundation at Bunbury during TC Alby (1978)

Box 2: Statistical Terminology

Annual Recurrence Intervals and Annual Exceedance Probability

Average Recurrence Interval (ARI) and Annual Exceedance Probability (AEP) are different ways of describing how often or likelihood a water level occurs.

What is the Average Recurrence Interval?

ARI is used to communicate the typical length of time between occurrences of a given sea level. It is implicit that time between exceedances is generally random, and this time may be much shorter or longer, depending on conditions experienced.

ARI is alternately called "return period". Common misinterpretations are that ARI implies regular intervals (cycles) between events or that extreme levels can only occur once within the given length of time. Instead, they can happen once, multiple times, or not at all. For example, in any given year there is a 1% chance that a 100 year ARI water level could be reached. However, occurrence does not modify the behaviour of subsequent events, and it is possible for multiple 100 year ARI events to occur within a single year.

What is Annual Exceedance Probability?

AEP is defined as the probability or likelihood that a given water level will be exceeded in any one year.

How does AEP relate to ARI?

With ARI expressed in years, the relationship is:

$$\mathrm{AEP} = 1 - \exp\left(\frac{-1}{\mathrm{ARI}}\right) \qquad (1)$$

Likelihood of exceedance increases over multiple years (Y), indicated by the relationship:

$$\mathrm{EP} = 1 - \exp\left(\frac{-\mathrm{Y}}{\mathrm{ARI}}\right) \qquad (2)$$

ARI has been used in this study for consistency with most coastal inundation studies reported previously for WA LGs.

Relationship between Average Recurrence Interval (ARI) and Annual Exceedance Probability (AEP) through time

ARI	AEP	Time Frame Considered (years)						
(years)	(per year)	1	2	5	10	25	50	100
0.5	86%	86%	98%	100%	100%	100%	100%	100%
1.0	63%	63%	86%	99%	100%	100%	100%	100%
1.5	49%	49%	74%	96%	100%	100%	100%	100%
2.0	39%	39%	63%	92%	99%	100%	100%	100%
3.5	25%	25%	44%	76%	94%	100%	100%	100%
5.0	18%	18%	33%	63%	86%	99%	100%	100%
10	10%	10%	18%	39%	63%	92%	99%	100%
20	5%	5%	10%	22%	39%	71%	92%	99%
35	3%	3%	6%	13%	25%	51%	76%	94%
50	2%	2%	4%	10%	18%	39%	63%	86%
100	1%	1%	2%	5%	10%	22%	39%	63%
200	0.5%	0%	1%	2%	5%	12%	22%	39%
500	0.2%	0%	0%	1%	2%	5%	10%	18%

1yr ARI has a ~63% probability of being equalled or exceeded in any one year, but a 99% probability of occurring or a 1% probability of not occurring over a 5 year period of observation.

20yr ARI has a ~5% probability of being equalled or exceeded in any one year, and a 39% probability of occurring or a 61% probability of not occurring within 10 years.

100yr ARI has ~1% probability of being equalled or exceeded in any one year, and a 22% probability of occurring or a 78% probability of not occurring over 25 years.

100yr ARI + 0.9m has been used as an upper limit event, to consider sensitivity to extreme water levels. 0.9m was selected due to its use as an allowance for projected sea level rise in long-term planning, although the inundation risk assessment does not consider sea level rise *per se*.

3 Inundation Hazard Assessment

A primary objective for the Statewide assessment is to identify the scope of coastal inundation management appropriate for WA, with an end objective to support business case development for strategic interventions.

3.1 Site Summary Background Information

To support site-specific consideration, background information on morphology, climate, development record, inundation history, existing hazard assessments and existing planning controls were summarised for each of the 23 LGAs (Table 3.1). This background information was included, with inundation assessment outcomes, in individual Site Summaries for each LG (Appendix A).

Table 3-1: Site Summary Background Information

Aspects	Approach
Morphology	Present-day morphology with specific reference to factors effecting inundation impact: • Site summary • Information collated through a review of available CHRMAP reporting and any other available coastal hazard and risk assessment information for each of the study areas (e.g., Erosion Hotspots reporting; Landforms of WA reporting)
Climate	Climate factors effecting inundation: • Site specific summary of pertinent weather and climate factors to describe physical setting of each LG e.g., wind, waves, water levels
Development Record	Development record summary pertinent to inundation impacts: • Pre aerial imagery- CHRMAP review • Shire website mini histories • Review of Landform Assessment Reports
Coastal Inundation History	Summary of inundation history for each of the areas under consideration with a focus on top 3 extreme water level event with identified inundation impacts: • Collation of Seashore in-house knowledge base on water level histories for each site with tide gauge information. • Cross check information for each LG to establish applicability and identify gaps. • Review of relevant information in CHRMAPs and other available reporting.
Hazard: Existing Assessment	Collation of coastal inundation assessments under consideration: • Summary of CHRMAP findings • ID Data sources and analysis methods employed.
Existing Controls	Identification of existing planning/management controls used for each LG: • Basis for adoption, and their targeted role (e.g., human safety or protection) • Review of Phase 1 information previously collated through questionnaires and targeted interviews.

Site summaries also contain information developed through the project:

Assets	Assets: Exposure of Coastal Assets to Inundation Impacts	See Section 0
Planning	Review of the Planning Framework for each LG: • Planning Strategies & Schemes • CHRMAP & supporting studies	See Section 3.4

3.2 Inundation Assessment Method

Phase 1 identified a financially based approach, using a relationship between inundation damage and depth of inundation, to characterise impacts [7] which has been applied for this assessment. Potential financial impacts from coastal inundation have been evaluated using a combination of inundation likelihood, potential spatial extent of inundation, exposure of infrastructure, and estimation of damage associated with inundation conditions (Figure 3-1). This applies the national framework for hazard management, incorporating asset exposure, likelihood, and asset sensitivity [3]. Further description of the methodology is included in Appendix B.

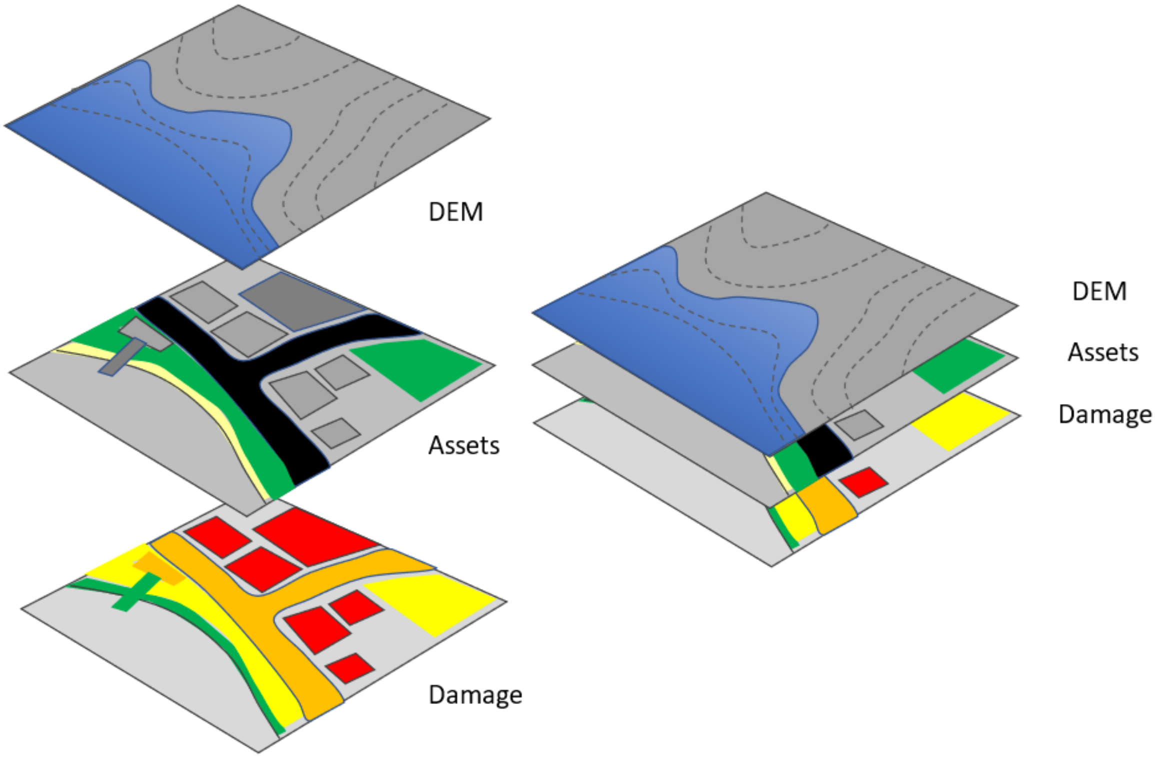


Figure 3-1: Spatial Integration of Asset Exposure with Damage

The method used is based on available information for hazard (exposure), assets, and damage, with objectives for streamlined and timely assessment. More detailed information may be available at individual sites, supporting refined evaluation.

Phase 1 involved reviewing completeness, consistency, information transfer, and quality of data used to support inundation assessment and management in WA. This identified challenges in the consistency of information between sites. The recommended method involves integrating hazard mapping using high resolution topography, with asset location and valuation efficiently provided by AEIP, a portal to the NEXIS database developed by Geoscience Australia [4]. It is acknowledged the derived approach does not use the best available information corresponding to each location, but limits biases introduced by varying sources of information. Consequently:

- The approach used is considered appropriate for a strategic, Statewide assessment.
- For decision-making at a local scale, higher quality information may support more detailed investigations, such as CHRMAP [8].

Steps undertaken to implement the inundation assessment are summarised by evaluation of the HAZARD, assessing the impact to ASSETS and the estimate of financial DAMAGE, with more detailed description of the methodology provided in Appendix B. Topography datasets used in Phase 2 analysis are summarised in Table 3-3.

Table 3-2: Overall Inundation Assessment Approach

Element	Approach
Hazard	Percolation assessment and generation of inundation hazard maps from high resolution topographic data for the 57 Inundation Exposure Areas (IEAs) considered across 23 LGs
Asset Financial Exposure	• Shapefiles describing inundation hazard submitted to AEIP, with data reports collated in sequence. • Primary information extracted includes financial reconstruction costs for residential, commercial, industrial buildings and roads (main and arterial) • Collation of information to yield a set of financial exposure curves for each of the 57 IEAs
Damage Financial Vulnerability	Transformation of financial exposure to estimate damages undertaken by integrating financial exposure with damage curves for each asset category; DWER approach to damage estimation based solely on residential building counts was also applied for comparison
Mitigation	• Evaluation of coastal inundation pathways provides a basis for preliminary identification of mitigation options. *A framework for future consideration of mitigation activities has been presented in Section 5.*

Table 3-3: Topography Dataset Used for Analysis

High resolution topography (LIDAR or similar) was accessed for all LGs except Carnarvon and Shark Bay.

Local Government	Type	Date	Source	Grid Spacing/Horizontal Resolution (m)
Broome	LiDAR	2013	DWER	1
Port Hedland	LiDAR	2010	Landcorp	1
Karratha	LiDAR	2010	Landcorp	1
Ashburton	LiDAR	2010	Landcorp	1
Exmouth	LiDAR	2006	DWER	1
Carnarvon	Ortho DEM	2014	DoT	1
Shark Bay	Ortho DEM	2017	DoT	2
Northampton	LiDAR	2016	DoT	5
Geraldton	LiDAR	2016	DoT	5
Coorow	LiDAR	2016	DoT	5
Dandaragan	LiDAR	2016	DoT	5
Gingin	LiDAR	2016	DoT	5
Fremantle	LiDAR	2008	DoW	1
Rockingham	LiDAR	2008	DoW	1
Mandurah	LiDAR	2008	DoW	1
Murray	LiDAR	2008	DoW	1
Harvey	LiDAR	2008	DoW	1
Bunbury	LiDAR	2008	DoW	1
Capel	LiDAR	2008	DoW	1
Busselton	ALS	2023	Busselton	1
Shire of Augusta MR	LiDAR	2016	DoT	2
City of Albany	LiDAR	2021	Landgate	1
Shire of Esperance	LiDAR	2010	Shire	1

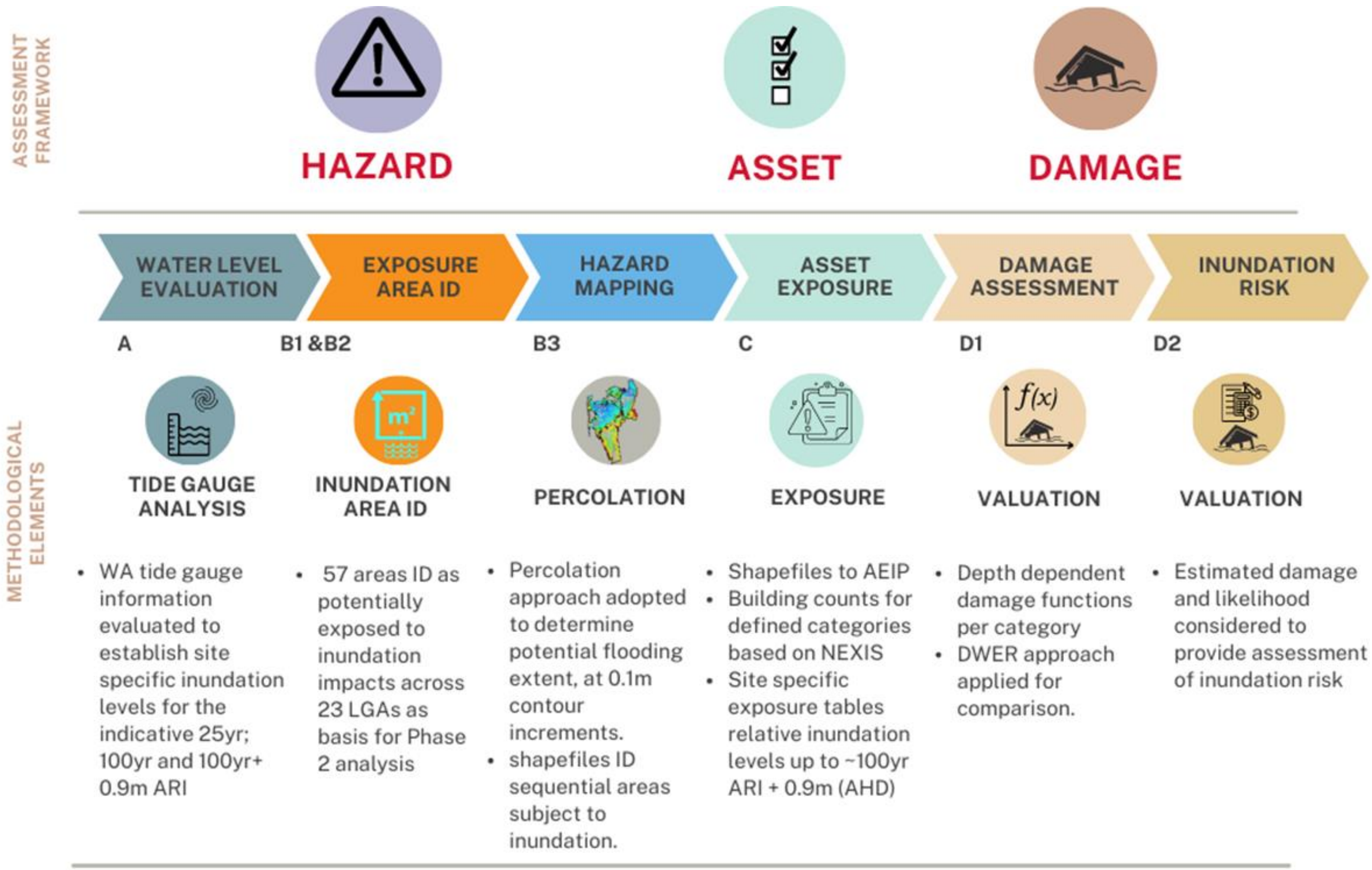


Figure 3-2: Steps to implement inundation assessment

3.3 Inundation Assessment Components

For each site, application of the inundation assessment method generated:

- **Percolation assessment** shapefiles for each location of interest.
- **Hazard maps** for each of 23 LGs subdivided into 57 inundation exposure areas.
- **Financial Exposure:** assessment of potential value of:
  1. Building reconstruction values across residential, commercial, and industrial classes, exposed to inundation impacts.
  2. Exposed institutions, infrastructure, businesses, agriculture, and environmental assets.
- **Asset Exposure:** identification of exposed asset counts.
- **Financial Vulnerability:** Calculation of damage values for exposed buildings through application of depth related damage functions.

3.3.1 Percolation Assessment

The percolation assessment is a simplified representation of the spatial extent for inundation events. Areas are generated, using the highest resolution topography available for each townsite by identifying where land levels are below a threshold level, with a hydraulic connection to the ocean. Percolation mapping has been conducted at each site for 0.1m vertical intervals, allowing identification of discrete inundation pathways (Figure 3-3). For application in the inundation assessment, it was important that successive areas were cumulative (i.e. area below 1.4m AHD, area below 1.5m AHD etc., rather than area 'bands' from 1.3-1.4m AHD, 1.4-1.5m AHD etc.) to interact with the exposure database (see Section 3.3.4). The methodology used to develop percolation is described in Appendix B, and shapefiles of the percolation assessment are accessible via electronic archive:

https://damarawaptyltd-my.sharepoint.com/:f:/g/personal/matt_eliot_damarawa_com
/EjXVa5C3hfZKgKPdKx2COhwBKe_3rDnmqDXH4qwKFdIcYw?e=WEfabB

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3.3.2 Hazard Maps

A sub-selection of the percolation assessment was used to develop hazard maps for each inundation site, which have been included in site summaries. For each location, three inundation levels were chosen, based on statistics derived from tide gauge observations (see Appendix C) with no allowance for wave setup. As tide gauge locations are typically located to minimise the influence of wave effects, which can occur nearshore, the analysis method described in Appendix 3 results in the inundation recurrence to not directly match the tide gauge ARI. Derived levels are indicative, and specifically used to focus on statewide strategic assessment purposes reported on here only. They should not be used in engineering design, as integration of local factors (see Section 5.3) and design conservatism should be applied.

High Inundation: this level of inundation approximately corresponds to a 25-year ARI water level selected to allow a consideration of the likely extent of inundation hazard at the present time.

Extreme Inundation: this level of inundation approximately corresponds to a 100-year ARI water level.

Extreme +0.9m Inundation: is shown to demonstrate relative sensitivity of inundation to other contributing factors, including uncertainty about inundation levels, wave components, or mean sea level change. A value of 0.9m was chosen because of its application for long-term (100-year) planning as a sea level rise allowance, to support closer comparison to typical CHRMAP projections. However, it is reiterated this assessment has been developed with a 25-year forecast time frame (aligning with general LG capital work planning), over which sea level rise is projected to be less than 0.2m.

Where identified from the percolation assessment, the main pathways by which coastal inundation occurs have been indicated by arrows, for example, hazard map of the City of Fremantle in Figure 3-5. In some townsites, sub-areas were identified for the purpose of inundation assessment, based on distinct pathways for inundation.

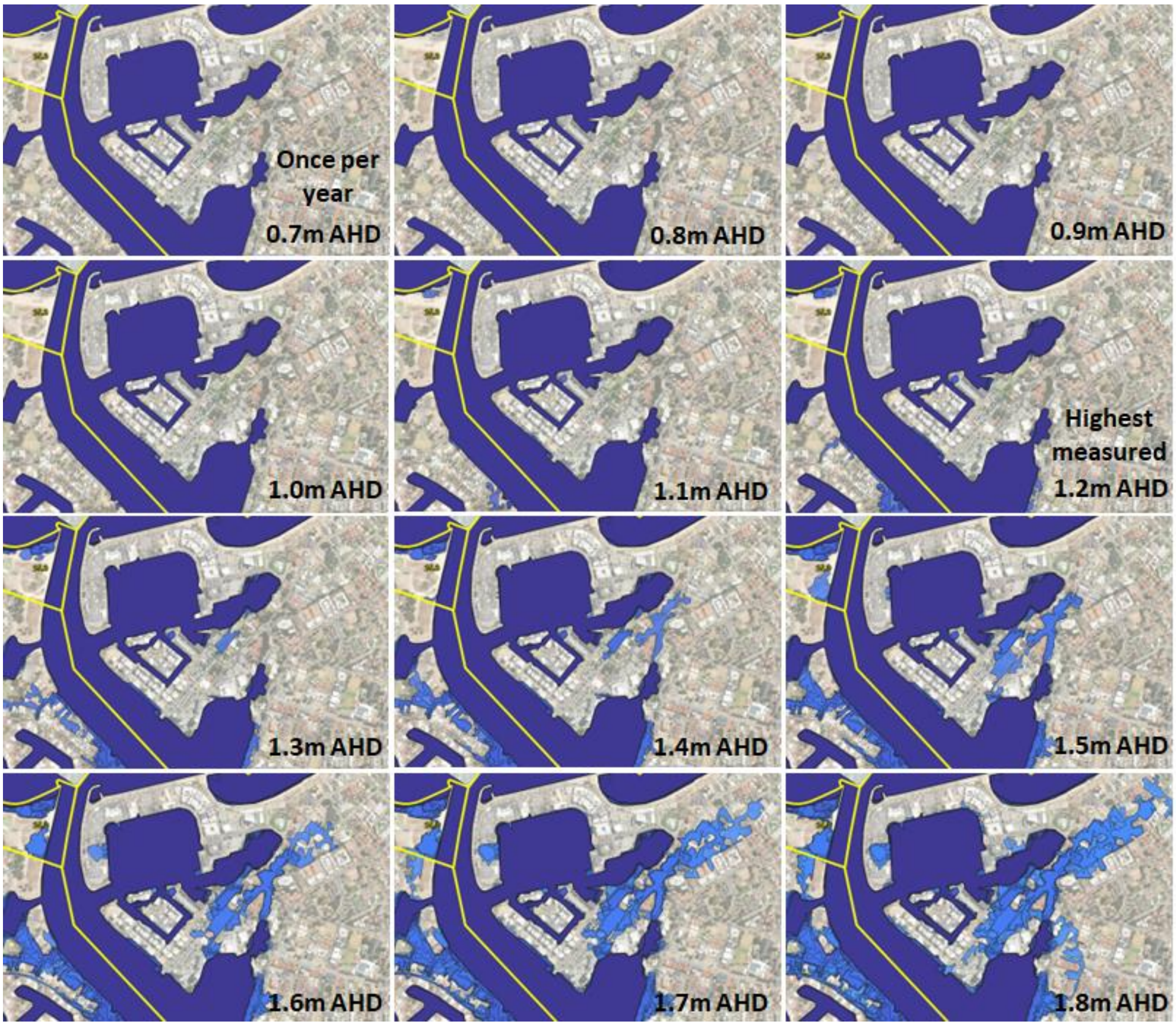


Figure 3-3: Percolation Assessment Example for Mandurah Estuary

The percolation assessment allowed an understanding of the spatial extent of inundation at discrete water levels as well as an identification of flood pathways within the study area. Consideration of the visual outputs of the percolation assessment assist an understanding of the extent of inundation in the context of previously recorded water levels; in the example above water levels recorded once per year (0.7m AHD) and the highest ever measured water level (1.2m AHD).

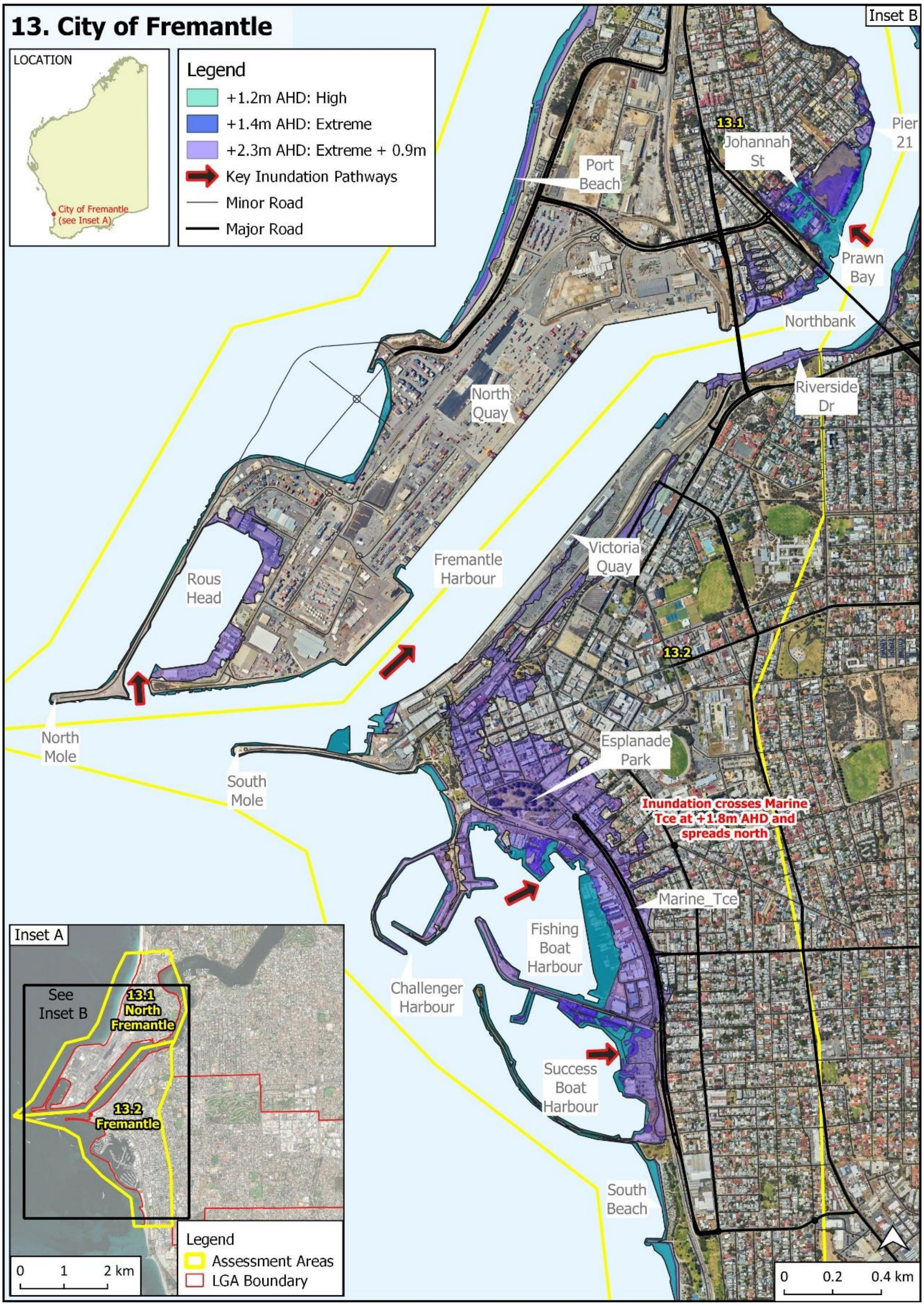


Figure 3-4: Hazard Map example for City of Fremantle showing three inundation thresholds. Red arrows indicate primary flood pathways. Inundation areas mapped approximately correspond to 25yr ARI, 100yr ARI and 100yr ARI +0.9m. High and Extreme inundation impacts are mainly around Fremantle Boat Harbour Area or Prawn Bay. At water levels above +1.8m AHD, inundation crosses Marine Terrace and spreads north.

3.3.3 Financial Exposure

Financial exposure at each 0.1m increment was identified by submitting the percolation assessment shapefiles through the AEIP Data reports returned by email include several information formats, with .xlsx, .json and .html files containing the exposure summary (Figure 3-5). Within each report, there is a combination of assets at risk, financial values, and socio-economic data (Figure 3-6).

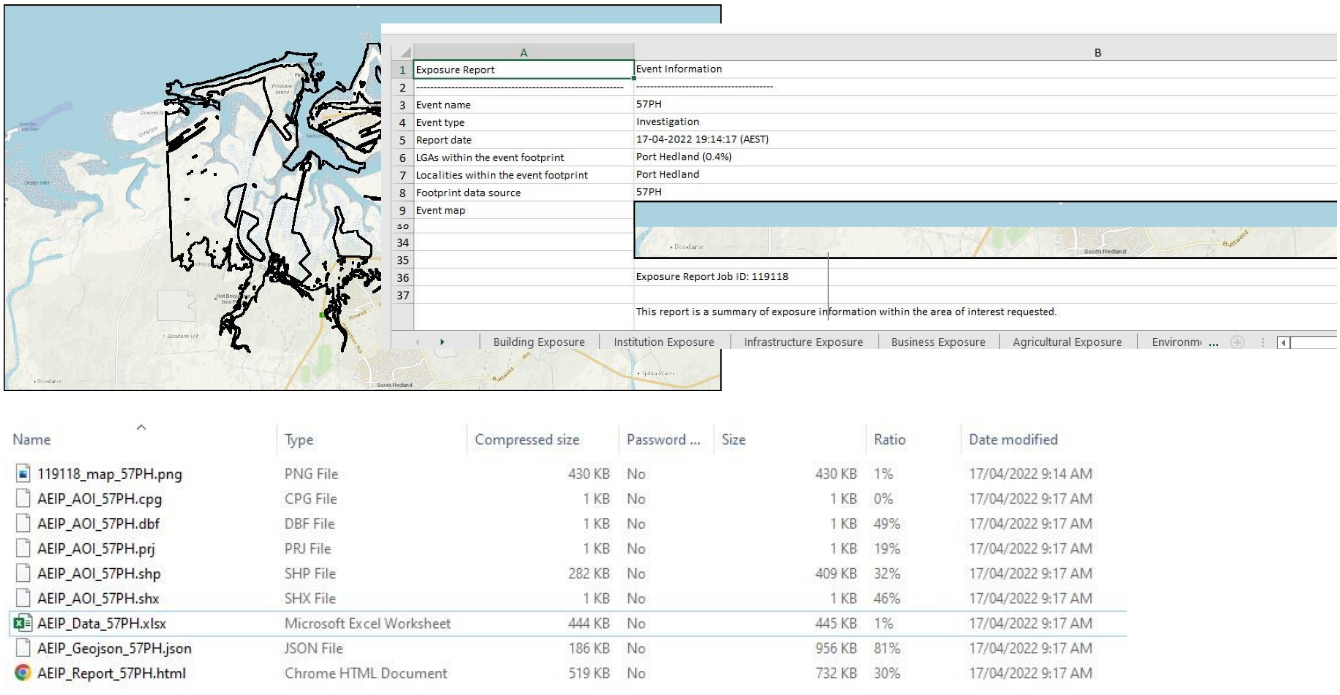


Figure 3-5: Example of Emailed Output Report & Formats from AEIP

Information about exposure is provided for buildings, institutions, infrastructure, businesses, agriculture, and environmental assets. Financial information relevant to coastal inundation hazard assessment for townsites is mainly associated with buildings, with several sub-categories of exposure:

- Residential Buildings – Reconstruction Value
- Residential Buildings – Contents Replacement
- Commercial Buildings – Reconstruction Value
- Industrial Buildings – Reconstruction Value
- Agriculture Production – Estimated Value

Although this information provides an effective base to support vulnerability assessment, it is a 'black box' component, with financial values provided as an aggregate across the whole area. This limits the capacity to incorporate local knowledge of financial values and constrains both quality and information updates to Geoscience Australia's activity for AEIP, affecting potential present and longer-term use (see Section 6.4).

Following email query regarding reliability of the information provided through AEIP, Geoscience Australia noted that information across Australia had been provided by State agencies (the Valuer General in WA), and that no substantive attempt to test reliability of this information across Australia had been undertaken. Testing of exposure assessment was undertaken for each site by confirming building counts, checking road and key infrastructure exposure.

Building Exposure, V11 September 2020	
Residential	**Event**
Population count	433
Dwelling count*	350
Building count	215
Pre 1980 construction count	32

Dwelling estimates where residents:			
Demographic*	**Event**	**WA(Av)#**	**Nat(Av)**
Are all aged 65 or over	3.4%	15.2%	16.9%
Includes persons aged 14 years and under	12.3%	26%	25.4%
Includes an Indigenous person	9.1%	3.1%	3%
Are a single parent family	3.2%	5.4%	5.5%

Building Exposure, V11 September 2020	
Pre 1990 probable asbestos containing products**	114
Reconstruction value	$187,190,000
Contents value	$14,360,000
Commercial	
Building count	45
Reconstruction value	$357,440,000
Industrial	
Building count	74
Reconstruction value	$145,460,000
2016 SEIFA IRSAD*	
Dwellings in area with a SEIFA decile 10 score (most advantaged)	26
Dwellings in area with a SEIFA decile 9 score	-
Dwellings in area with a SEIFA decile 8 score	161
Dwellings in area with a SEIFA decile 7 score	37
Dwellings in area with a SEIFA decile 6 score	27
Dwellings in area with a SEIFA decile 5 score	56
Dwellings in area with a SEIFA decile 4 score	-
Dwellings in area with a SEIFA decile 3 score	19
Dwellings in area with a SEIFA decile 2 score	-
Dwellings in area with a SEIFA decile 1 score (most disadvantaged)	-
Dwellings in area without a SEIFA score	24

Dwelling estimates where residents:			
Are in need of assistance for self-care activities	2.0%	7.7%	10%
Include persons not proficient in English	0%	0.4%	1%
Do not have access to a motor vehicle	8.9%	5.2%	7.5%
No one has completed Year 12 or higher	12.3%	15.1%	15.5%
Moved to the region in the last 1 year	18.7%	12.6%	12.2%
Moved to the region in the last 5 years	37.7%	34.8%	32.3%
Top 5 employing industry*:			
Transport Postal Warehousing, Mining, Construction, Health Care Social Assistance, Accommodation Food Services			
Economic*	**Event**	**WA(Av)#**	**Nat(Av)**
Are low income ($1-$499/week)	7.0%	21.3%	23.5%
Are medium income ($500-$1,499/week)	26.7%	51%	53%
Are high income ($1,500+/week)	65.5%	26.4%	22.1%
Are in public housing	5.9%	4.6%	4.2%
Are all unemployed	0.7%	1.5%	1.1%

** Demographic information is based on 2016 Census. Residential demographic and economic information is not provided for dwelling counts less than 20 or when the population count is zero*

***Buildings may contain asbestos cement materials, especially in the eaves, internal and external wall cladding, ceilings (particularly in wet areas such as bathrooms and laundries), corrugated products (roofing and cladding) and fences*

 # State averages and state proportions are not displayed when the area of interest crosses state boundaries

Figure 3-6: Partial Extract from AEIP Report

Note AEIP reporting provides substantially greater socio-economic information than has been used for this evaluation. This is because the purpose of the work undertaken here was a strategic statewide assessment intended for direction setting for inundation management for WA.

Limitations of AEIP performance that were consequently identified, and required consideration in the inundation assessment include:

- AEIP has been developed with a 50m resolution (grid). Intersection with the percolation shapefiles consequently can represent building value as being up to 50m away from their location, which has been identified as resulting in exaggerated inundation risk for buildings along estuary foreshores or adjacent to canal walling.
- Building counts under 20 are not reported in financial values by the AEIP due to privacy constraints.
- Checks indicated slightly variable performance between sites, with apparent influences from the age of information used, variability of classifications and some differences in valuation method (i.e. in some locations building reconstruction costs were closer to market building costs, whereas in some others, valuation appeared closer to present-day house and land purchase value). This variability occurred internally to townsites and has not been documented in the study.
- There were a limited number of buildings identified from AEIP in areas where no buildings could be identified from aerial imagery (i.e. at low inundation levels). This potentially indicates a small number of geolocation issues. Where identified, these values were removed, due to the significant financial weighting caused by assets at low ground levels that have a hydraulic connection to the ocean.
- Larger assets, such as schools or airports have their value assigned across multiple AEIP grid cells, corresponding to the overall facility boundary. Consequently, the facility value was identified at the lowest point within the boundary, which can occasionally be well below buildings levels. Where identified, these effects were corrected, due to the significant financial weighting caused by assets at low levels.
- Local roads are not identified through AEIP, and the definition of sub-arterial roads apparently varies between locations. Consequently, while the length of road reported via AEIP could generally be related to the extent of inundation at a specific location, comparison of these values between locations has limited meaning.

3.3.4 Asset Exposure

Asset exposure for each townsite was developed as:

- **Initial exposure**: defining the level and approximate likelihood, at which assets are first exposed to coastal inundation. This parameter is indicative only, as for many sites the most exposed assets are designed to tolerate inundation (e.g. floodproofed), which is not identified in the NEXIS database. There is also potential for identification of buildings at lower or higher levels than they are built at due to the mapping limitations of the 50m resolution (grid).
- **Financial exposure**: describing the values reported by AEIP for reconstruction costs associated with residential, commercial, or industrial buildings, at 0.1m vertical intervals. Due to apparent inconsistency in building classification between locations, these values were summed for the purpose of describing financial exposure in the site summaries (Appendix A) with additional reported values included in Appendix D.
- **Asset exposure**: the building count and length of major roads reported by AEIP potentially reached by inundation has been identified at 0.1m vertical intervals. This is included in tables within the site summaries (Appendix A). As noted in Section 3.3.3, description of roads only includes major roads. These are not always comparable assets between LGs.
- **Key Facility Exposure**: where identified, key facilities such as hospitals, schools and railways have been included.

Financial exposure is shown within each site summary as plots of inundation likelihood, over 1 and 25 year periods and cumulative value of exposed assets for increasing inundation levels (Figure 3-7).

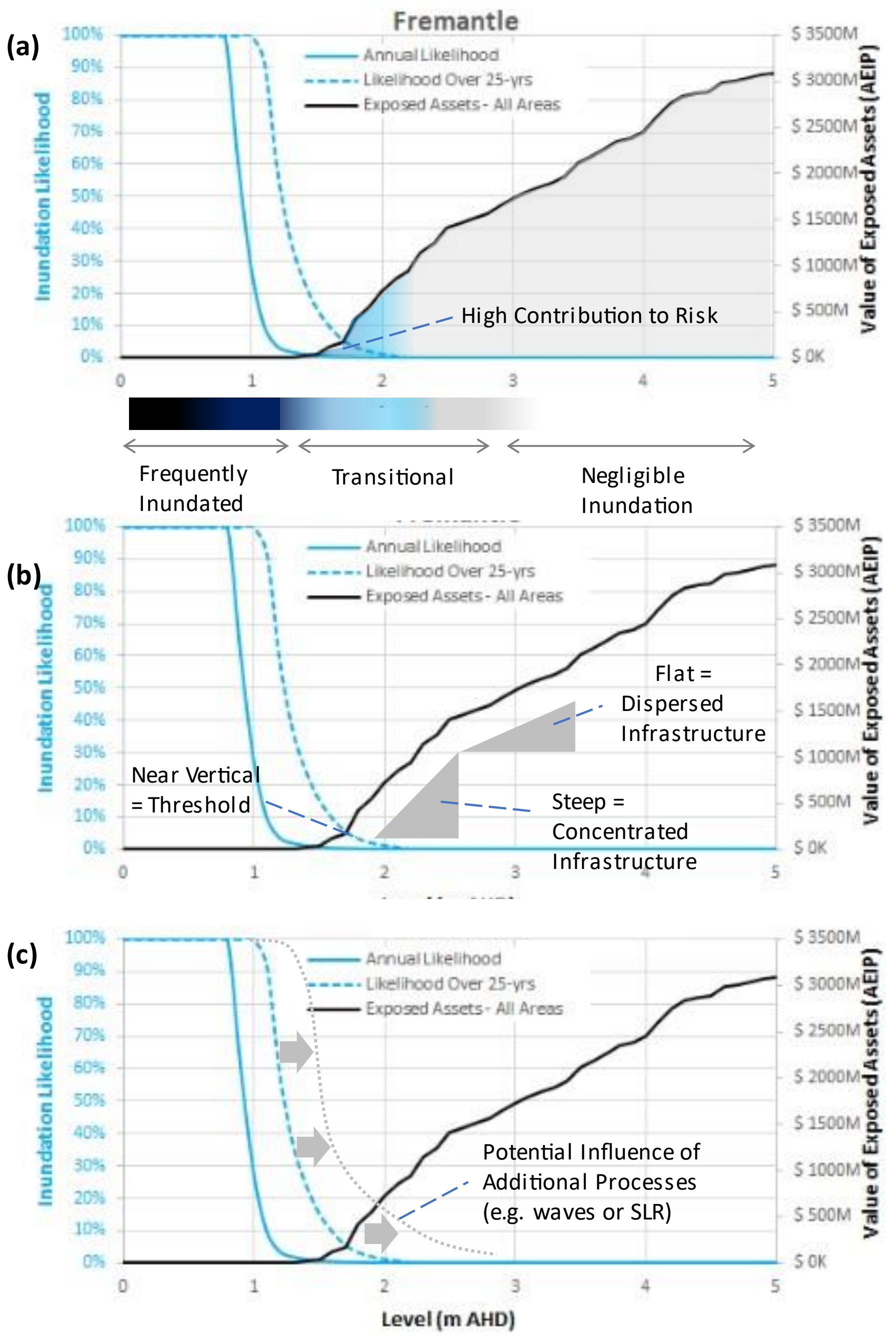


Figure 3-7: Interpretation of Inundation Exposure Curves for the City of Fremantle.

The relationship between water level (x-axis), Inundation likelihood (y-axis) and financial exposure (z-axis) is represented here. Likelihood is shown over a one-year period (solid blue line) and 25-year period (dashed blue line) and the cumulative financial exposure of assets indicated by the solid black line.

a) The two inundation likelihood curves (blue lines) indicate the transition from a level that is frequently inundated (1yr ARI), to levels that experience negligible inundation (25yr ARI).

b) Steep slope on the exposed assets curve indicates a range of water levels with concentrated infrastructure, potentially creating a focus of inundation risk.

c) The potential influence of additional processes contributing to inundation hazard, such as waves or sea level rise (dotted grey line), is shown indicatively.

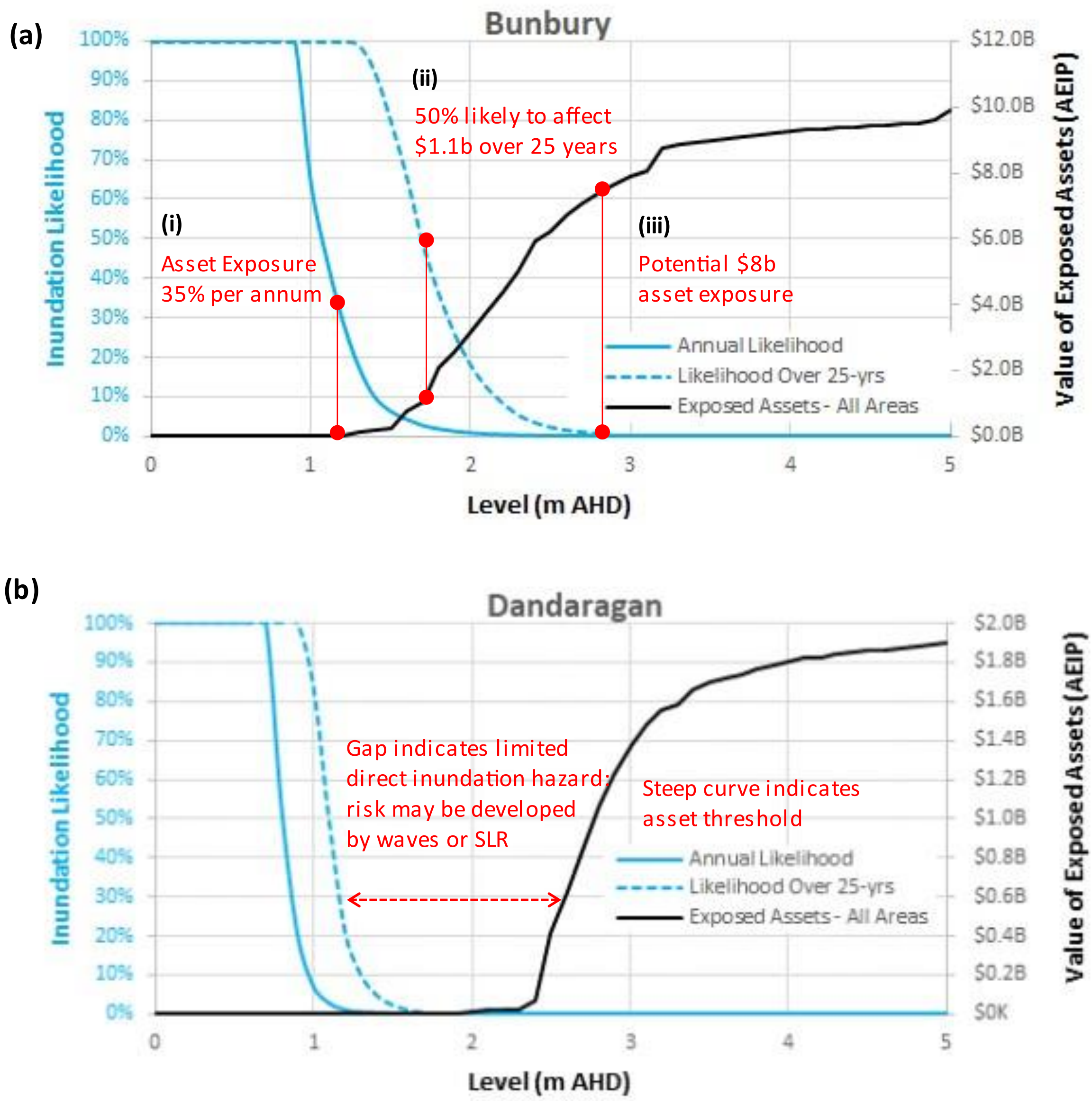


Figure 3-8: Inundation-Exposure Interactions for Bunbury and Dandaragan

a) Relative position of likelihood and asset exposure curves provides a simplified representation of inundation risk. For example, in Bunbury there is a 35% likelihood of asset exposure to inundation per year at a water level of 1.2m; (ii) a water level of 1.7m has a 50% likelihood to occur in 25 years and the associated exposed asset value at 1.7m is $1.1b; and (iii) at an inundation level of 2.9m AHD potential of just under $8b asset exposure.

b) In cases where the curves do not overlap, there is limited likelihood of direct inundation However, the gap or separation between the curves indicates the scale of additional processes, such as waves or sea level rise, that may need to occur to cause marine impacts.

Inundation likelihood and exposed asset curves were used to support recommendations for focal areas of inundation management. Those areas with negligible or low present day direction inundation risk, but where there is a narrow foreshore reserve (i.e. wave effects can be significant) were identified to have focal **Management at the Foreshore**. If the gap between inundation and exposed asset curves is less than 0.9m, being the allowance for projected sea level rise over the next 100 years, the site was identified as having appropriate focus for **Adaptation Priority**.

3.3.5 Financial Vulnerability

Financial and asset exposure information identifies when there is potential for inundation to reach a particular asset. However, this does not directly relate to financial impact (cost), which develops when inundation causes damage. This requires consideration of:

- Many buildings and assets can withstand low depths of inundation, for a short duration, without causing significant damage.
- There is significant variation between locations where the frequency with which specific inundation levels (and associated damage) may occur.
- For any level considered, there is always a possibility of higher levels of inundation, generally capable of causing a greater amount of damage.

Damage has been estimated using a proportion of the building cost, based upon relative depth, from zero at the commencement of inundation, up to 100% at a notional depth of structural failure. The effect of frequency has been treated through weighting by likelihood.

Subsequently, financial vulnerability has been considered in three ways:

- **Threshold Event Damage**: refers to the estimated total financial impact caused by an event with nominal likelihood. For this assessment, high and extreme events approximately correspond to 25 and 100 year ARI inundation levels.
- **Average Annual Damage**: the average financial value of damage due to coastal inundation per year. This is calculated as the sum of estimated damage per inundation increment multiplied by the estimated likelihood of that inundation increment and is a per year cost.
- **Residual Risk**: overall impact of potential hazard occurrences beyond the level targeted for effective mitigation, considering susceptibility of affected values and assets. For this assessment, it has been assumed that protection is at 100-year ARI inundation level for each location, and the residual risk occurs at an inundation level above the 100yr ARI.

3.4 Planning Framework Check

Interviews with LG representatives showed the key role of CHRMAP for development of LG coastal inundation knowledge and management practices. However, review of coastal inundation governance demonstrated that decision-making is applied in discrete stages. This includes consideration of where assets are located relative to hazard (**planning**), characteristics of structures (**building**) and coordination of people before, during and after an inundation event (**emergency management**). Presently in WA, planning and building approvals processes are separate, with emergency management generally expected to respond to shortfalls of hazard management.

As planning is typically the starting point for many practitioners, development of more robust, integrated coastal inundation management may need existing planning instruments to be revised. Specifically, this should identify how non-planning tools, including building design guidelines and emergency management provisions, can be incorporated into the decision-making process.

Directions for longer-term refinement of both State and Local Government Planning Frameworks identified in Phase 1 are reiterated in Section 5. To further support this process, review of existing planning documents was undertaken, with key objectives to:

Key Review Objectives:

1. Identify the variance of coastal inundation management across the State.
2. Evaluate the clarity and scope of guidance for hazard mitigation and adaptation.
3. Assess the capacity for integration of non-planning tools into the decision-making process.

The approach undertaken included liaison with senior State coastal planning staff, to identify opportunities within planning instruments, and review of local government planning framework documents, typically comprised of the Local Planning Strategy, Local Planning Scheme and CHRMAP, with any supporting studies.

As identified in the Phase 1 review of CHRMAP, there is no single system that is appropriate for all locations across the State, with each site having different inundation hazards, different tools for management and different legacies from previous development and decision-making. Consequently, a 'health check' approach was used, identifying the status of various aspects of the planning framework (Table 3-4), specifically with respect to key review objectives. It was generally anticipated that depth and integration of information would have largely developed in response to existing or forecast coastal inundation pressures.

Table 3-4: Planning Framework Health Check

MITIGATION: Planning Framework Health Check		
Available planning documents have been assessed for their capacity to support holistic management of coastal inundation, particularly the integration of adaptation, building controls, emergency management and financial tools. Documents considered include: • Local Planning Strategies • Local Planning Schemes • CHRMAPs • Coastal Vulnerability Studies It is acknowledged that planning instruments, by definition, are focused on approvals processes for land development, and therefore are primarily tied to land release, subdivision, and development phases. For factors that may need to become active for new development or redevelopment in areas likely to be impacted by inundation, special control areas are typically used. A 'health check' approach has been used, considering eight aspects of the planning framework. It highlighted there are few right or wrong approaches, as different combinations of management instruments may be practical in each setting, with their effectiveness changing over time.		
Item	**Aspect**	**Consideration**
HC1	Scope of processes	Does available information consider coastal inundation and its potential interaction with other complex processes such as waves, erosion, or runoff?
HC2	Storm scenario & SLR	What inundation scenarios have been considered, including storm recurrence, sea level components (e.g. wave run-up), and sea level rise allowance?
HC3	Clarity of information	Is information used to characterise inundation hazard unambiguous and readily available? e.g. Does inclusion of updated information require policy revision?
HC4	Mitigation options	Is information available regarding preferred, viable or acceptable forms of inundation mitigation? Are responsibilities for strategic or property level protection identified?
HC5	Adaptive framework	Do planning documents identify a preferred pathway for adaptation for areas subject to inundation hazard? e.g. Is adaptation tied to development approval phases or pressure on landowners?
HC6	Safety management	Is the role of emergency management linked to inundation thresholds and planning approvals?
HC7	Building controls	Do planning documents identify the role of building controls for areas subject to inundation hazard? Are these linked to Australian Building Codes for flood proofing?
HC8	Funding framework	Does the planning framework incorporate funding provisions with capacity to provide targeted strategic intervention? Most commonly a special control area is required to apply a levy.

4 Assessment Results

4.1 Onset of Exposure

The lowest elevation assets for each town site were identified and mapped, as they define the onset for consideration of inundation management. Relative exposure is indicated by the annual likelihood to inundation at the asset level, described by annual likelihood (Figure 4-1). Importantly, the onset of exposure generally does not correspond to the onset of damage. In most cases buildings with high exposure are known to be susceptible and have been built to withstand low-moderate levels of inundation.

Onset of exposure varies from <1% through to 52% likelihood per annum at Capel, with 65% of the LGs having less than 5% annual likelihood. Overall, this implies that **for most sites, coastal inundation is a rare event**.

The low-lying foreshores along Geographe Bay, from Busselton to Harvey have assets at the lowest level. This is consistent with the national perception of coastal vulnerability of this region [16] and with the presence of inundation barriers in Bunbury, Busselton and Capel. Exposure at Australind (Shire of Harvey) and Peppermint Grove Beach (Shire of Capel) are located inside estuaries, which are likely to experience lower inundation than the adjacent ocean levels, and with building floor levels above the ground level.

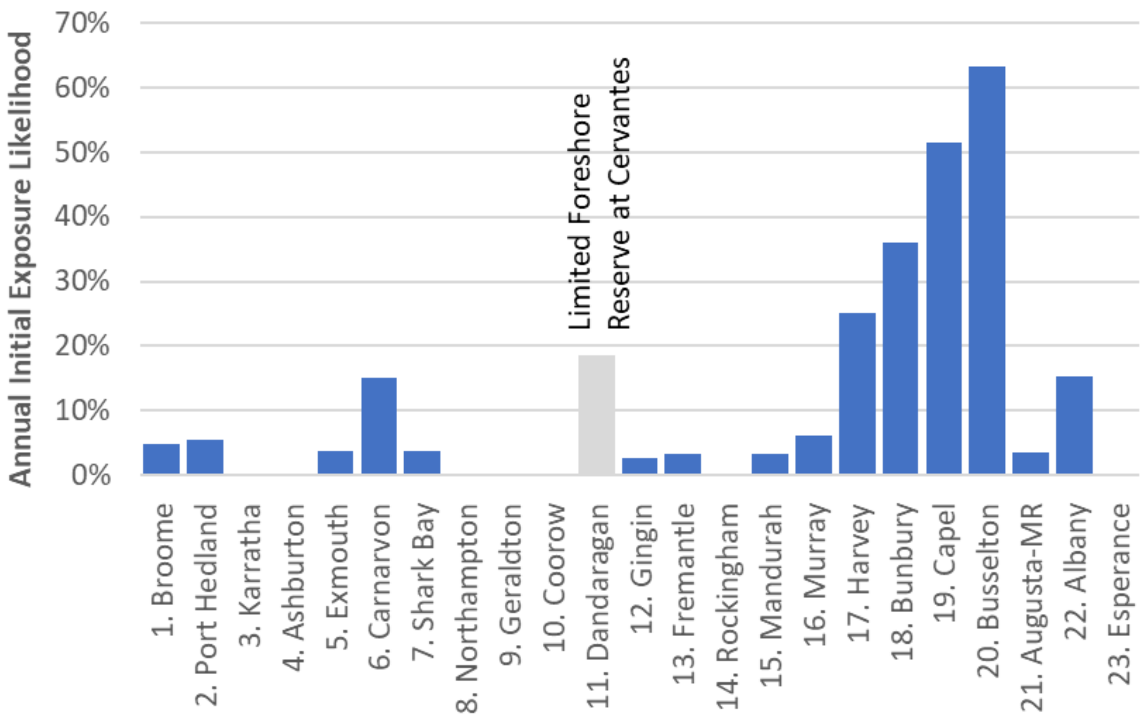


Figure 4-1: Initiation of Exposure

Exposure risk at Cervantes (Shire of Dandaragan) is shown in grey due a change in method. Initial exposure was identified at 0.5m lower than the assets due to absence of a meaningful foreshore reserve to mitigate storm waves.

4.2 Identification of Inundation Pathways

Percolation assessments for each site gave indications of the nature of inundation arrival. As an example, a sequence of percolation areas for Peppermint Grove Beach (Figure 4-2) shows multiple pathways into Stirling Wetlands, active under different conditions and at different levels.

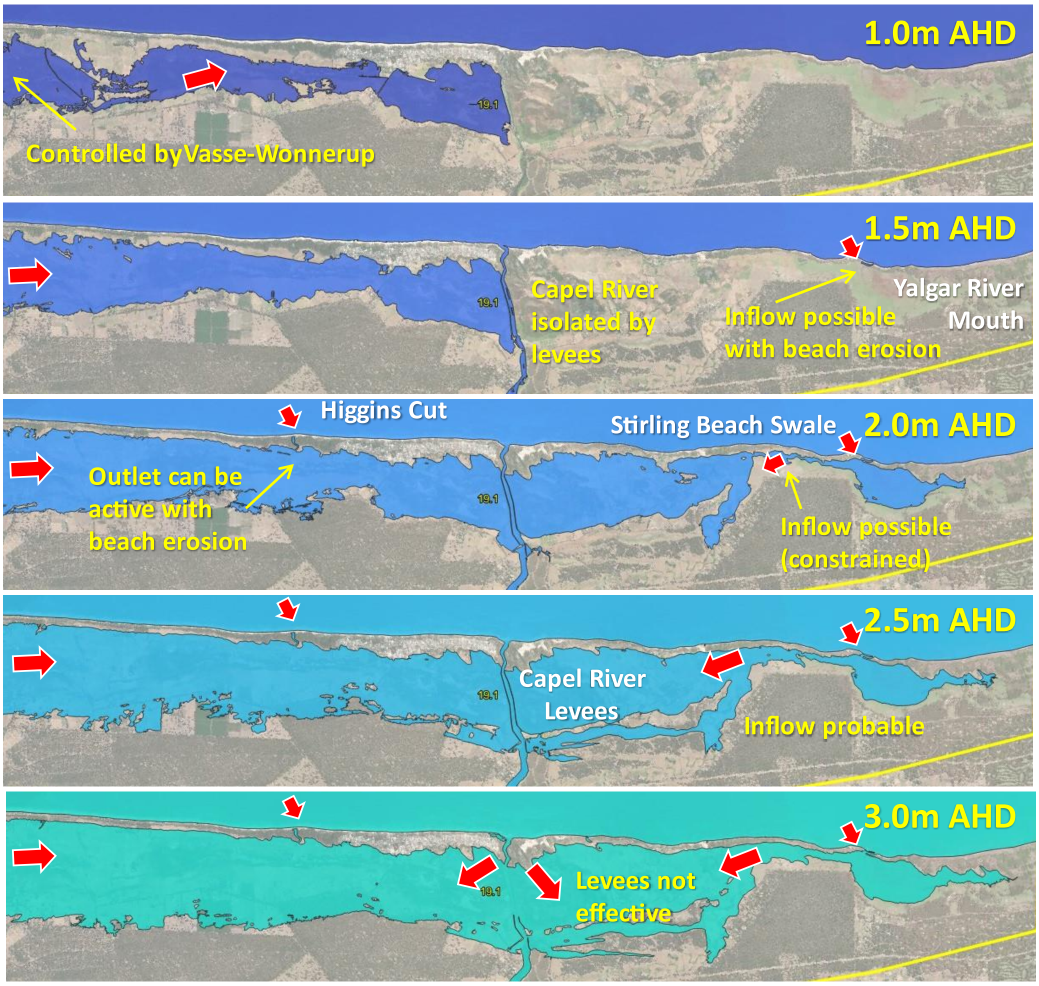


Figure 4-2: Key Example of Percolation Assessment for Peppermint Grove Beach, Capel

Although each pathway is narrow, the benefits of addressing one are limited to protection up to the next threshold, where another pathway can become active (Table 4-1).

Table 4-1: Pathways and Restrictions for Capel Inundation
Site Summary 19: Shire of Capel in Appendix A

Pathway	Restriction	Typical Limit of Restriction	
Vasse-Wonnerup	Controlled by Surge Barriers	+1.5m AHD	High WL threshold at +1.7m AHD
Yalgar River Mouth	Seasonally limited by beach berm	+1.5m AHD	
Higgins Cut	Restricted by beach berm	+1.9m AHD	
Stirling Beach Swale	Constrained by swale size	+2.2m AHD	Extreme WL threshold at +2.0m AHD
Capel River Levees	Levees	+2.7m AHD	

Examples of inundation pathways for Busselton/Capel and Carnarvon are shown by Figure 4-3.

Figure 4-3: Inundation Pathways for Busselton/Capel and Carnarvon
Inundation hazard for each townsite may arrive through multiple pathways. For Busselton and Capel, a key pathway for inundation hazard is through narrow river and agricultural channels. At Carnarvon, inundation may arrive through waterways, or overland, through the mangrove flats.

Inundation pathways are identified within individual site summaries (Appendix A). Considering the range of inundation scenarios shown on the hazard maps, sites have been qualitatively classified as suitable for **Targeted Mitigation** where there is a narrow pathway through to a larger low-lying, built-up area (Table 4-2). This characteristic is recommended for consideration in future management directions (see Section 6.4).

Table 4-2: Targeted Mitigation Sites

Local Government	Location	Description	High WL	Extreme WL
Port Hedland	West End	Central Port Hedland, along the Esplanade from +4.7m AHD.	+4.2m AHD	+5.0m AHD
Ashburton	Onslow *	Arriving through Third St at +3.9m AHD.	+2.5m AHD	+3.5m AHD
Exmouth	South of Exmouth Marina	Along Crevalle Way at +3.5m AHD via a coastal breakout ~700m to the south.	+2.3m AHD	+3.1m AHD
Carnarvon	South Carnarvon *	Arriving through Yacht Club at +1.6m AHD.	+1.7m AHD	+2.1m AHD
Gingin	Lancelin	Inundation to low lying areas depends on dune breaching.	+1.0m AHD	+1.2m AHD
Fremantle	North Fremantle	Arriving along Johannah St at +1.1m AHD.	+1.2m AHD	+1.4m AHD
Rockingham	Palm Beach	Arriving across Esplanade near Fisher St at +1.9m AHD.	+1.2m AHD	+1.4m AHD
Mandurah	Manjar Bay	Along Ormsby Tce and Cooper St, from +1.4-1.5m AHD.	+1.2m AHD	+1.4m AHD
Bunbury	Bunbury *	Arriving at Bunbury CBD at +1.3m AHD. Mitigated by storm surge barrier to +2.16m AHD.	+1.6m AHD	+1.9m AHD
Capel	Peppermint Grove Beach *	Arriving at +1.2m AHD via Stirling Wetland. Mitigated by Vasse-Wonnerup storm surge barriers to ~+1.5-2.0m AHD.	+1.7m AHD	+2.0m AHD
Busselton	Multiple sites *	Pathways through coastal dunes, estuaries, and agricultural drains at a range of levels.	+1.8m AHD	+2.1m AHD
Albany	Behind Middleton Beach	Arrival at +1.6m AHD via inlet at Emu Point.	+1.1m AHD	+1.3m AHD
Esperance	The Esplanade	Arrival at +2.3m AHD north of Taylor St Jetty.	+1.3m AHD	+1.5m AHD

* These sites have existing inundation mitigation structures.

In counterpoint, for those locations where extreme inundation scenarios potentially affect large townsite areas, but water can arrive across a broad area, it is recommended that future inundation management includes focus on **Emergency Management** (see Section 6.4)

4.3 Inundation Exposure Summary

Inundation exposure, within townsite areas, has been identified through submission of percolation shapefiles for high, extreme and “extreme +0.9m” to AEIP (see Appendix B). An overall summary of asset exposure to inundation is provided by Figure 4-4, with inundation exposure for buildings and roads summarised by Table 4-3, and for other assets by Table 4-4. The townsites of Bunbury, Busselton and Peppermint Grove Beach have been evaluated for an “unmitigated” case, where existing storm surge barriers are treated as ineffective.

	HIGH	EXTREME	EXTREME +0.9M
# OF RESIDENCES	1,063	2,493	16,311
# OF COMMERCIAL BUILDINGS	74	271	1028
# OF INDUSTRIAL BUILDINGS	8	60	200
KM OF ROAD *	50	80	200
CRITICAL SERVICES INFRASTRUCTURE	25km railtrack	50km railtrack 1 Nursing & Retirement Home 1 School 2 Wastewater Treatment /Management sites	130km railtrack 7 Nursing & Retirement Homes 11 Schools 7 Wastewater Treatment /Management sites 3 Airports: Onslow; Carnarvon; Broome 4 Ambulance Stations 1 Power Station: Carnarvon

*Roads considered in AEIP analysis are major to sub arterial roads only. No local roads are included.

Figure 4-4: Summary of Asset Exposure to Inundation at Event Thresholds

This is the exposure which would be developed if all locations experienced events at an equivalent level (high, extreme, or extreme +0.9m).

This evaluation shows that residential buildings are extensively exposed compared with other assets. In general, building count was generally identified to perform well, with some switching between categories. As building information provides the key financial basis for Section 4.4, this is the most important asset category.

For more extensive description of exposure for different asset types, refer to Appendix C.

Table 4-3: Inundation Exposure Summary for Buildings & Roads

	Local Government	Residential Buildings			Commercial Buildings			Industrial Buildings			Total Road: Major and Sub-arterial (km)		
		High	Extreme	Extreme +0.9m	High	Extreme	Extreme +0.9m	High	Extreme	Extreme +0.9m	High	Extreme	Extreme +0.9m
1	Broome	7	23	116	-	20	43	-	-	-	-	3	5
2	Port Hedland	3	88	257	-	20	46	-	43	78	10	26	33
3	Karratha	-	-	-	-	-	-	-	-	-	-	-	8
4	Ashburton	14	48	100	-	14	30	-	-	-	1	2	7
5	Exmouth	1	4	16	-	-	18	-	-	-	-	-	1
6	Carnarvon	105	268	530	-	1	29	-	-	-	1	1	9
7	Shark Bay	3	19	55	-	3	8	-	-	-	1	2	2
8	Northampton	-	-	-	-	-	-	-	-	-	-	-	-
9	Geraldton	-	-	146	-	-	8	-	-	21	-	-	3
10	Coorow	-	-	277	-	-	-	-	-	-	-	-	7
11	Dandaragan	-	-	22	-	-	-	-	-	-	-	-	-
12	Gingin	20	40	527	-	-	-	-	-	-	-	-	-
13	Fremantle	7	13	146	-	1	103	-	-	-	2	2	5
14	Rockingham	-	-	243	-	-	-	-	-	-	-	-	2
15	Mandurah	11	51	881	-	-	28	-	-	-	4	4	7
16	Murray	16	37	1,206	-	-	1	-	-	-	5	5	10
17	Harvey	28	49	160	-	-	-	-	-	-	3	6	8
18	Bunbury*	561	930	2,697	71	202	477	1	2	21	6	10	26
19	Capel*	1	15	43	-	-	-	-	-	-	1	1	1
20	Busselton*	278	891	8,639	3	10	237	7	14	94	16	21	41
21	Augusta-Margaret River	-	2	31	-	-	-	-	-	-	-	-	-
22	Albany	8	15	200	-	-	-	-	-	-	2	2	8
23	Esperance	-	-	19	-	-	-	-	-	-	-	-	1
Total													
Total – unmitigated*		**1,063**	**2,493**	**16,311**	**74**	**271**	**1,028**	**8**	**59**	**214**	**52**	**85**	**184**

Table 4-4: Inundation Exposure Summary for Other Assets

Local Government	Airports: Major Areas/Landing Grounds			Agricultural Area (ha)			Ambulance Station			Nursing/Retirement Home			Railway Tracks (km)			Schools		
	High	Extreme	Extreme +0.9m	High	Extreme	Extreme +0.9m	High	Extreme	Extreme +0.9m	High	Extreme	Extreme +0.9m	High	Extreme	Extreme +0.9m	High	Extreme	Extreme +0.9m
1 Broome		1	1															
2 Port Hedland		1	1	87	351	760							21	46	111			
3 Karratha	1	1	1															
4 Ashburton*	1	1	1						1			1						1
5 Exmouth																		
6 Carnarvon	1	1	1			13							1	1	5		1	3
7 Shark Bay																		
8 Northampton																		
9 Geraldton				2	2	3									6			
10 Coorow									1									
11 Dandaragan																		
12 Gingin																		
13 Fremantle													2	2	4			
14 Rockingham																		
15 Mandurah																		
16 Murray				273	404	1,729												1
17 Harvey																		
18 Bunbury*						1			1		1	1	1	1	3			4
19 Capel*				38	52	1,823												
20 Busselton*				1,152	1,563	2,294			1			5						2
21 Augusta-Margaret River																		
22 Albany				31	40	169												
23 Esperance															1			
Total – unmitigated*	**3**	**5**	**5**	**1,583**	**2,412**	**6,792**	**-**	**-**	**4**	**-**	**1**	**7**	**25**	**50**	**130**	**-**	**1**	**11**

*Onslow Airport was substantially modified after the DEM capture. Post-construction exposure has not been identified.

4.4 Scale of Inundation Cost

Potential costs for coastal inundation across the State are summarised by Figure 4-5, showing total costs if each site were to experience high (~25yr ARI), extreme (~100yr ARI) or “extreme +0.9m” scenarios. These values are consequently not “real” as it is virtually impossible for extremes to occur along all townsites within any discrete period. However, they indicate the financial scale of extreme events, and its potential for substantial increase with event severity (Figure 4-5).

	HIGH	EXTREME	EXTREME +0.9M
DAMAGE WITH SSB*	$25M AUD*	$133M AUD*	$4,100M AUD*
DAMAGE WITHOUT SSB**	$48M AUD**	$288M AUD**	$4,100M AUD**
# SITES IMPACTED**	10 sites**	15 sites**	20 sites**
# SITES OVER $1M AUD**	Carnarvon Bunbury Busselton	Broome Port Hedland Ashburton Carnarvon Shark Bay Mandurah Harvey Bunbury Busselton	All except Karratha, Northampton, Esperance

*with the protection provided by Bunbury Storm Surge Barrier (SSB)
** without protection provided by Bunbury Storm Surge Barrier (SSB)

Figure 4-5: Total Costs of 23 coastal LGs Estimated at Event Thresholds
This is the estimated damage that would be developed if all locations experienced events at equivalent level (high, extreme, or extreme +0.9m).

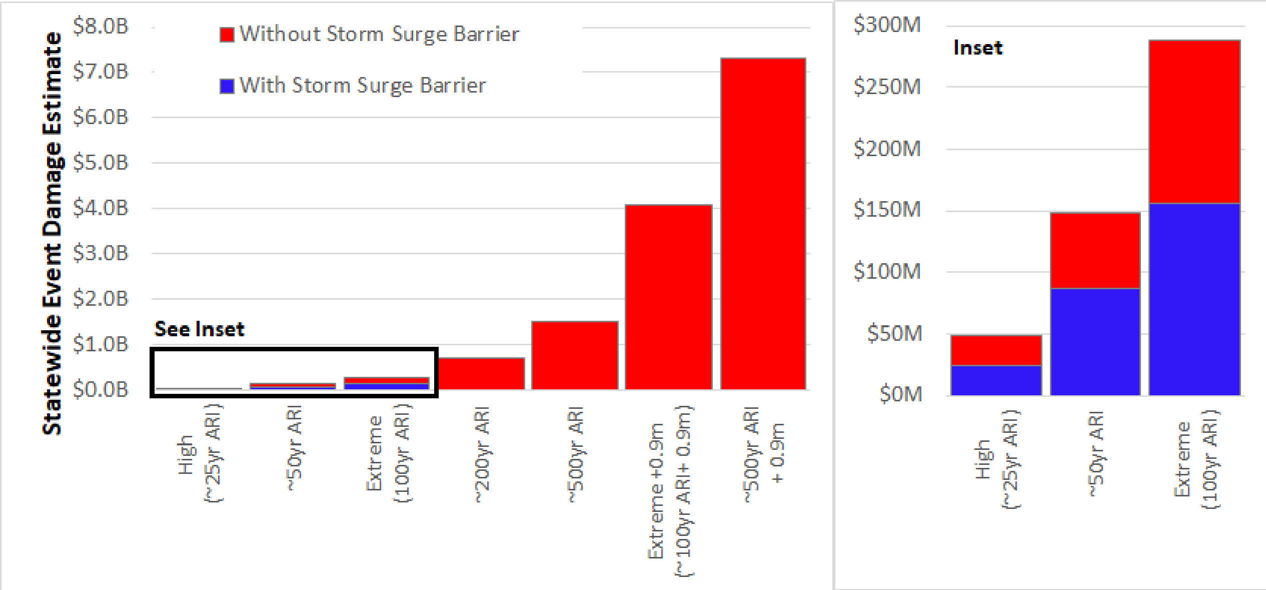


Figure 4-6: Damage Variation for 23 coastal LGs with Event Severity. Mitigation by Bunbury storm surge barrier is shown, noting Busselton barriers have limited effect above the 'high' scenario if percolation is used to evaluate inundation.

Geographic distribution of estimated inundation damage is shown in Figure 4-8: Estimated Damage per Local Government for event scenarios.

For high inundation scenarios (~25 yr ARI) findings are for high potential damage at Busselton, Bunbury, and Carnarvon:

- Most of the potential damage for Bunbury is mitigated by the storm surge barrier, which provides protection up to a water level of 2.16m AHD for Bunbury Townsite. This reduces potential cost for the high scenario by $23M from $48M to $25M.
- While storm surge barriers control inflow to Vasse-Wonnerup and Abbey-Geographe (Backwater) waterways in the City of Busselton, the percolation assessment identified potential for entering through low lying land on Layman Road (+1.5m AHD), next to the storm surge barrier which is set at +2.16m AHD. This pathway implies frequent inundation, that has not been historically observed, which suggests that the percolation analysis is likely to exaggerate inundation arriving through shallow, constricted flow paths.
- South Carnarvon has potential for substantial damage through a low point in the South Carnarvon surge wall via Carnarvon Yacht Club. It is unknown whether this pathway is a result of temporary works, captured during the survey, or whether protection provided by the surge wall was incomplete or has been modified. A refined DEM has subsequently been captured in 2023 by Department of Water and Environmental Regulation but was not available at the time of evaluation.

For an extreme inundation scenario, potential damage was estimated as $133M across the 57 exposure areas of the 23 LGs. Bunbury storm surge barrier effectively provides $156M protection at this level as listed in Figure 4-4.

Although Busselton and Bunbury dominate damage estimates for the high and extreme scenarios, the sensitivity case of "extreme +0.9m" has been used to capture residual risk associated with the exceptional storms, and to indicate potential implications from other contributing processes (e.g. wave processes and sea level rise). For this sensitivity scenario, potential damage is massively increased, with a total across the State of $4.1billion, and 15 LGs having potential damage above $20M. Bunbury and Busselton contribute $3.1 billion of the total, with strategic interventions ineffective at these levels. It is acknowledged that this scenario is not realistic in the present day, but it highlights the general need to consider residual risk, and longer-term adaptation.

Overall, the importance of Bunbury Storm Surge Barrier for inundation hazard mitigation is clearly demonstrated. The value of Busselton surge barriers is downplayed through the percolation methodology. However, in both locations, residual risk has an enormous scale. Decision-making in these locations is effectively playing lottery: mitigating potential damage during high-extreme events has resulted in substantial investment in these locations. Greater investment means greater potential damage during exceptional events. This highlights the need for ongoing maintenance and upgrade of the protection systems, as well as the future need for substantial adaptation. The significant residual risk also indicates a critical need for emergency management, although in most applications this is focused on safety, rather than damage to infrastructure.

Sites with inundation protection structures were identified as needing focus on **Active Management**, along with those which had previously made significant town planning decisions based on inundation extent, including Port Hedland, Karratha and Geraldton (see Section 6.4). Areas with high residual risk were identified as needing focus on **Emergency Management**, along with those with potential for large areas of townsites to be inundated at extreme levels.

4.5 Average Annual Damage

Average annual damage has been used as part of standard flood and inundation risk assessment techniques [19], balancing the frequency and severity of inundation impacts. This provides an estimation of overall financial cost from inundation impacts across the State. Estimated average annual damage is shown in Figure 4-7, shown with cumulative damage up to event thresholds for high (~25 year ARI), extreme (~100 year ARI) and higher thresholds.

Overall, estimated average annual damage is $14.4M/yr, with $10.5M/yr from inundation above extreme levels. The role of storm surge barriers at Bunbury and Busselton is significant, with approximately $9.7M/yr of damage mitigated. Actions to bring Busselton inundation protection wholly up to or above the extreme level would mitigate a further $2.6M/yr.

Findings include:

- Inundation damage does not typically occur in a sustained or regular manner as, on average across WA townsites, inundation exposure is typically experienced only once per 20 years or 5% AEP (see Section 4.1).
- Estimation of damage is effectively based on an assumption that assets have no flood proofing. However, in general, as assets are closer to levels which may be affected by inundation, there is increased use of flood proofing techniques, even such simple actions as building on the highest part of a block or using a floor level raised above the ground.
- Assets most exposed to inundation are residential buildings. Inundation damage to residential buildings is partly obscured, with only severe damage being directly apparent and reported. Low to moderate level damage, which includes minor structural degradation, replacement of fittings or minor repairs often goes unreported. There is an absence of insurance reporting on inundation damage following exclusion of the actions of the sea from most insurance policies since 2014.

Geographic distribution of average annual inundation damage is shown in Figure 4-9.

	HIGH	EXTREME	EXTREME +0.9M	ALL WATER LEVELS
DAMAGE WITH SSB*	$2.0M/yr*	$3.9M/yr*	$11.1M/yr*	$14.4M/yr*
DAMAGE WITHOUT SSB**	$5.9M/yr**	$10.3M/yr**	$20.7M/yr**	$24.1M/yr**
# SITES IMPACTED**	10 sites**	15 sites**	19 sites**	20 sites**
# SITES OVER $1M AUD**	Busselton $4.4M/yr Bunbury $1.4M/yr	Busselton $5.6M/yr Bunbury $3.8M/yr	Bunbury $9.3M/yr Busselton $8.5M/yr	Bunbury $9.7M/yr Busselton $8.9M/yr Port Hedland $2.0M/yr Carnarvon $1.2M/yr

*with the protection provided by Bunbury Storm Surge Barrier (SSB)
** without protection provided by Bunbury Storm Surge Barrier (SSB)

Figure 4-7: Average Annual Damage for 23 coastal LGs

Average annual damage potentially developed across all water levels has been split into three contributing sets of events, separated at Event Thresholds (i.e. less than high, high to extreme, or above high). Average annual damage was not identified for Esperance, Karratha and Northampton at all water levels. Average annual damage was not identified for Coorow at extreme +0.9m due to very low likelihood of inundation events up to this threshold, although damage at this level was estimate (Figure 4-5).

These results are broadly consistent with outcomes from damage at event thresholds (Section 4.4) with the most substantial damages associated with Busselton, Bunbury, Port Hedland, and Carnarvon.

For high inundation scenarios (~25 yr ARI) high potential for damage for Busselton was identified, associated with understatement of protection provided by Vasse-Wonnerup surge barrier when using percolation analysis to define inundation areas.

Carnarvon has the largest average annual damage from inundation up to extreme (~100 year ARI) levels, particularly due to a breach identified in the South Carnarvon surge wall, which exposes South Carnarvon to inundation hazard.

Considering the cumulative damage from events exceeding the extreme case demonstrates the significant scale of residual risk for many LGs, including Busselton, Bunbury, Port Hedland, Carnarvon, Broome, Ashburton, Harvey, Mandurah, Exmouth, Shark Bay, Fremantle, and Dandaragan. As noted in Section 4.4, high residual risk indicates a need for maintenance of existing inundation mitigation provisions, suggests the significance of future adaptation pressure and implies the need for effective emergency management.

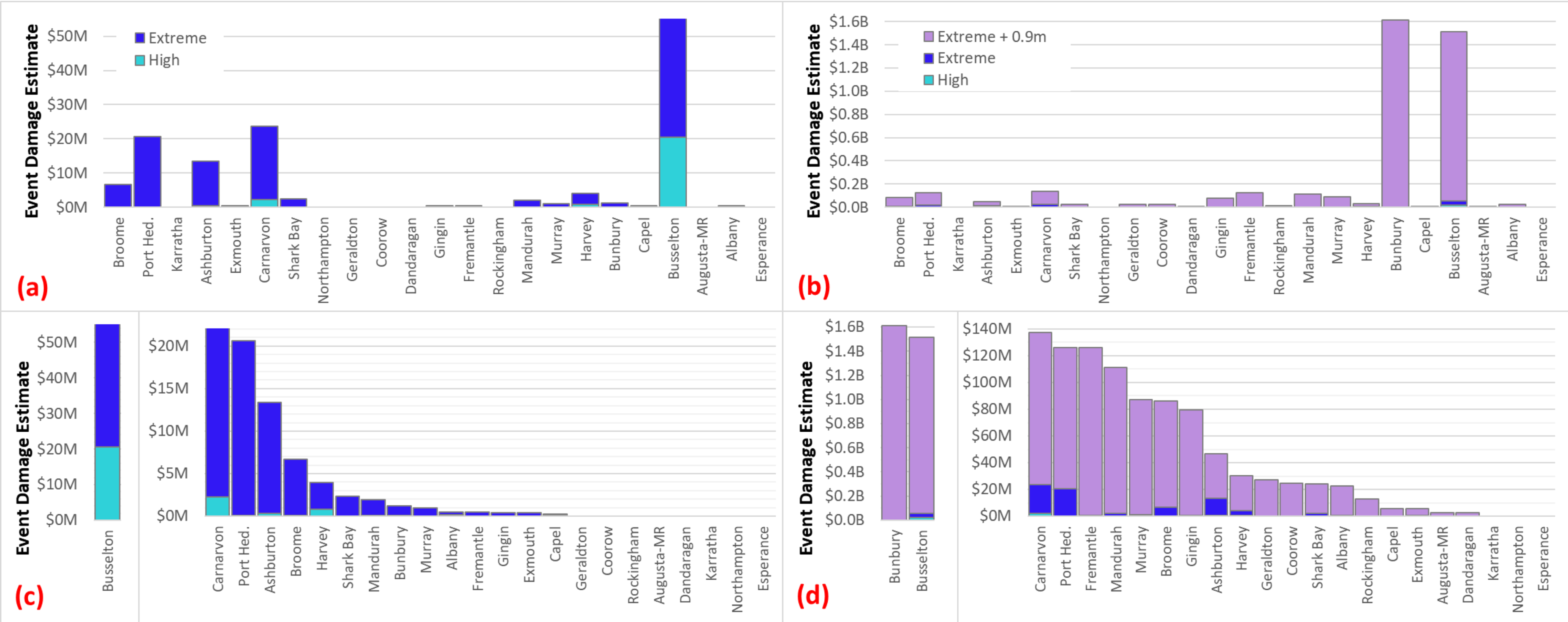


Figure 4-8: Estimated Damage per Local Government for event scenarios

(a) Sorted from north to south, showing extreme and high scenarios.
(b) Sorted from north to south, showing extreme, high and 'sensitivity' (extreme +0.9m) scenarios.
(c) Sorted by estimated damage for extreme scenario. Busselton is shown on a separate scale because it is substantially larger than other sites.
(d) Sorted by estimated damage for extreme + 0.9m scenario. Bunbury and Busselton are shown on a separate scale, being an order of larger than other sites.

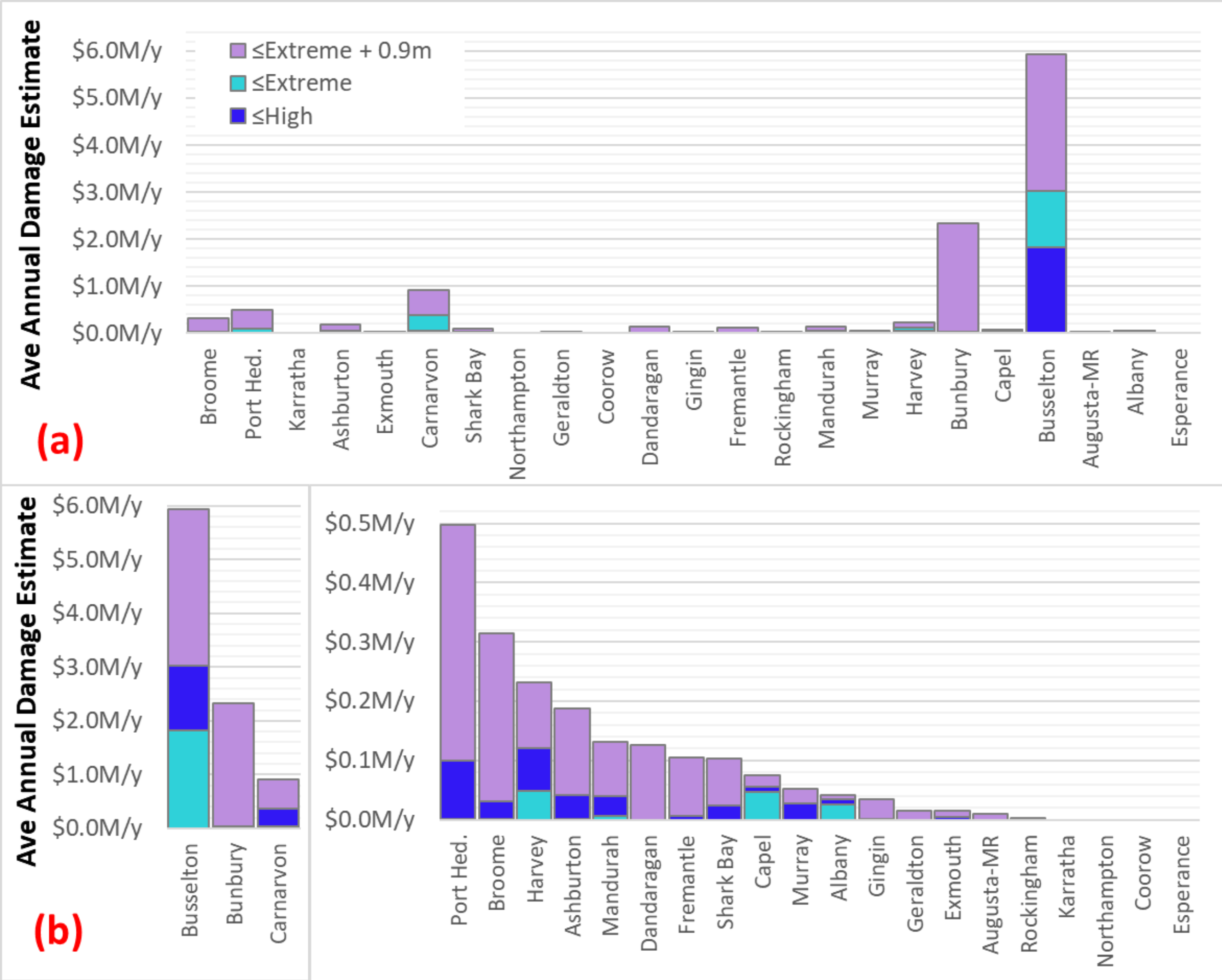


Figure 4-9: Average Annual Damage per LG

(a) Geographic distribution. (b) Sorted by average annual damage for all events. Teal and blue suggest damage from events below typical standards of protection (approximately 100 year ARI). A change in scale has been used for Bunbury, Busselton and Port Hedland, as average annual damage is 3-5 times larger than for other LGs.

4.6 Inundation Attribute Classes

*Evaluation of inundation has identified attributes of **scale**, **immediacy**, and **sensitivity** at different town sites. Using selected inundation parameters to represent these attributes (Table 4-5), their relative importance across the state has been separated into classes (Table 4-6), using apparent divisions in the distribution of parameters (Figure 4-10). Attribute classes have been used to guide direction for ongoing actions (see Section 6.4) with overall rating (*

Figure 4-11) developed through a combination of P1: immediacy, P2: damage scale and P3: sensitivity.

Table 4-5: Inundation Hazard Attributes

Attribute	Description	Parameter Used
Damage Scale	Total potential financial damage across all possible inundation events	Average Annual Damage
Immediacy	Contribution to potential financial damage from more frequent events	Damage up to High Scenario
Immediacy*	Contribution to potential financial damage from less frequent events	Damage up to Extreme Scenario
Sensitivity	Relative increase in potential financial impacts associated with higher events (including underestimation or SLR)	Ratio of Damage up to Extreme Scenario compared to higher events

Table 4-6: Attribute Classes by Local Government

Immediacy, damage and sensitivity scales are based on natural divisions in the parameters, with examples shown in Figure 4-10.

	Attribute	**Immediacy**	**Damage Scale**	**Sensitivity**	**Immediacy***
	Parameter	AAD (High)	AAD	AAD ≥ Extreme / AAD ≤ Extreme	AAD ≤ Extreme
ID	**Local Government**	**P1**	**P2**	**P3**	**P4**
1	Broome	5	3	1	4
2	Port Hedland	5	2	3	3
3	Karratha	6	5	6	6
4	Ashburton	5	3	3	4
5	Exmouth	6	4	3	5
6	Carnarvon	3	2	4	2
7	Shark Bay	6	4	3	4
8	Northampton	6	6	6	6
9	Geraldton	6	5	4	6
10	Coorow	6	6	6	6
11	Dandaragan	6	4	3	6
12	Gingin	6	5	1	5
13	Fremantle	6	4	3	4
14	Rockingham	6	5	5	6
15	Mandurah	4	4	2	4
16	Murray	6	5	4	4
17	Harvey	3	4	4	3
18	Bunbury	1	1	4	1
19	Capel	3	4	4	4
20	Busselton	1	2	1	1
21	Augusta-Margaret River	6	5	4	6
22	Albany	3	5	4	4
23	Esperance	6	6	6	6

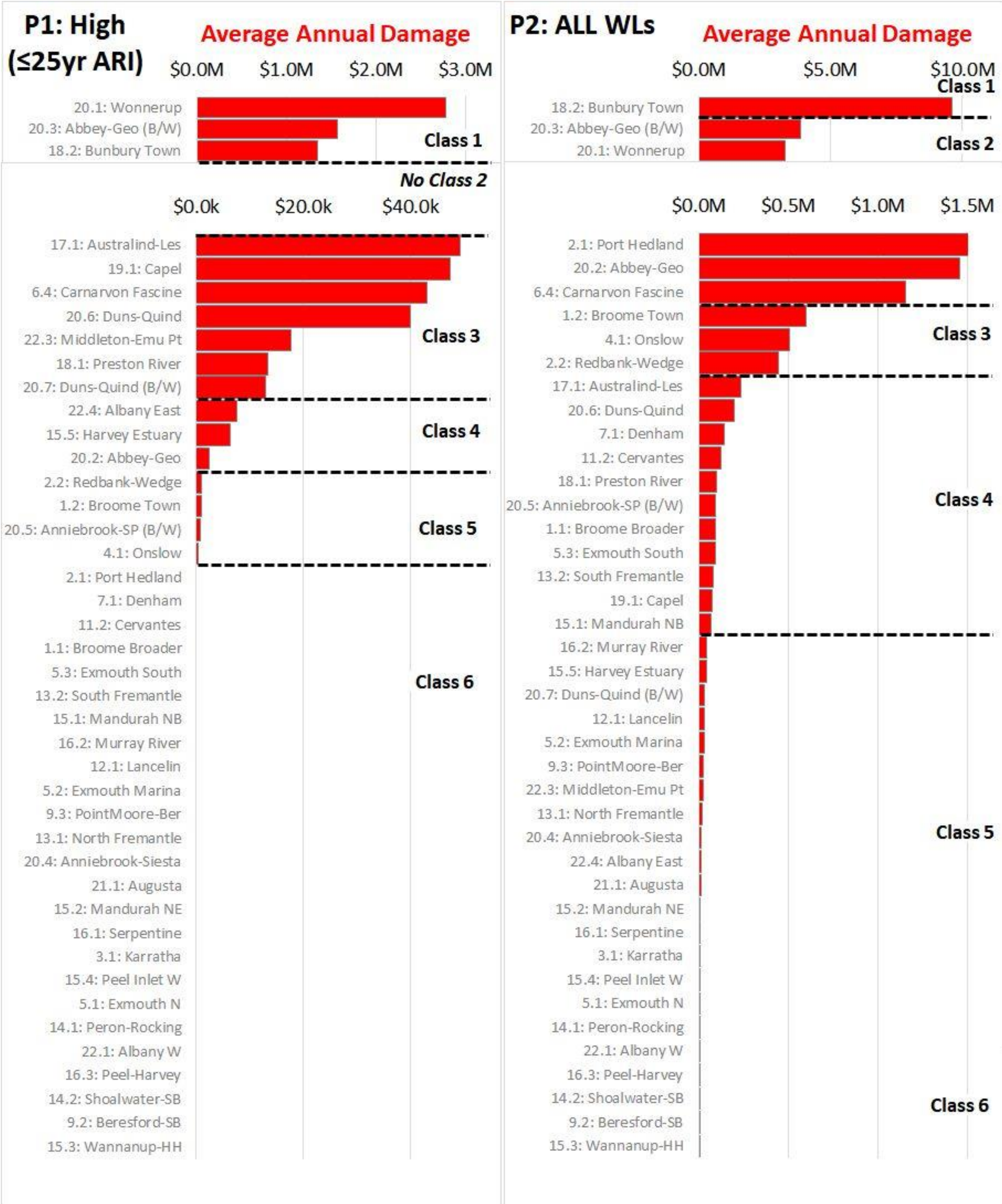


Figure 4-10: Attribute Class Divisions for Immediacy and Scale.
Class divisions for immediacy (P1) and scale (P2) are illustrated, with sites sorted by damage parameters identified in Table 4-6.

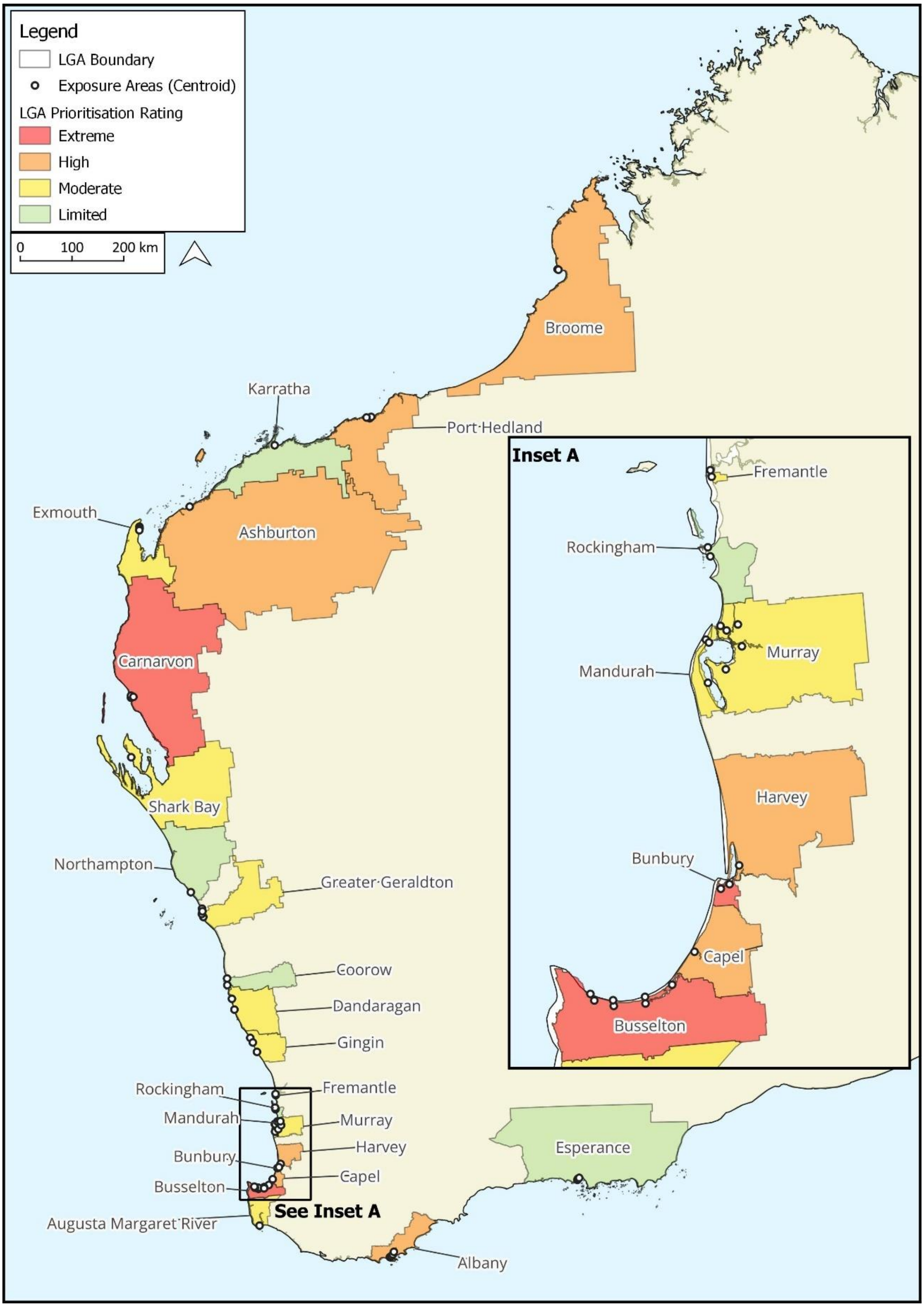


Figure 4-11: Statewide Inundation Hazard Rating.

Coloured areas do not represent extent of inundation, with locations assessed shown at dots. Colour coding for each LG is based on the highest rated site, using a combination of parameters from Table 4-6. Only coastal inundation by ocean water is assessed.

4.7 Planning Framework Review

Initial discussions with DPLH staff highlighted that the main planning tools for managing coastal inundation include State Government strategies, policies, and guidance, notably SPP 2.6 [2] and CHRMAP guidelines [8]. Implementation at the LG level is through Local Planning Strategies, Local Planning Schemes, and CHRMAPs, which also incorporate supporting vulnerability assessments. These form a part of the overall management framework for coastal inundation (Figure 4-12), specifically the aspects dealing with assessment of whether a site is appropriate for development.

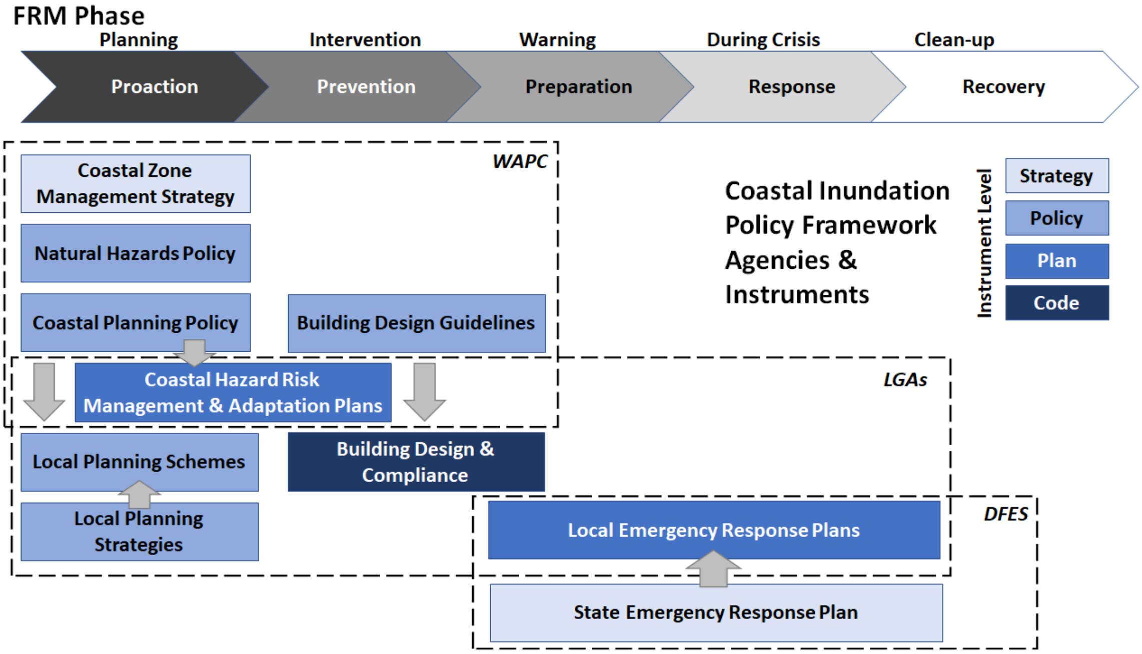


Figure 4-12: Policy Frameworks Relevant to Coastal Inundation
Shown with reference to Flood Risk Management (FRM) phases.

This stipulated role for the planning framework is important, as initial choice to allow a site to be developed creates an expectation of *permanent* tolerable risk from natural hazards. Further, there are expectations by landowners for preservation of land value, and freedom to use land with limited encumbrances. There is also a common perception that State and LG decision-makers have liability for hazards affecting freehold land and a responsibility to undertake strategic works to maintain standards of protection from coastal hazards. Consequently, future coastal changes that may undermine present-day decisions about development approvals have significant implications.

As advised by DPLH, under existing planning legislation, development contingent on future activities beyond land release requires the use of Special Controls. Two major tools stipulated by DPLH are:

1. **Notifications on Title**: this provides forewarning that tolerable risk may change over time and implies that strategic or property level mitigation may become necessary.
2. **Special Control Areas (SCA)**: this allows special provisions for issues relevant to the area. This can include imposition of conditions extending beyond land release.

However, use of SCA may have negative public connotation, as they are often linked to Special Area Rates, where moneys can be levied by LGs to support activities benefitting the target area. As implied by Figure 4-12, LGs also have opportunity to manage inundation hazard through:

3. **Building Codes**: which can define areas where flood-proofing is required. However, implementation is often slow, as it is strongly linked to building renewal cycles.

4. **Emergency Management**: which typically has a focus on human safety rather than mitigating financial costs associated with damage from coastal inundation.

A 'Planning Framework Health Check' has been developed following review of LG planning documents, specific to whole-of-system coastal inundation management (Appendix A). It is important to note there are few right or wrong outcomes, but these checks indicate potential constraints to using various coastal inundation management tools. Outcomes from the planning framework health check are summarised in Table 4-7.

Applicability or benefit of these tools to each LG has not been assessed. Choice of management tools is influenced by socioeconomics, local morphology, and planning legacies. Typically, this requires a complementary set of activities, mixing planning approval, strategic and property level protection, building requirements and non-structural measures, including emergency management [17].

Table 4-7: Overall Summary of LG Planning Framework Review

MITIGATION: Planning Framework Health Check

Item	Aspect	Conclusion from Review of LG Planning Frameworks
HC1	Scope of processes	Most LGs have identified locally relevant interactions of coastal inundation with other processes.
HC2	Storm scenario & SLR	Inundation scenarios all use 100 or 500 year ARI storm recurrence, with most using 0.9m sea level rise allowance. Inclusion of other sea level components (e.g. wave run-up or a freeboard allowance) is inconsistent.
HC3	Clarity of information	Many LGs have inundation hazard information that is inaccessible, ambiguous, or difficult to distinguish components, which may be required to distinguish between mitigation options.
HC4	Mitigation options	Direction towards mitigation options is limited. Individual LGs often focus singularly on strategic or property level protection. In general, only a limited number of mitigation options are identified.
HC5	Adaptive framework	Few LGs have yet defined adaptive pathways in response to coastal inundation. Opportunity for adaptation remains largely linked to a development approval process.
HC6	Safety management	Emergency management is widely acknowledged, but its specific role and integration with coastal inundation management is limited.
HC7	Building controls	A few LGs have identified opportunity for building controls as part of coastal inundation management. Only one LG acknowledges the Australian Building Codes flood proofing guidance.
HC8	Funding framework	Many LGs have identified SCA for coastal hazards, providing a pathway to support targeted interventions. One LG has removed a coastal SCA, identifying integrated flood and inundation hazard at a townsite scale.

Overall, there is wide variability in how well existing LG planning frameworks support holistic coastal inundation management. There is some influence of historic inundation, socioeconomics or local morphology (i.e., driven by present day needs). However, the main factor affecting the status of the planning framework is the maturity of coastal adaptation planning within each LG. This is a direct reflection of CHRMAP development being a primary source of inundation management knowledge [7]. However, it is also through this longer-term lens that mitigation options have been considered, resulting in a relatively limited range being used (Table 4-8, also see Section 5.5).

At present, LG planning frameworks do not support use of the full range of coastal inundation management tools. This doesn't align with LG's expressed interest in having a choice of approaches, able to be effective and fit-for-purpose across a range of scales [7].

Table 4-8: Identification of Inundation Mitigation Tools

ID	Local Government	Wave Barrier	Wave Damping	Wetland	Drainage	Levee Structure	Flood Gates	Temporary Protection	Dune Buffer	Min Ground Level	Finished Floor Level	Understory Throughflow	Flood Proofing	Land-use Constraint	Warning System	Evacuation Route	Insurance
1	Broome	✓ (red)							✓ (red)	✓ (red)	✓ (red)	✓ (red)	✓ (red)				
2	Port Hedland				✓ (blue)				✓ (blue)		✓ (red)						
3	Karratha	✓ (red)			✓ (blue)	✓ (blue)			✓ (blue)		✓ (red)	✓ (red)	✓ (red)				
4	Ashburton				✓ (red)	✓ (blue)			✓ (blue)		✓ (red)				✓ (blue)	✓ (blue)	
5	Exmouth								✓ (blue)		✓ (red)						
6	Carnarvon	✓ (blue)				✓ (blue)			✓ (blue)		✓ (red)		✓ (red)		✓ (blue)		
7	Shark Bay	✓ (blue)															
8	Northampton								✓ (blue)								
9	Geraldton	✓ (blue)			✓ (blue)				✓ (blue)		✓ (red)						
10	Coorow								✓ (blue)								
11	Dandaragan								✓ (blue)								
12	Gingin								✓ (blue)								
13	Fremantle	✓ (blue)			✓ (blue)	✓ (red)											
14	Rockingham	✓ (blue)				✓ (red)			✓ (blue)						✓ (red)	✓ (red)	
15	Mandurah	✓ (blue)			✓ (blue)				✓ (blue)								
16	Murray					✓ (blue)				✓ (red)			✓ (red)				
17	Harvey								✓ (blue)	✓ (red)							
18	Bunbury	✓ (blue)			✓ (blue)	✓ (blue)	✓ (blue)		✓ (blue)		✓ (red)						
19	Capel					✓ (blue)	✓ (blue)		✓ (blue)		✓ (red)						
20	Busselton	✓ (blue)			✓ (red)		✓ (blue)		✓ (blue)		✓ (red)				✓ (blue)	✓ (blue)	
21	Augusta/MR								✓ (blue)								
22	Albany	✓ (red)			✓ (red)				✓ (blue)		✓ (red)						
23	Esperance	✓ (blue)				✓ (red)			✓ (blue)								
	Policy / 2014 Review	52%	0%	0%	39%	39%	13%	0%	87%	13%	48%	9%	17%	0%	17%	13%	0%
	LGA Survey	23%	23%	23%	38%	31%	31%		46%	46%	63%	23%	15%	54%	62%	0%	70%
	Difference	29%	-23%	-23%	1%	8%	-18%		41%	-33%	-15%	-14%	2%	-54%	-45%	13%	-70%

Inundation mitigation tools were identified via review of planning framework documents (red ticks) or by a previous Statewide review (blue ticks). Percentage use of different tools has been compared against reported rates of use identified from LG survey in Phase 1 of the Coastal Inundation Assessment. Two points of interest are:

- *Land-use Constraints are actively used by LGs. However, no LG policies formally identify land-use limitations associated with coastal inundation hazard.*
- *Many LGs identify insurance as a tool for mitigation of coastal inundation hazard, which may be available through the State Government Insurer. However, insurance is not generally available for private residences, except for contingent (non-standard) insurance.*

5 Inundation Management

Interviews with LGs have identified that existing knowledge about inundation management is strongly drawn from the CHRMAP process. This inherently is focused on adaptation and, in existing applications, is also focused on planning aspects of coastal inundation management (see Section 4.7).

5.1 Existing Decision-Making

Decision-making regarding inundation risk management is substantially based on:

- Probability based thresholds, generally 100-yr or 500-yr ARI (see Box 3), often with supplementary allowances for sea level rise, wave processes, or uncertainty, as a freeboard.
- Application of risk matrices, considering exposure likelihood and value of assets. Inundation often has reduced significance compared to erosion, based on perceived tolerance of assets to short-term inundation.

Box 3: Basis for Inundation Design Criteria

General natural hazard risk criteria were developed from an 'Act of God' consideration, leading to government intervention. This was subsequently adopted by the insurance industry, which eventually became widely defined as a 100-yr ARI recurrence. This became a typical policy basis for Flood Management, later adapted for general Natural Hazard Management [18].

Public Works Department evaluation noted inundation damage was typically associated with events exceeding 100-yr ARI. They commonly adopted the highest regionally observed event as a basis for inundation management.

During initial development of SPP2.6 in 2001, it was identified the maximum criteria that could be reasonably identified from existing datasets and analysis tools was the 100-yr ARI criteria. Consequently, this level, plus 0.3-1.0m freeboard, was typically used as a design criterion.

Subsequent review of the policy in 2013 identified improvement in analytic techniques and data could support assessment of more infrequent events associated with damage. Subsequently, an 'avoidance' criterion of 500yr ARI was set. It was identified this recurrence level has ~18% likelihood of occurrence over a planning time frame of 100 years, but with acknowledgement of general tolerance to short-duration inundation from more extreme events, provided depths remain relatively shallow.

Occurrence of inundation impacts only during extreme (100 year ARI) conditions, with potential for significantly larger impact during exceptional (>100 year ARI) events. This may affect application of risk-based techniques (Figure 5-1) and used with lower likelihood thresholds, can effectively neglect inundation hazard (Figure 5-2).

For example, if a 500-yr ARI event is considered "tolerable" over a 100 year forecast, this has 18% chance of occurring (see Box 2, equation 2). Using commonly applied risk matrices [8] then asset tolerance to short-term inundation would increase the occurrence to 35-50% over the 100 year forecast time frame "tolerable". This approach neglects further consideration of damage caused by more severe events (>100 year ARI).

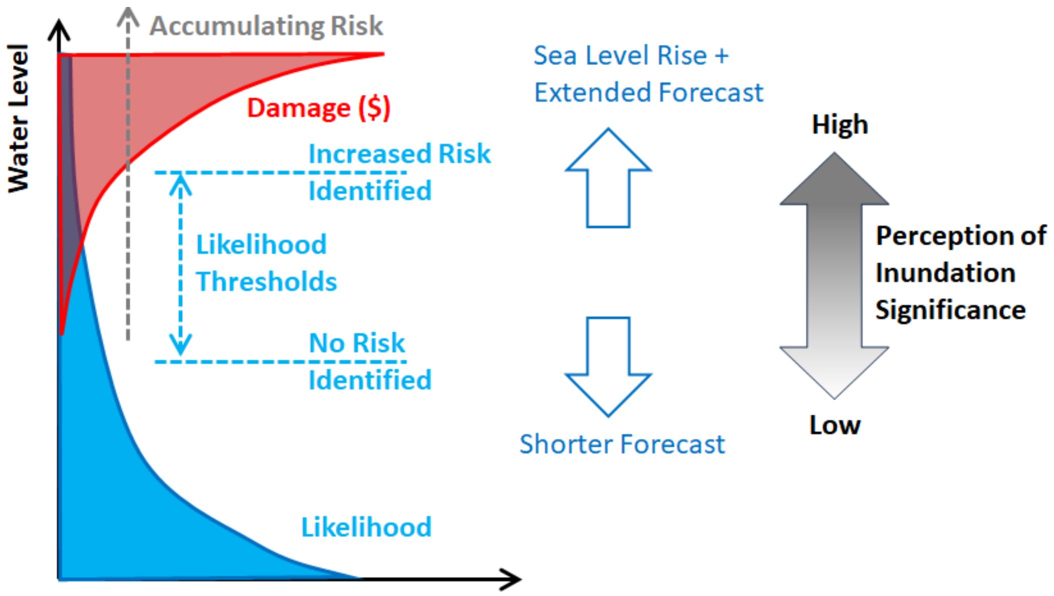


Figure 5-1: Schematic of SLR and Forecast Length Influence on Perception of Inundation Risk

Perception of risk is related to likelihood threshold, above which damage is considered sufficiently rare that damage is not factored into decision-making, typically by assuming that it will be dealt with through emergency management, insurance, or post-event disaster relief. Damage can substantially increase with a small rise in water level, particularly where structural thresholds are used (e.g. defined minimum floor levels). For this evaluation, average annual damage has been adopted as a risk measure, calculated by summing damage multiplied by likelihood across a wide range of events, extending well above typical standards of protection. This is widely used in international flood risk management practice [19].

The risk matrix approach [8] is better for adaptation planning than present-day decision-making. Use of higher ARI thresholds, or incorporation of sea level rise, provides greater capacity to incorporate potential damage associated with extreme and exceptional events.

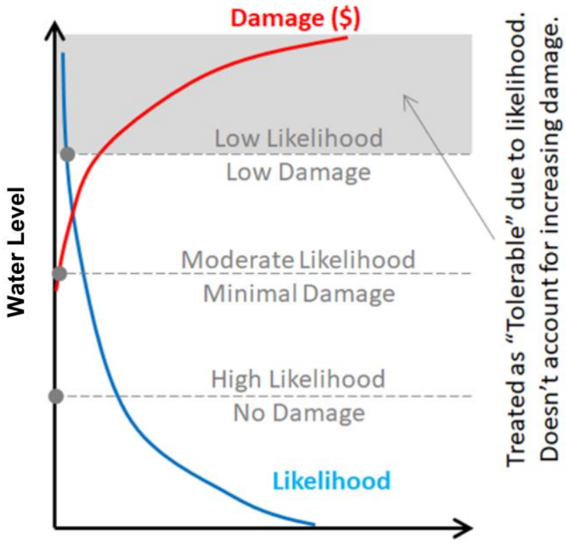


Figure 5-2: Schematic showing Effect of Discrete Assessment of Inundation Risk where risk is evaluated via damage severity and likelihood.

5.2 Selection of Mitigation Options

Inclusion of sea level rise and extreme likelihood thresholds provides opportunity for increased recognition of potentially severe impacts from inundation. However, this also modifies decision-making regarding mitigation options.

Use of high thresholds may restrict the range of viable interventions. This may be reasonable for adaptation planning, where a key objective is to identify longer-term changes to active management practices. However, this reduces consideration of mitigation cost-effectiveness, and in many cases results in identification of substantial, very expensive interventions. Response by LGs has diverged:

- Overstated risk has resulted in some LGs making large budget commitments.
- Perception that management is beyond their financial capacity has resulted in some LGs deferring assessment of inundation. This decision is typically supported by an observation of limited historic damage from inundation events.

For management of inundation at existing townsites, it is appropriate to:

1. Consider roles of existing inundation controls.
2. Consider the use of complementary actions.
3. Evaluate cost-effectiveness of mitigation across a full range of events. It may be viable to use an intervention which is effective at lower levels, which addresses the combined peak of likelihood and damage (Figure 5-3), provided higher levels can be addressed separately.
4. Consider how mitigation modifies potential damage associated with exceptional events (Table 5-1).

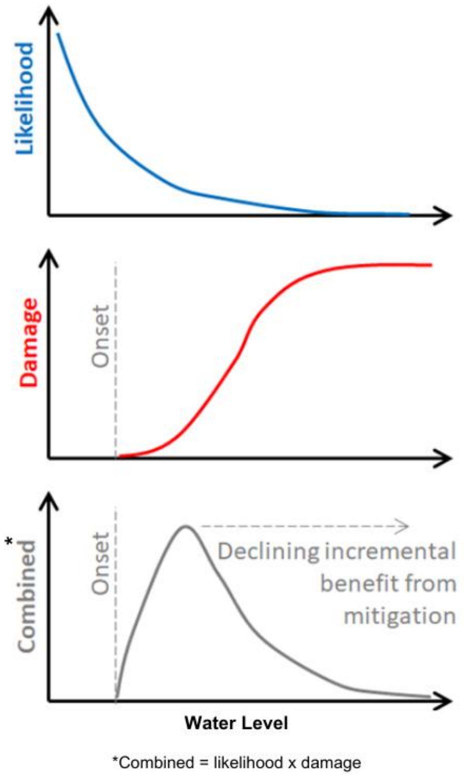


Figure 5-3: Damage-Likelihood Integration

Interaction of damage and likelihood can cause reducing incremental benefit at increasing design water levels. This means that cost effectiveness should focus on lower water levels, where a wider range of options for mitigation may be available.

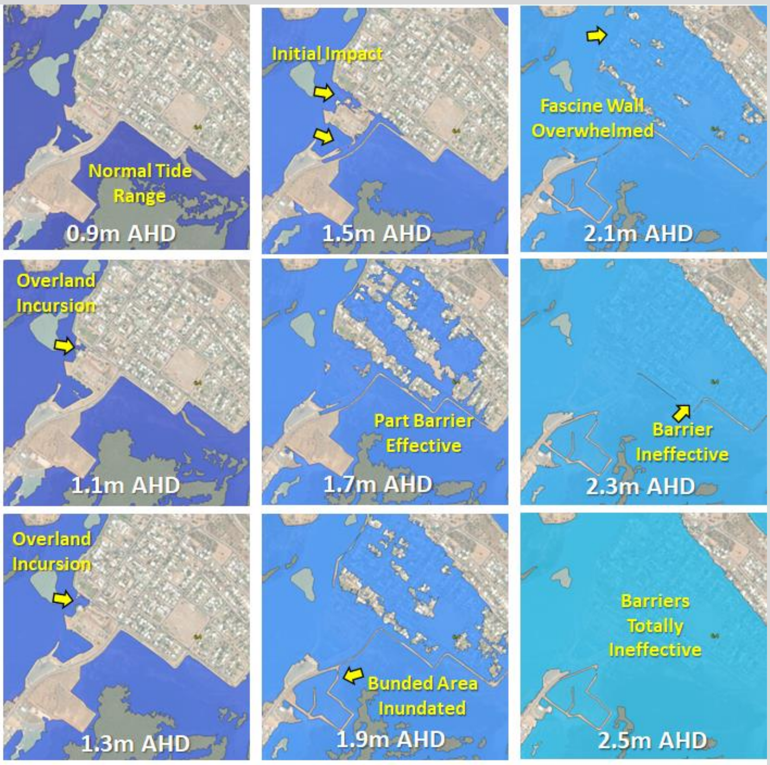
An example of mitigation option evaluation for Carnarvon is presented in **Box 4**.

Table 5-1: Implications of Mitigation Actions

"Implication of underestimation" describes consequences of having a mitigation action set at a low inundation level. "Enhanced response" indicates when damage can significantly increase with marginally higher levels above protection, when using a mitigation action.

	MITIGATION ACTION	IMPLICATION OF UNDER ESTIMATION	ENHANCED RESPONSE
WAVES	Wave Barrier	Increased overtopping	Enhanced response, sensitive infrastructure
	Wave Dampening	Effectiveness reduces with inundation	
	Wetland	Effectiveness reduces with inundation	Enhanced response
	Drainage	Insufficient drainage leading to hyper-elevation	Enhanced response
STRATEGIC PLANNING	Levee Structure	Increased overtopping risk	Enhanced response
	Flood Gates	Potential for bypassing	Enhanced response with breaching
	Temporary Protection	Limited functional flood depth	N/A
	Dune Buffer	Increased breach risk	Enhanced response with breaching
	Minimal Ground level	As above, plus potential for accelerated flow	Enhanced response, h>0.3m
PROPERTY LEVEL	Finished Floor Level	Unexpected wetting of areas	Enhanced response, h>0.3m
	Understory Throughflow	Upper story loading	
	Flood Proofing	Increased structural load & services risk	
	Land-use Constraint	Unexpected wetting of areas	Sensitive infrastructure
NON STRUCTURAL	Warning system	Areas not evacuated in time	Enhanced response, h>0.3m
	Evacuation Route	Potential for stranding	Enhanced response, h>0.3m
	Insurance	Coverage not supported	

Box 4: Carnarvon Mitigation Options



South Carnarvon Surge Wall presently provides inundation protection along the southern perimeter of South Carnarvon residential area to approximately +2.1 to +2.2m AHD (100yr ARI). However, inundation ingress can still occur, initially via Carnarvon Yacht Club, which reaches West Street at +1.4m AHD (~6yr ARI) and causes widespread inundation at +1.6m AHD (~20yr ARI).

Opportunity for inundation mitigation using foreshore levees along Carnarvon Fascine are identified adjacent to the Yacht Club and Olivia Terrace. This mitigation is considered practical up to the level of the Surge Wall:

- Next to the Yacht Club, a ~350m structure is required, 0.3-0.9m above ground level.
- Along Olivia Terrace, local raising would be needed to reach +2.1m AHD.

At higher levels, inundation can arrive all along South Carnarvon Surge Wall. Consequently, alternatives are to raise the entire length of the surge wall, or to raise finished floor levels for the low-lying parts of south Carnarvon.

Potential damage prevention provided by foreshore levees to +1.9m AHD (~50yr ARI) or +2.1m AHD (~100yr ARI) and finished floor levels up to +2.5m AHD have been evaluated using AEIP exposure and selected depth-damage functions. This suggests use of levee or structures around the foreshore may provide a practical and cost-effective for mitigating a proportion of the risk and should be investigated further. Use of finished floor levels may provide a longer-term approach, but requires consideration of practical fill levels, implementation timeframes, and sea level rise. For context, the use of a finished floor level to +2.5m AHD will reduce the present-day average annual damage for the entire Carnarvon Fascine segment from $1.15M/yr down to $510k/yr (i.e., 55% reduction).

Mitigation	**Benefit**	**Fill Volume**	**WL ARI**
Levees to +1.9m AHD	$80k/yr	<1,000m³	50yr ARI
Levees to +2.1m AHD	$250k/yr	1,000-2,000m³	100yr ARI
Finished Floor Level +2.1m AHD	$280k/yr	80,000m³	200-300yr ARI
Finished Floor Level +2.3m AHD	$440k/yr	130,000m³	>500yr ARI
Finished Floor Level +2.5m AHD*	$640k/yr	170,000m³	>500yr ARI

*Finished floor level to +2.5m AHD may be impractical due to alternative inundation pathways.

5.3 Inundation Management at the Foreshore

Wave effects, including wave runup and setup develop nearshore, and typically decline to landward (Figure 5-4). Wave effects are variably included in inundation assessment across WA (see Section 3.3.4). Inclusion or exclusion of waves can substantially affect identification of inundation hazard and choice of mitigation actions.

- Propagation of wave allowances to landward typically results in reduced consideration of drainage or wave reduction tools, which usually cost less than an equivalent elevation for inundation mitigation.
- Exclusion of wave processes understates foreshore elevations which may be required. This is important for coastal dunes, as elevation relates to required foreshore reserve width.
- Wave reduction tools (e.g. walling or foreshore vegetation) may be effective across a restricted range of water levels.

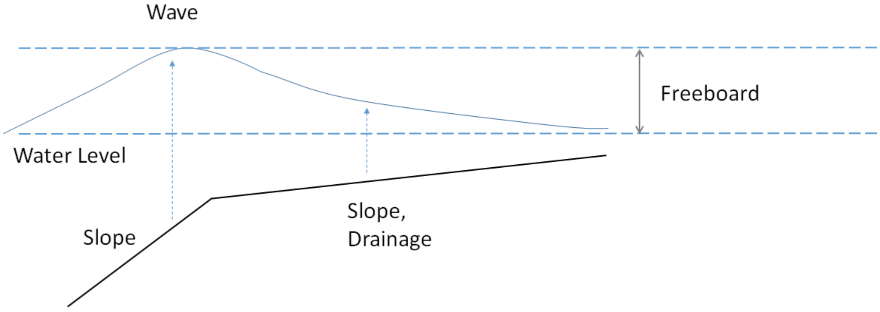


Figure 5-4: Schematic of Spatial Considerations of Wave Components

Interactions of waves and water levels varies across the coast. Nearshore wave propagation, including runup and setup are strongly influenced by beach slope, along with other factors. Landward, the role of drainage becomes increasingly significant. Consequently, freeboard selection is typically influenced by position landward.

In general, wave contributions to inundation can be cost-effectively managed at the foreshore (i.e. it is easier to build a revetment rather than retrospectively fill a foreshore suburb). This is substantially supported through preservation and management of foreshore reserves [2]. However, requirements are strongly site and structure specific (Figure 5-5).

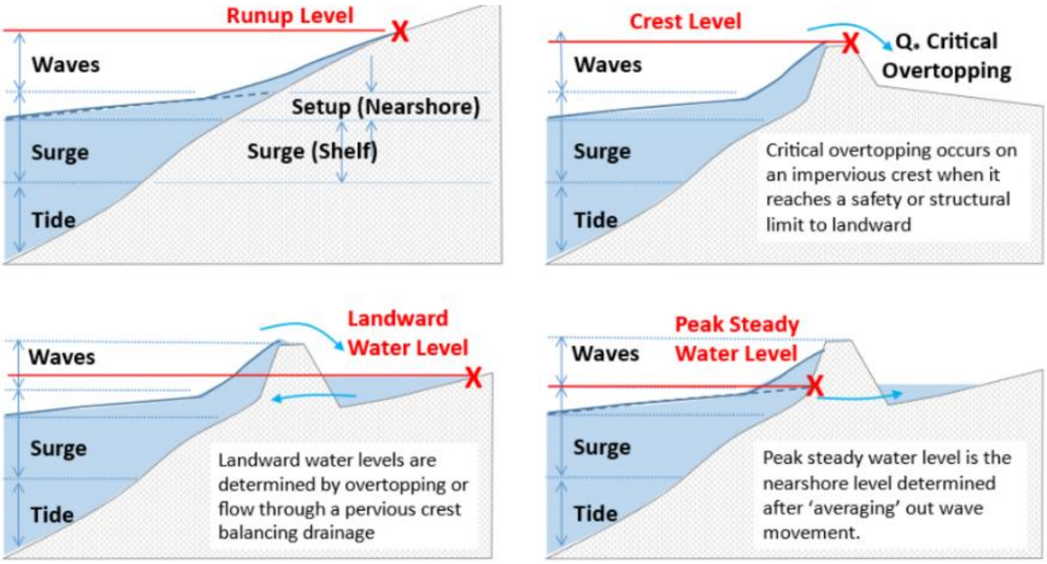


Figure 5-5: Schematic of Wave-Inundation Interactions

Design water levels may require site-specific combinations of wave and inundation.

Figure 5-6: Foreshore Reserves at Cervantes & Exmouth

Contrasting foreshore reserves at Cervantes and Exmouth have implications for how inundation should be evaluated. At Cervantes, where there is negligible foreshore reserve, waves and overtopping are significant factors in potential inundation impacts. For Exmouth, the high coastal dunes and wide flood basin determine that waves can largely be neglected from inundation impact assessment.

5.4 International Practice

Directions for inundation management are suggested by change to management strategies with increasing investment in flood hazard zones [7,17]. These include:

- Consideration of hazard using risk management principles (likelihood & consequences), including potential for events to be above the standard of protection.
- Evaluation of both financial and safety aspects of inundation hazard.
- Development of holistic assessment techniques, across planning, building and emergency management.
- Consideration of a complementary mix of mitigation actions, which may blend strategic and property-level interventions with non-structural actions (Figure 5-7).
- Refinement and development of inundation governance, to support implementation of selected inundation management strategies.

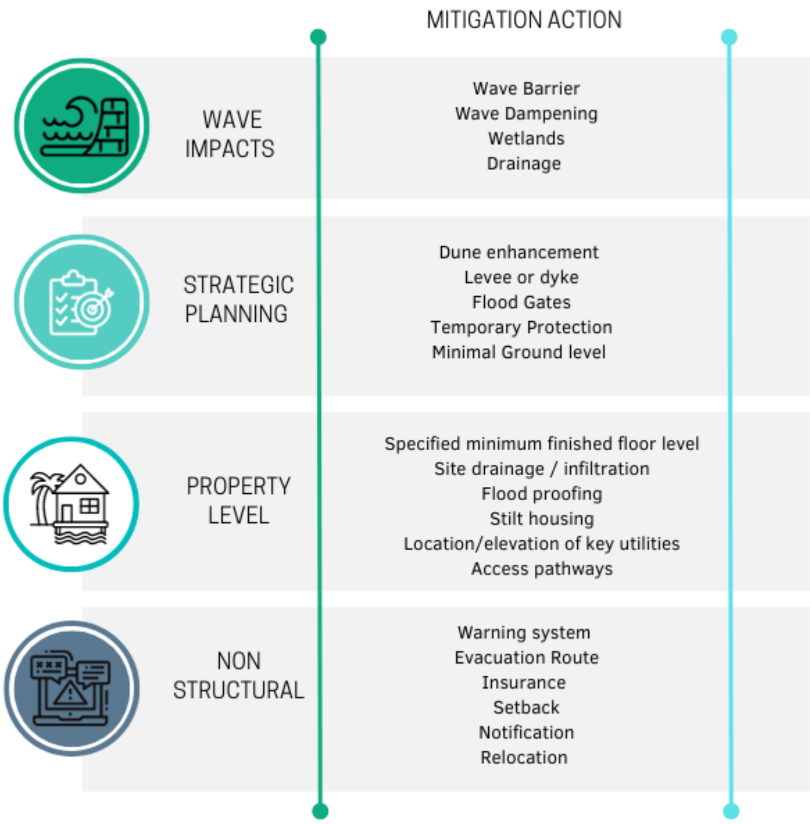


Figure 5-7: Inundation Mitigation Actions

5.5 Pathways Forward

Identification of pathways for improved management of inundation at individual sites requires more detailed assessment at each location, accounting for additional impacts, non-financial values, and community opinion. In some locations, this may require higher resolution DEM, or integration of wave and flow modelling with more refined damage assessment. However, the strategic evaluation outlined in Section 3 provides initial pathways for focus, with Table 5-2 summarising directions for each of the LGs within the following categories:

- **Active management**: these sites have been identified either as having significant inundation mitigation structures, or where major planning decisions have previously been made based upon perceived inundation hazard (see Section 4.4).
- **Adaptation Priority**: areas for which the sensitivity scenario indicated a substantial increase in potential inundation damage (see Section 3.3.4).
- **Management at Foreshore**: locations where the foreshore reserve is presently being used to mitigate wave components (e.g. via dunes) or if the foreshore reserve is inadequate for mitigating wave setup and runup (see Section 5.3).
- **Targeted Mitigation**: at sites where there is a narrow pathway for inundation waters to travel inland (see Section 4.2).
- **Emergency Management**: locations where inundation may affect large areas of townsite, arriving via multiple pathways (see Section 4.4). There is also increased imperative for emergency management at locations where inundation is actively managed, due to potential impacts from defences failing or being overwhelmed.

Areas of focus are not mutually exclusive, and aspects of inundation management that are not identified as focal points should not be neglected.

	Local Government	Active Management	Adaptation	Management at Foreshore	Targeted Mitigation	Emergency Management
1	Broome		●			●
2	Port Hedland	●			●	●
3	Karratha	●	●	●		●
4	Ashburton	●	●	●	●	●
5	Exmouth		●	●	●	
6	Carnarvon	●	●		●	●
7	Shark Bay		●	●		
8	Northampton					
9	Geraldton	●	●	●		●
10	Coorow		●	●		
11	Dandaragan		●	●		
12	Gingin		●	●	●	●
13	Fremantle		●	●	●	●
14	Rockingham		●	●	●	●
15	Mandurah		●		●	
16	Murray	●	●	●		●
17	Harvey		●	●		
18	Bunbury		●	●	●	
19	Capel		●	●	●	
20	Busselton	●	●	●	●	
21	Augusta/MR		●			
22	Albany		●		●	
23	Esperance		●	●	●	

Active Management · Adaptation · Management at Foreshore · Targeted Mitigation · Emergency Management

Table 5-2: Recommended Inundation Management Focus

6 Conclusions & Recommendations

6.1 Inundation Assessment

Evaluation of 23 LGs across WA has identified that inundation risk is substantially associated with exceptional events, above typical standards of protection (100-500yr ARI). Considering annualised risk, with estimated damage multiplied by likelihood, then 44% of risk is associated with exceptional events, and 40% of risk is mitigated by existing inundation protection measures (Figure 6-1).

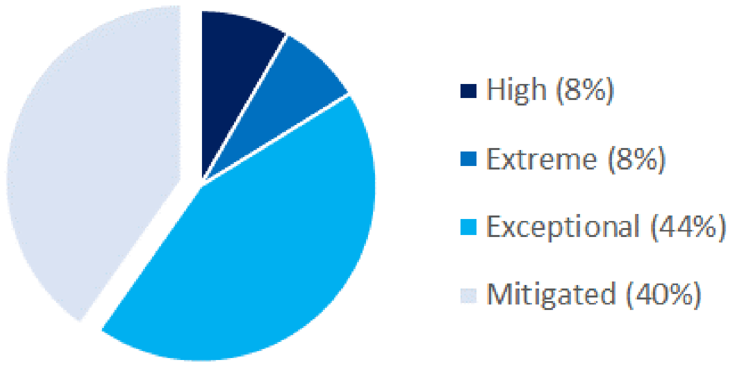


Figure 6-1: Distribution of Annualised Average Damage
Considered for all sites, this represents the proportion of annualised damage (estimated damage times likelihood) associated with high (up to ~25yr ARI), extreme (~25-100yr ARI) or exceptional (above ~100yr ARI) events.

Findings from the evaluation include:

1. The most significant sites for inundation management are at Bunbury and Busselton, which are actively managing existing risk through use of protective structures such as storm surge barriers, levees, and coastal sea walls. The importance of these structures is immense, mitigating an estimated $9.7M/yr damage, although subsequent development has introduced substantial risk associated with exceptional events (see point 4).
2. Assessment at a strategic level suggests an immediate need to review Busselton's inundation protection in detail, with local actions to enhance protection considered likely. This need has been identified by the City of Busselton, who are presently undertaking detailed investigations.
3. Frequent exposure of built assets to inundation occurs across low elevation coastal areas of Geographe Bay, between Busselton and Australind, which corresponds to previous evaluation [16]. Other sites with high frequency of inundation exposure include Carnarvon, due to low elevation, and Cervantes, where there is inadequate foreshore reserve to mitigate waves. At most other sites exposure to inundation commences with extreme events (around 100yr ARI) with significant damage generally developed by exceptional events.
4. Financial impact from inundation has been estimated as an average of $11M/yr, combined for all 23 coastal LGs. However, relatively infrequent exposure determines that inundation damage does not occur with regularity. Much of the annualised average damage (~73%) has been assessed to occur during exceptional events. Almost all of this risk is associated with overwhelming of existing inundation defences at Bunbury and Busselton or their failure, which can produce devastating damages in the order of $100M to $1000M. Critical events have present-day recurrence of 200-2000 year ARI, with significant increase to likelihood under projected sea level rise. Potential impacts at other sites, which are not reliant on storm surge

barriers, is generally smaller, but still in the potential range of $10M to $100M for Carnarvon, Port Hedland, Fremantle, Mandurah, Shire of Murray, Broome and Lancelin.

5. Existing tools used for inundation assessment typically do not incorporate risk associated with exceptional (above 100-500yr ARI) events, which can and do occur (see Section 5.1). It is implicitly assumed that emergency management provides adequate mitigation of inundation impacts during exceptional events. However, emergency management actions largely focus on human safety, rather than financial impacts.
6. Inundation risk is substantially associated with private residences. Since 2014, this financial risk cannot be offset by standard insurance policies. Consequently, the financial impact will be on private landowners.

WA's existing decision-making tools and governance are not well positioned to support the transition from management focused on hazard avoidance towards risk-based inundation management (Figure 6-2). International flood management practice has demonstrated this requires a paradigm shift, with development of holistic approaches, and consideration of exceptional events. This needs better integration of planning, protective works, building design and emergency management.

Figure 6-2: Schematic of Threshold and Risk Based Management

a) Threshold Based Management: single Line used to discriminate acceptability.
b) Risk-Based Management: wide range of possible inundation events considered (supports consideration of SLR). Note that inundation lines and location of land raising are not data-based. They are shown for illustration only.

A potential pathway for improved management of coastal inundation is suggested in Section 6.4.

6.2 Planning Framework Review

As advised by DPLH, planning instruments are largely restricted in application to development approvals. Consequently, special controls are required for conditional development provisions after development approval, such as flood-proofing or adaptation to coastal change. Presently, 9 out of 23 LGs use SCAs for inundation management, identified by DPLH review of planning scheme text.

More detailed evaluation of LG planning frameworks, including Local Planning Strategies, Local Planning Schemes and CHRMAP indicated that presence or absence of SCAs does not solely determine preparedness for coastal inundation management in each LG. Existing planning frameworks are typically a result of planning legacies, as well as socioeconomics and local morphology. Capacity for inundation management is strongly tied to maturity of climate change assessment in each LG, including CHRMAP development. This has resulted in each LG having an individual set of information and tools. Although often similar, especially between adjacent LGs, this complexity defies imposition of a single approach towards refining management for coastal inundation – hence while SCAs provide an obvious pathway from the perspective of planning legislation, not all LGs may choose to use this approach.

A 'planning health check' assessment is outlined in Section 3.4 and results are summarised in Section 4.7. Overall, there is wide variability in how well existing LG planning frameworks support holistic coastal inundation management. Appropriate pathways for refinement will be distinct for each LG, but in general, recommended actions include:

- More consistent use of agreed methodologies and inundation scenarios. This possibly requires enhancement of SPP 2.6 guidelines, to specifically identify the interaction between mitigation choice and inundation criteria (see Sections 5.2 and 6.4).
- A focus of avoiding inconsistency and ambiguity within planning documents. This may be conducted as part of regular review and update of planning documents. However, as this occurs intermittently, typically every 5-10 years, there may be benefit having centralised knowledge to support the review, such as through WALGA or DPLH.
- Consideration of a wider range of mitigation options may improve the cost-effectiveness of managing coastal inundation. Application of hazard-asset-damage-mitigation methods outlined in Section 6.3 provides a pathway for improved use of alternative approaches, such as better use of modelling to estimate damage across a wider range of events. Assembly of a handbook of coastal inundation mitigation techniques, like that developed for Queensland [20], but covering a wider range (Figure 5-7) may also support improved future management.
- Improved recognition of the role of building design [21] and emergency management for coastal inundation is required, particularly how their inclusion may modify appropriate inundation criteria.

6.3 Limitations and Opportunities

A hazard-asset-damage evaluation method for inundation assessment (see Section 3.2) has been developed to ensure consistency across the State, based upon information limits, with an overall objective for rapid assessment. Consequently, it was necessary to compromise on the overall quality of information, compared to the best available information at each site (Table 6-1).

Table 6-1: Statewide Inundation Assessment Information Quality

Information	Source	Quality
Topography	High resolution DEM	High
Hazard Likelihood	Tide gauge data analysis (Appendix C)	Moderate
Hazard Areas	Percolation assessment	Moderate *
Assets at Risk	AEIP Portal	Moderate, coarse geolocation
Valuation	AEIP	Moderate, variable between sites
Damage	Published literature [5]	Moderate, depth-based only

* Percolation assessment is considered likely to overstate hazard within estuarine settings

Enhancement of Valuation Method

Incorporation of shapefile functionality through the AEIP portal provided a significantly accelerated process for evaluation of assets at risk and their valuation. However, in its present format, AEIP provides constraints to the evaluation:

- Provenance of exposure information within the NEXIS database (accessed via AEIP) is not documented, resulting in a need to check information at each site. It is understood that information is originally generated by LGs or Landgate for the WA Valuer General, which is subsequently transferred to NEXIS database, with access provided via AEIP.
- AEIP reports information on a 50m grid, with value for larger assets linked to all cells that the asset intersects. This constrains the intersection of high-resolution representation of hazard areas with the valuation, which can result in incorrect levels being assigned when assets are adjacent to the foreshore (e.g. estuary edges or canal ways).

It is recommended that liaison with Geoscience Australia be undertaken, to identify opportunities for local-scale refinement of exposure information. This may include:

1. More direct transfer of valuation and asset information from LGs to Geoscience Australia *.
2. Development of higher-resolution positioning of assets at selected coastal locations.
3. Refinement of damage functions, to better incorporate local building information and hazard characteristics (e.g. water levels, waves and currents).

* Increasing use of Building Information Management (BIM), and certification of capacity for buildings to withstand natural hazards was identified by LGs in Phase 1. A deeper shared understanding of information requirements appropriate for damage-based inundation assessment may support improved knowledge flow. A primary example is identification of building floor levels as part of BIM submission for development, which otherwise can be a challenging exercise to develop post-development.

Enhancement for Detailed Assessments

Although the strategic method applied for this assessment was simplified, it offers several opportunities for improvement of detailed inundation assessments typically undertaken to support CHRMAP. These include:

1. Use of the percolation assessment, or equivalent, provides a clear first pass evaluation of the identification of hazard onset and pathways than use of hazard lines commonly presented in CHRMAP. Presentation using levels alone reduces the focus on event likelihood, which often

has low certainty, and is subject to change over time. Presentation in this way facilitates more rapid reassessment when inundation likelihoods are reassessed.

2. Incorporation of shapefile functionality into the spatial intersection of assets exposure and hazard facilitates better linking of detailed coastal hazard assessment, derived through numerical modelling. This can include delineation of inundation hazard shapefiles based on a more complete set of oceanographic parameters, that influence inundation impacts, including wave conditions, duration of inundation, and speed of flow.
3. Identification of incremental damage estimates supports simplified financial justification for mitigation works, by submitting amended shapefiles to AEIP for valuation.

Limitations of percolation assessment within flow constrained settings (estuaries and overland) are acknowledged. However, it is also recognised that scientific knowledge of different processes contributing to coastal inundation is variable (Figure 6-3). Identification of how inundation events transfer through estuaries and overland is relatively poorly understood, preferably requiring use of modelling combined with suitable monitoring, capturing extreme or exception events, to support model validation.

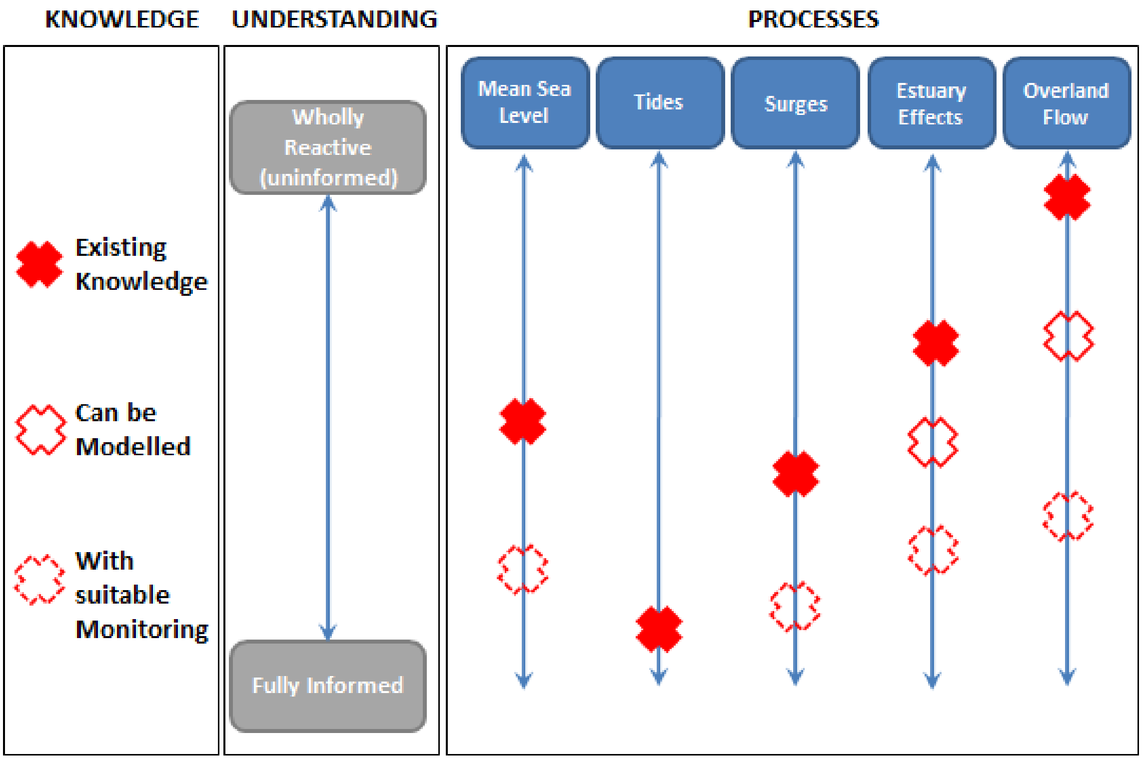


Figure 6-3: Knowledgebase for Inundation Processes

Knowledge of different physical processes contributing to inundation varies, with limited understanding of estuarine processes and overland effects. Improved confidence can be developed through modelling and monitoring. Waves have been excluded from this figure.

Refined understanding of estuarine behaviour may be required for Augusta-Margaret River, Bunbury, Busselton, Capel, Fremantle, Harvey, Mandurah, and Murray, with some sites having established water level monitoring. Characteristics of overland propagation are generally more difficult to validate, with historic mapping of debris lines following exceptional events typically providing the main source of information.

6.4 Where to from Here

Evaluation of inundation hazard and asset exposure has identified the scale and extent of coastal inundation pressures across WA. This highlights that inundation impacts, while infrequent at most sites, can be substantial, with $10M-$100M damage possible at many townsites, mostly affecting residential dwellings. When evaluated only up to 'extreme' scenarios, approximately 100-year ARI level, existing inundation hazard is limited for most LGs, which is generally consistent with anecdotal observations of damage. However, the ability to identify damage is at least partly obscured by private residences being the primary subject for inundation impacts. Most residences with some exposure to inundation hazard are already built with flood-proofing elements, even simply raised floor levels. Exceptional events, which exceed these protective measures, may have the capacity to cause significant damage.

Exceptional inundation events can and do occur. They can be developed through extreme storm intensity, timing with respect to tide, unusual storm characteristics (path or speed) or coincidence or multiple water level phenomena. Consequently, across the range of LGs, there is a need to expand from focusing on coastal adaptation, to recognise and consider implications of exceptional events. Two pathways for improved management at LGs are identified:

- **Relative exposure to exceptional events should be a key driver for inundation management decision making, rather than assuming risk above mitigation thresholds is tolerable.**
- Focal areas for inundation management should be used as a basis for directing investigative effort.

Table 6-2: Coastal Inundation Susceptibility and Decision-Making
These are indicative only.

Susceptibility Rating	**0**	**1**	**2**	**3**	**4**
Inundation Susceptibility	Negligible	Limited	Moderate	High	Extreme
Decision-making timeframes	>25 years	>25 years	5–25 years	1–5 years	Active
Hazard Assessment	N/A	CHRMAP Hazard Lines		Damage Based Hazard Assessment	
Actions to be Taken	N/A	N/A	Review WL Likelihood	Review Sensitivity	Economic Review
Management Plans	Regional Coastal Management Plan only			Assess need for Plans	Inundation Plan
Basis for Classification	Above Design Storm WLs	Future Inundation Risk	Low Inundation Risk	Moderate Inundation Risk	High Risk / Active Management
LGs		Coorow Esperance Karratha Northampton Rockingham	Augusta-MR Dandaragan Exmouth Fremantle Geraldton Gingin Mandurah Murray Shark Bay	Albany Ashburton Broome Capel Harvey Port Hedland	Bunbury Busselton Carnarvon

It is highlighted the existing planning approach in SPP2.6 [2], to preferentially avoid coastal hazard with a long-term forecast, remains international best practice. However, tools used to delineate zones of hazard avoidance are not well-suited to identification of inundation mitigation actions in developed sites, where it is impractical to avoid the hazard. In these locations, there is increased need to evaluate across the range of possible inundation events. The Statewide assessment of coastal inundation and decision making (Table 6-2) has been used as a basis for directing how inundation management framework should vary between LGs:

- It is noted the 'Design Storms' approach [22], simulating a single severe storm of loosely defined recurrence, was developed with an objective to distinguish between negligible and low levels of inundation hazard. This simplified technique is considered inappropriate for risk delineation at higher levels of inundation hazard.
- For sites with present day negligible or low levels of susceptibility to inundation hazard (Table 6-2), it is appropriate to focus on coastal adaptation, using existing frameworks outlined in SPP 2.6 [2] and the CHRMAP Guidelines [8].
- For moderate inundation hazard, CHRMAP-based hazard lines have been identified as inconsistent between location, due to variations in processes considered and significant differences in outcomes depending on the analytic method used. It is noted that conservative inundation estimates are tolerable for adaptation but will overstate the imperative for mitigation. Ongoing refinement of CHRMAP should include review of water level likelihoods defined for each LG. This is likely to be best achieved through initial development of a guidance note for LG consultants to prepare inundation hazard assessments, identification of how to deal with methodological confidence, and enhanced review processes.
- Where there is significant inundation hazard (suggested by susceptibility rating 3 or 4 in Table 6-2), use of hazard lines potentially obscures significant risk associated with exceptional (>500 year ARI) events. For these cases, it is recommended to transition towards a damage-based assessment of inundation (i.e. a greater focus on present-day or emerging inundation risk and active mitigation, rather than adaptation and mitigation through avoidance). This is anticipated to support more refined identification of mitigation actions and facilitate effective use of a wider range of responses.
- For high inundation susceptibility (rating 3), the AEIP damage-based assessment should be evaluated in a context of sensitivity, such as considering cost-effectiveness of potential mitigation actions should existing management criteria be raised by 0.5-1.0m. This evaluation should also identify the need for inundation management action plans, which may involve focus on dune management, adaptation and/or emergency management.
- Very high inundation susceptibility (rating 4) indicates potential for substantial damage associated with exceptional events. For these locations, it is recommended that an economic review be undertaken, with the specific objective of identifying whether the adopted standard of protection represents an appropriate risk, given relative exposure during exceptional events.

Levels of inundation decision-making suggested for each LG are considered the minimum applicable. It may be beneficial for some LGs to undertake further evaluation, particularly when considering extensive additional townsite development. In the longer term, subject to projected sea level rise, it is anticipated that a progressively increasing number of LGs will need to move towards more informed inundation decision-making (Figure 6-4). In all locations, it is appropriate to consider all aspects of coastal inundation. However, as discussed in Section 5.5, existing townsite layouts and management suggest different areas of focus for inundation management, not mutually exclusive, broadly classed into active management, management at the foreshore, targeted mitigation, emergency management and adaptation priority (Figure 6-4). For example:

- Sites with **active management**, particularly those with structural mitigation, should identify the basis for their inundation decision (or structure performance) and define conditions under which this performance is inadequate.
- For areas where inundation **management at the foreshore** is required, it is appropriate to assess the contribution of wave processes to risk, and the performance of foreshore protection measures (e.g. required dune elevation and width). This may require characterisation of wave conditions and evaluation of drainage capacity.
- At areas of **targeted mitigation**, local assessment of cost-effectiveness of mitigation should be undertaken, even if they cannot practically defend against an extreme inundation event.
- **Emergency management** requires development of an emergency management plan, incorporating warning, action plan and recovery, following EMA guidance [23].
- Areas where **adaptation** has been identified as a focus have a significant change in inundation exposure within 0.9m sea level rise, likely to require a shift from adaptation planning through to active inundation management. Almost all sites have this challenge. Port Hedland and Karratha are sites where inundation management systems in place, which are designed to cater for extreme tropical cyclones, may be adapted with rising sea level, but not change significantly. Northampton was the only LG where inundation hazard is expected to remain dominated by wave action under 'extreme' scenarios (~100-year ARI).

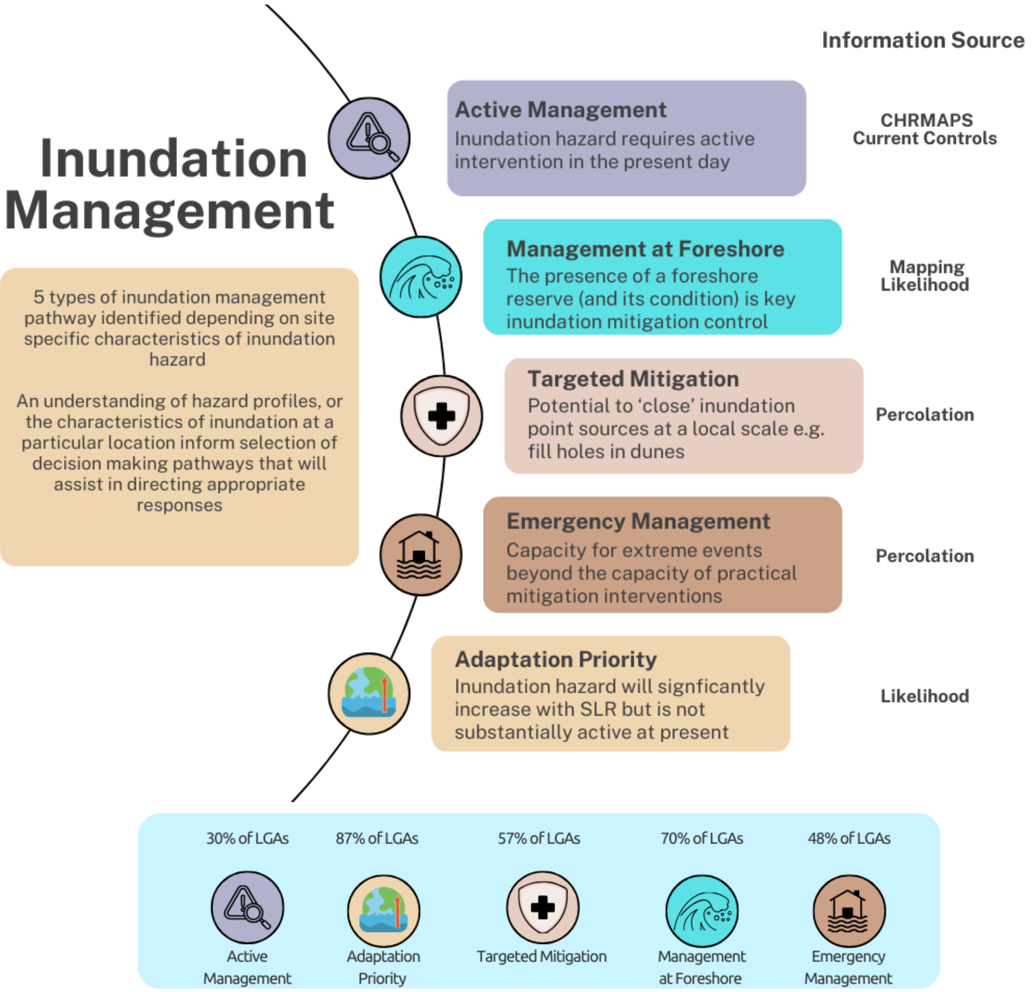


Figure 6-4: Focal Areas for Inundation Management

A summary of recommended actions for each LG is provided in Table 6-3 with a brief description of each actin in Table 6-4.

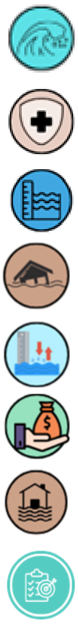
Table 6-3: Recommendation Actions by Local Government

	Local Government	Inundation Rating	Foreshore Management	Targeted Assessment	WL Review (CHRMAP)	Damage Based Assessment	WL Sensitivity	Economic Review of Criteria	Emergency Plan	Inundation Plan
1	Broome	High	✓	✓	✓	✓	✓		✓	TBC
2	Port Hedland	High	✓		✓	✓	✓		✓	TBC
3	Karratha	Limited	✓	✓					✓	
4	Ashburton	High		✓	✓	✓	✓		✓	TBC
5	Exmouth	Moderate	✓	✓	✓					
6	Carnarvon	Extreme			✓	✓		✓	✓	✓
7	Shark Bay	Moderate	✓		✓					
8	Northampton	Limited	✓							
9	Geraldton	Moderate	✓		✓				✓	
10	Coorow	Limited	✓		✓					
11	Dandaragan	Moderate	✓	✓	✓					
12	Gingin	Moderate	✓	✓	✓				✓	
13	Fremantle	Moderate		✓	✓				✓	
14	Rockingham	Limited	✓	✓					✓	
15	Mandurah	Moderate	✓		✓					
16	Murray	Moderate	✓		✓		✓		✓	
17	Harvey	High	✓	✓	✓	✓			✓	TBC
18	Bunbury	Extreme	✓	✓	✓	✓	✓	✓	✓	✓
19	Capel	High		✓	✓	✓				TBC
20	Busselton	Extreme			✓	✓		✓	✓	✓
21	Augusta/MR	Moderate	✓	✓	✓					
22	Albany	High		✓	✓	✓	✓			TBC
23	Esperance	Limited	✓							

Limited Moderate High Extreme

**TBC – To Be Confirmed indicates that further information is required at a site-specific level to inform whether an Inundation Plan is recommended for this LGA*

Table 6-4: Description of Recommended Actions



Foreshore Management	Using the foreshore reserve to support inundation mitigation, by limiting transfer of waves to landward.
Targeted Assessment	Evaluation of a local inundation pathway, to determine whether targeted works may cost-effectively alleviate inundation risk.
Water Level Review (CHRMAP)	As part of ongoing CHRMAP review, refine & update inundation and wave estimates used to characterise inundation.
Damage Based Assessment	Undertake damage-based evaluation of inundation risk, to identify a cost-effective suite of mitigation actions.
Water Level Sensitivity Review	Evaluate the sensitivity of proposed mitigation actions to variation of inundation criteria by 0.5-1.0m upwards.
Economic Review of Criteria	Undertake an economic-based risk evaluation to determine the appropriateness of existing inundation protection criteria.
Emergency Plan	Develop an emergency management plan specific to coastal inundation hazard.
Inundation Plan	Develop a plan specific to inundation, identifying key tools, responsibilities, and management actions. This should integrate adaptation and emergency management.

7 Appendices

Appendix A **Site Summaries**

Appendix B **Inundation Assessment Technical Method**

Appendix C **Supplementary Evaluation**

Acronyms

AAD	Average Annual Damage
AEIP	Australian Exposure Information Platform
AEP	Average Exceedance Probability
AHD	Australian Height Datum
ALS	Aerial Laser Scan
ARI	Average Recurrence Interval
CHRMAP	Coastal Hazard Risk Management and Adaptation Plan
DEM	Digital Elevation Model
DoT	Department of Transport
DPLH	Department of Planning Lands and Heritage
DRM	Disaster Risk Management
DWER	Department of Water and Environmental Resources
HC	Health Check
LG	Local Government
NEXIS	National Exposure Information System
SCA	Special Control Area
SLR	Sea Level Rise
SPP	State Planning Policy
SLR	Sea Level Rise
TC	Tropical Cyclone
WA	Western Australia
WL	Water Level

Glossary of Terms

Adaptation pathways: a sequential set of actions responding to changing conditions, aimed to maintain a tolerable level of risk.

Assets Register: a list of assets, usually with complementary information, generally owned or managed by a stakeholder, such as a local government agency.

Assets: physical object regarded as having value. In this study, classes of asset reported via AEIP include agricultural land, residential contents and commercial, industrial, or residential buildings.

Average Annual Damage (AAD): nominal representation of potential damage due to inundation, estimated by integration (sum) across an entire range of plausible events, of damage estimated for a particular inundation event, multiplied by the likelihood of that event being reached.

Average Exceedance Probability (AEP): the average chance of exceeding a threshold in any particular year. This concept is closely linked to average recurrence interval, approximately with ARI ~ 1/AEP.

Average Recurrence Interval (ARI): average length of time between events beyond a threshold.

Coastal Inundation: flooding of normally dry land by actions of the sea.

Coastal Inundation Management: actions to reduce negative impacts from coastal inundation, which may include planning, relocating assets, protective works, evacuation management or recovery actions.

Coastal Inundation Threshold: identified level of inundation marking a change in impact. Typical thresholds are identified for initial wetting, a limit of pedestrian safety, or expected inundation level causing structural failure.

Commercial Buildings: buildings classified as providing commercial services, such as retail shops, offices, service stations, or short-term accommodation. Classification from AEIP.

Damage: an impact from a hazard which reduces performance or value of assets.

Damage Function: a mathematical representation of relationships between environmental variables and corresponding damage to assets. Inundation damage functions range from a function of depth only, to including multiple parameters, such as flood depth, duration, rate of rise, flow speed and wave action.

Damage Curve: a graphical representation of a damage function relating to a single variable. Inundation damage curves are typically related to inundation depth.

Decision-making Pathway: the process by which decisions are made, which typically involves collection and synthesis of relevant information, with discussion among stakeholders to resolve a course of action.

Digital Elevation Model (DEM): representation of a topographic surface using a set of spatial coordinates describing the level of the ground surface.

Disaster Risk Management (DRM): actions to reduce negative impacts from disasters, which may include planning, relocating assets, protective works, evacuation management or recovery actions.

Exceptional Event: inundation event exceeding the standard of protection provided by hazard mitigation (protection or avoidance).

Exposure: presence of societal elements (e.g. people, buildings, land-use, environmental assets) in an identified area of hazard.

Exposure Threshold: a nominated hazard level beyond which hazard is considered to be tolerably infrequent, or insufficiently severe to require hazard mitigation,

Extreme Inundation: inundation associated with exceptionally rare events. For this report, extreme inundation has been classed as events exceeding a 1% AEP or 100-year ARI level.

Financial Exposure: monetary value of assets located within an identified area of hazard.

Financial Vulnerability: a monetary measure of hazard impact, integrating likelihood of hazard events and corresponding impact to financial assets.

Flood Risk Management: actions to reduce negative impacts from flooding, which may include planning, relocating assets, protective works, evacuation management or recovery actions.

Flooding: when water, from rainfall, streamflow, or runoff, occupies areas that are usually dry, causing hazard such as potential damage to property or risk to human welfare.

Flow Pathways: how water arrives at a location. This generally includes the water source, its direction of movement, and influences of features it passes over to get there. This may involve rainfall, stream channels, wave action, tides, or storm surge.

Industrial Buildings: buildings classified as providing industrial services, such as factories, storage areas, ports, or utilities. Classification from AEIP.

Inundation Event Scenarios: a representation of an inundation event used to assess the need for inundation management actions. This may be based on a historic event or be developed using statistical principles. Typically, 0.2% and 1% AEP (or 500-year and 100-year ARI) inundation event scenarios are used for town planning.

Inundation Exposure: presence of societal elements (e.g. people, buildings, land-use, environmental assets) in an identified area of inundation hazard. This does not account for flood-tolerance, and (point of wetting)

Inundation Pathways: how ocean water arrives at a location. This generally includes the water source, its direction of movement, and influences of features it passes over to get there. This may involve wave action, tides, or storm surge.

Light Detection and Ranging (LIDAR): a device that measures reflection of pulsed light to determine a distance. In this study, it refers to capture of topographic elevation using this method.

Major Roads: vehicle access that carries a significant amount of traffic and provides a critical route. In this study, major roads correspond to reporting by AEIP.

Mitigation Pathways: a sequential set of actions responding to a perception of increasing hazard, aimed to maintain a tolerable level of risk.

National Exposure Information System (NEXIS): an information management framework and database developed by Geoscience Australia to provide information about societal elements at risk, including buildings, demographics, community infrastructure and agricultural commodities.

Percolation: spatial analysis method, applied in this study. This involves evaluation of a digital elevation model to identify areas which are connected to the ocean via one or more pathways continuously below a nominated level.

Residual Average Annual Risk: impact of potential hazard occurrences beyond the level targeted for effective mitigation, considering susceptibility of affected values and assets, and multiplied by estimated likelihood of these events in a single year.

Residual Risk: overall impact of potential hazard occurrences beyond the level targeted for effective mitigation, considering susceptibility of affected values and assets.

Shapefile Functionality: communication of spatial areas of interest via digital files generated through geographic information systems.

Susceptibility: inability to tolerate a hazard. This is often measured by relative damage experienced at given hazard conditions.

Wave Overtopping: movement of water beyond the crest of a structure. This may either refer to natural structures, such as dunes, or coastal defence structures, such as revetments or seawalls.

Wave Runup: movement of water up the face of a beach or sloped structure, associated with individual waves.

Wave Setup: rise of sea level towards the shore, sustained over multiple waves, due to release of wave energy and momentum.

8 References

[1] Seashore Engineering Pty Ltd. (2019) *Assessment of Coastal Erosion Hotspots in Western Australia*. Report SE052-01-Rev1. For the Department of Transport and Department of Planning, Lands and Heritage.

[2] Western Australian Planning Commission: WAPC. (2013) *State Planning Policy 2.6: State Coastal Planning Policy*. Prepared under Part Three of the State Planning and Development Act 2005, Perth.

3 Australian Emergency Management Institute. (2013) *Managing the floodplain - a guide to best practice in flood risk management in Australia*. Handbook 7, Australian Emergency Management Handbook Series. National Strategy for Disaster Resilience.

4 Dunford M, Charalambou C, Spry R & Hay R. (2020) *The Australian Exposure Information Platform: Uncovering National Exposure*. Bushfires & Natural Hazards CRC. Hazard Note No. 74.

5 Huizinga J, Moel H de, Szewczyk W. (2017) *Global flood depth-damage functions. Methodology and the database with guidelines*. EUR 28552 EN. doi: 10.2760/*16510.*

6 Australian Institute for Disaster Resilience: AIDR. (2017). Handbook 7: Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia, 3rd Edition. Australian Institute for Disaster Resilience, Victoria.

7 Seashore Engineering Pty Ltd. (2023). *WA Coastal Inundation Assessment. Coastal Inundation Identification and Pilot Hazard Assessment*. Report SE0133-01-Rev1. For the Department of Transport and Department of Planning, Lands and Heritage.

8 Western Australian Planning Commission: WAPC. (2019) *Coastal hazard risk management and adaptation planning guidelines*.

[9] Cardno (2021). *Inundation Risk Assessment: Port Hedland Community Center*. Report CW1151200-Rev B. For the Town of Port Hedland.

10 Bryant E, Walsh G & Abbott D. (2007) *Cosmogenic mega-tsunami in the Australia region: are they supported by Aboriginal and Maori legends?*. Geological Society, London, Special Publications, 273(1), 203-214.

11 Nunn PD & Reid NJ. (2016) Aboriginal memories of inundation of the Australian coast dating from more than 7000 years ago. *Australian Geographer*, 47(1), 11-47.

12 Nott J & Bryant E. (2003) Extreme marine inundations (tsunamis?) of coastal Western Australia. *The Journal of Geology*, 111: 691–705.

13 Dodson J, Eliot I, Eliot M, Chagué-Goff C & Goff J. (2014) Wrack line signatures of high-magnitude water-level events on the North-West Australian coast. *Marine Geology*.

14 Town Planning Department. (1974) *Coastal Erosion*. Town Planning Department, Perth, Western Australia.

15 Eliot I, Gozzard B, Eliot M, Stul T & McCormack G. (2014) *Geology, Geomorphology & Vulnerability of the Pilbara Coast, in the Shires of Ashburton, East Pilbara and Roebourne, and the Town of Port Hedland, Western Australia*. Damara WA Pty Ltd & Geological Survey of Western Australia. Damara Report 161-01.

16 Department of Climate Change: DCC. (2009) *Climate Change Risks to Australia's Coast: A First Pass National Assessment*. Australian Government. Canberra.

17 Sayers P, Yuanyuan L, Galloway G, Penning-Rowsell E, Fuxin S, Kang W, Yiwei C & Le Quesne T. (2013) *Flood risk management: a strategic approach*.

[18] Western Australian Planning Commission: WAPC. (2006) *Natural Hazards and Disasters*. State Planning Policy No. 3.4.

19 Penning-Rowsell E, Johnson C, Tunstall S, Tapsell S, Morris J, Chatterton J & Green C. (2005) *The benefits of flood and coastal risk management: a handbook of assessment techniques*. Middlesex University Press.

[20] Griffith University Centre for Coastal Management and GHD Pty Ltd. (2012) *Coastal Hazard Adaptation Options. A Compendium for Queensland Coastal Councils*.

[21] Australian Building Codes Board: ABCB. (2012) *Construction of Buildings in Flood Hazard Areas - Information Handbook*.

[22] Seashore Engineering Pty Ltd. (2018) *Design Storms for Western Australian Coastal Planning: Tropical Cyclones*. Report SE015-01-RevB.

[23] Emergency Management Australia: EMA. (2009a) *Flood Preparedness*. Manual 20.

Emergency Management Australia: EMA. (2009b) *Flood Warning*. Manual 21.

Emergency Management Australia: EMA. (2009c) *Flood Response*. Manual 22.