4 METEOROLOGICAL AND COASTAL PROCESSES

The Shire of Harvey has an almost west-facing coast, exposed to seasonal westerly storms and frequent southwest to westerly sea breezes. Micro-tidal conditions are experienced with storm surges observed up to 1.0m peaking in winter being of a similar order of magnitude to the tide. Wave conditions are generally moderate, with prevailing south-west swell interacting with locally generated wind-waves. The influences of winds, waves and storm surge are all strongest during winter months, providing a substantial difference between summer and winter coastal conditions.

The majority of information describing meteorological and coastal processes has been collected near Bunbury due to its higher population and infrastructure density. Due to the proximity of Bunbury to the Harvey Coast, this information is generally deemed to be applicable for the assessment of Harvey coastal processes and hazards.

4.1 Climate and Meteorology

South-west Western Australia experiences a relatively mild climate, with cool wet winters and hot, dry summers, commonly described as Mediterranean. The region lies within the lower half of the extra-tropical ridge and is dominated in summer by eastward travelling high pressure systems, within 26^{o}S to 45^{o}S, which cross the coast every 3-10 days [23]. During winter, a northward movement of the pressure belts allows the impact of mid-latitude low-pressure systems from latitudes 35^{o}S to 50^{o}S to increase, through fronts or more direct synoptic winds from northerly travelling systems. The influence of tropical systems is rare, although it may be significant, amply illustrated by the impact of TC Alby in April 1978.

Climates summaries from the Bureau of Meteorology for Bunbury AWS from 1995 to 2007 describe the seasonal ambient variations (Figure 4-1).

The land-sea breeze cycle dominates the prevailing winds of the region, particularly over summer, with moderate easterly winds in the morning and stronger (up to 15 m/s) southerly sea breezes in the afternoon commencing around noon and weakening during the night [24]. Their onset is rapid, initial velocities are relatively high, and the alongshore surface currents respond almost instantaneously. The sea breeze may occur in all seasons, although it is most frequent and intense during summer months [25].

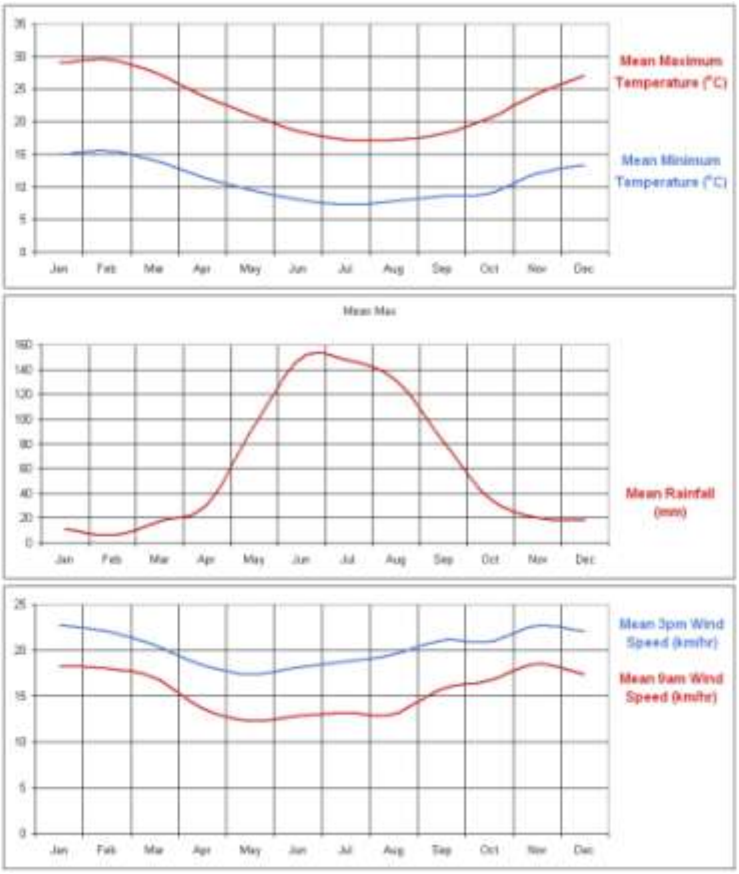


Figure 4-1: Mean Monthly Temperature, Rainfall & Wind Speed

The average wind speed, direction, duration, extremes and event frequency for the main weather systems experienced on the Perth Metropolitan Coast have previously been summarised (Table 4-1) [26]. It is expected that these will also be generally representative for the Harvey coast, with marginal deviations in strength and direction of winds.

Table 4-1: Characteristics of Main Local Weather Systems

Weather System	**Anticyclones** [23]	**Squalls** [27]	**Mid-latitude Lows** [23,27]	**Dissipating Tropical Cyclones** [23, 27]	**Sea Breezes** [24]
Occurrence	Annual	Dec – Apr	May – Oct	Oct – Mar	Oct – Mar (mainly)
Avg Wind Speed	Light	15-20 m/s	15-29 m/s	15-25 m/s	10 m/s
Avg Duration	Unknown	2-4 hours	10-55 hours	5-15 hours	~7 hours
Avg Wind Direction	All	All	N → NW → W → SW	Depends on path	180-200^{o}
Frequency	3-10 days	13 days	3-8 / year	1 in 10 years	> 15 days/month

High wave conditions on the southwest are almost exclusively related to onshore wind conditions from the northwest through southwest [28]. Studies of storm event climatology and extreme wind analysis [27,29] have identified that sustained high winds in the southwest region occur from five sources:

1. Dissipating Tropical Cyclones
2. Sea Breezes
3. Extra-tropical Cyclones
4. Pre-frontal Troughs
5. Cold Fronts

It should be noted that the last three sources of sustained high winds are all caused by mid-latitude depressions, although the mechanism and extent of wind generation may be considerably different. Approximately 20 storms per year were identified, peaking during July. During the passage of a frontal system, the region is subject to strong winds (up to 25–30 m/s) from the north-west, which rapidly change direction to the west then south-west over 12–16 hours. The south-westerly winds gradually weaken over two to three days, and calm, cloud-free conditions prevail for another three to five days before the passage of another frontal system.

4.2 Winds

Elevated wave conditions are associated with a range of synoptic events, which may vary in latitude, intensity, frequency and mobility [30,31,32]. The aspect common to these events is the occurrence of onshore winds, although direction may vary from southwest to northwest [33]. Applying this characteristic, a measure of storminess has previously been established for the period 1962-1980 using winds from Fremantle [27].

Wind measurements have been made at Bunbury since the 1890s. However, instrumented measurement of wind data for Bunbury did not occur until 1965 through the Bureau of Meteorology. The location of the weather station used for sampling has subsequently been changed on two occasions. Although this apparently affects median wind speeds, there remains reasonable correspondence of direction and high wind speeds between sites (Table 4-2). Extreme winds are significantly different between data sets, but this is typical for extreme conditions.

Table 4-2: Bunbury Wind Observations

Station	Location	Dates	50% Wind	90% Wind	Max Obs
9514	Bunbury Post Office	1965 – 1985	9 km/hr	28 km/hr	96 km/hr
9885	Bunbury Power Station	1985 – 1995	13 km/hr	28 km/hr	148 km/hr
9965	Bunbury AWS	1995 – present	15 km/hr	26 km/hr	65 km/hr

Speed and direction frequency plots indicate winds at Bunbury are bimodal, with the two dominant directions of south-east and west corresponding to land and sea breezes respectively (Figure 4-2). It is unclear whether the local topography at Bunbury influences these measured directions, as they contain significantly fewer southerly winds than Garden Island or Rottnest observations, which are

two of the longest coastal wind records held by the Bureau of Meteorology. Monthly frequency plots indicate the land-seabreeze cycle weakens during winter months and easterly winds become more frequent.

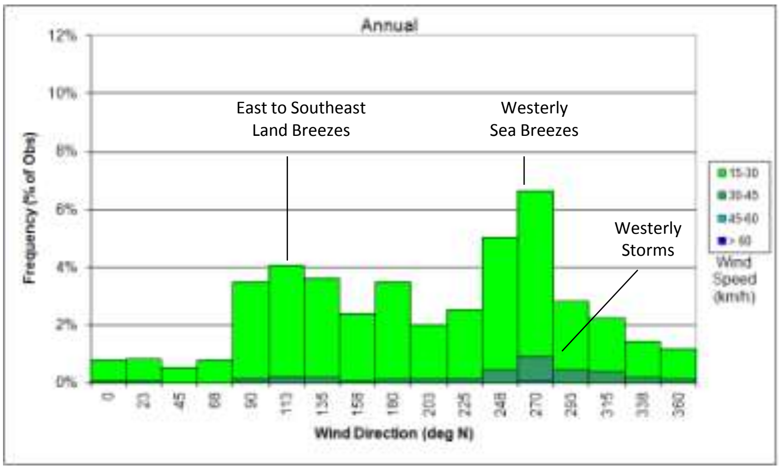


Figure 4-2: Annual Wind Frequency Plot 1995-2013
(BOM Station 9965)

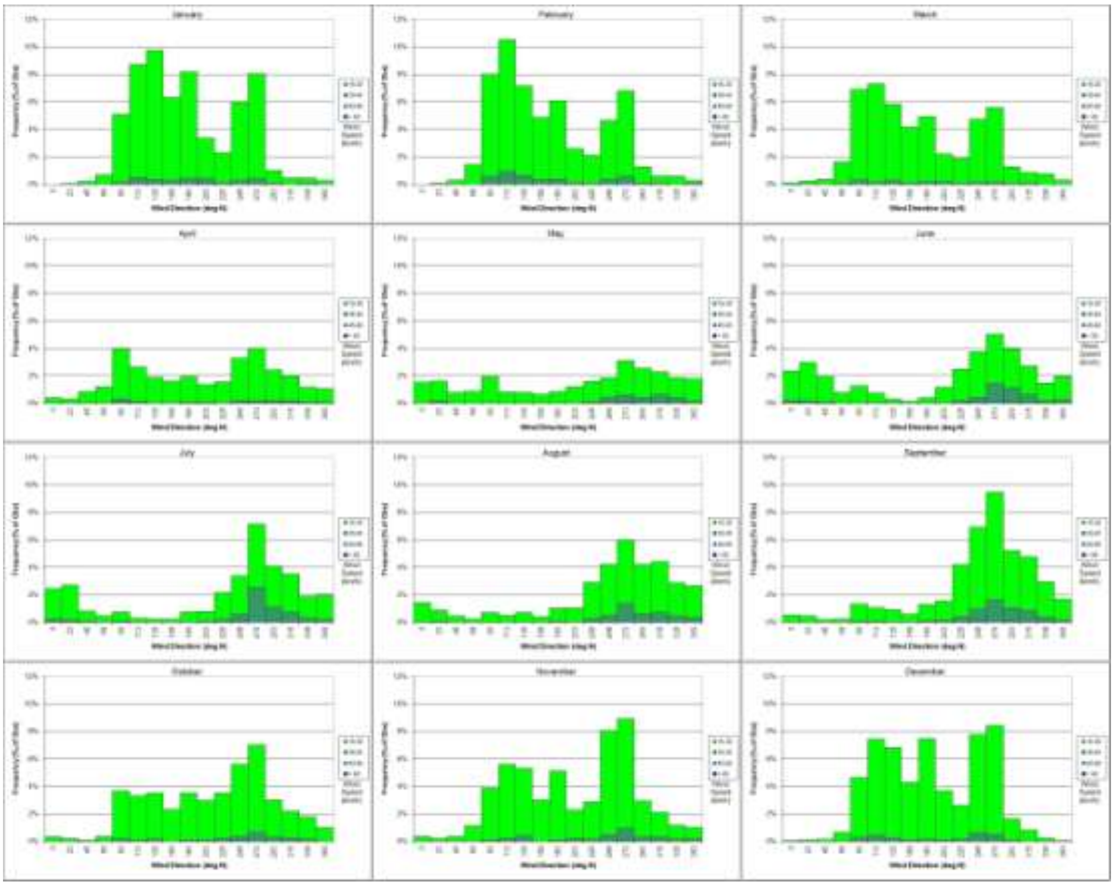


Figure 4-3: Monthly Wind Speed & Direction Frequency Plots 1995-2013

The strongest wind conditions at Bunbury are associated with winter mid-latitude storms, which mostly generate winds from the northwest through to southwest, varying significantly between events [27]. Northerly storms, which may be significant for alongshore sediment transport reversals, are relatively less frequent [33]. During the period 1968-1982, strong northwester storms were identified in 1968, 1973-1975, 1977 and 1980-1981[27]. Strong southwester storms were more evenly distributed, with severe events in 1970-1973, 1975, 1977-1978 and 1981[27]. The most well-known storm events are the most unusual, or those in recent memory. These include storms in April 1978 (TC Alby), June 1996 and May 2003.

Using wind speed and direction data obtained from the Bureau of Meteorology from the period January 1985 to September 2004, a simple extreme event analysis has been undertaken for Bunbury. It should be noted that much of the wind data has been derived from Beaufort wind scales, which have been converted to equivalent wind bands. This creates an artificial stepping of the extreme wind speeds and affects the statistical reliability of the fit (Figure 4-4). Furthermore, the relatively short sampling period dictates that the analysis is only relevant for events less than 100 years average recurrence interval (ARI).

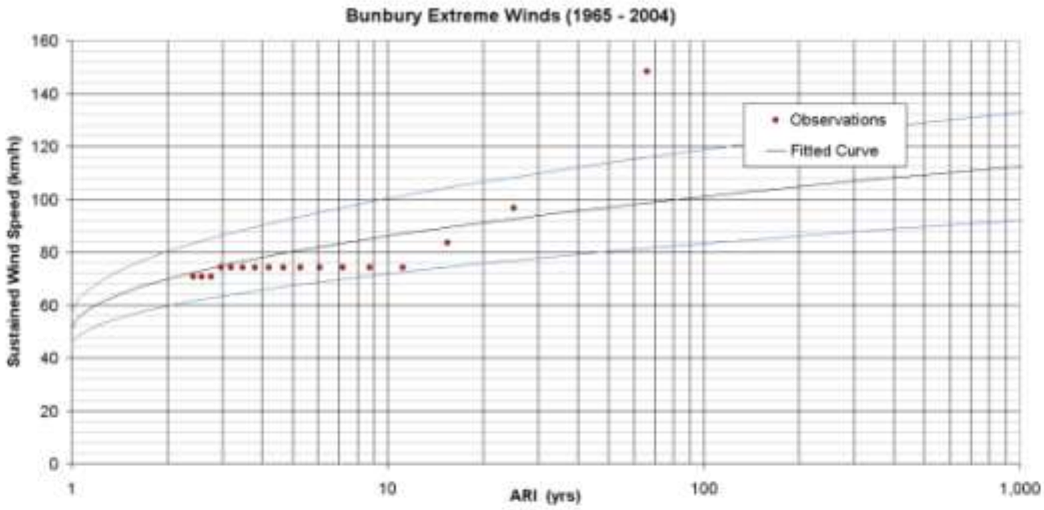


Figure 4-4: Extreme Wind Analysis

4.3 Waves

The Shire of Harvey is located at an approximate latitude of 33°S on the west-facing coast of Australia. It is exposed to wave generation from the Southern and Indian Oceans [34]. Regional wave conditions typically include a background swell component and a locally generated wind wave, as measured offshore from Rottnest [28,35]. Prevailing swell is south to southwest, generated from mid-latitude synoptic systems, with enhanced west to northwest activity during winter months. Observations of the Fremantle region offshore wave climate suggest a variable, sometimes high-energy coast [28]. Wave generation occurs principally over the extended fetch of the southern Indian Ocean, providing a background swell that is comparatively slowly varying.

Previous assessment of coastal change in the Bunbury to Mandurah region has identified that there is a strong relationship between the wave conditions and coastal dynamics [13,36,37]. Comparison of annual average wave conditions, as recorded off Bunbury, indicates that there is moderate

variability of ambient conditions from year to year (Figure 4-5). However, large variations have been observed in wave direction (Figure 4-8) and the occurrence of storminess, as represented by relatively short episodes of high wave energy (Figure 4-9).

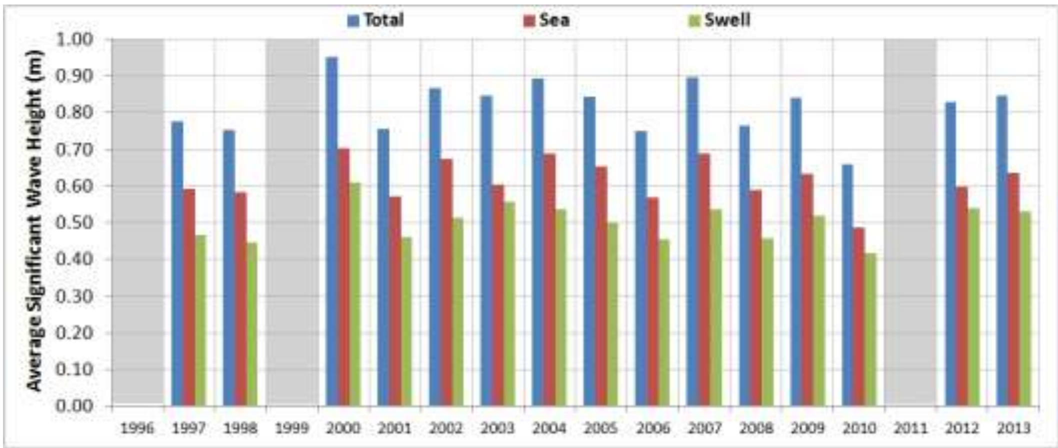


Figure 4-5: Annual Average Wave Conditions 1997-2013 (BPA Beacon 3)

An average wave height of around 0.8m has been observed at Bunbury Beacon 3 [38], with maximum significant wave heights of approximately 3.5m (Figure 4-6). This is substantially less than annual maxima of 7 to 10m reported from further offshore [39], or studies of deepwater wave conditions from Dawesville [40], Garden Island [34] or Rottnest [35] (Figure 4-7), indicating the role of seabed friction and refraction as the waves pass across the shelf. Available directional wave measurements suggest that net sediment transport along the open coast is likely to be northward, with occasional reversals that may last a whole winter (Figure 4-8).

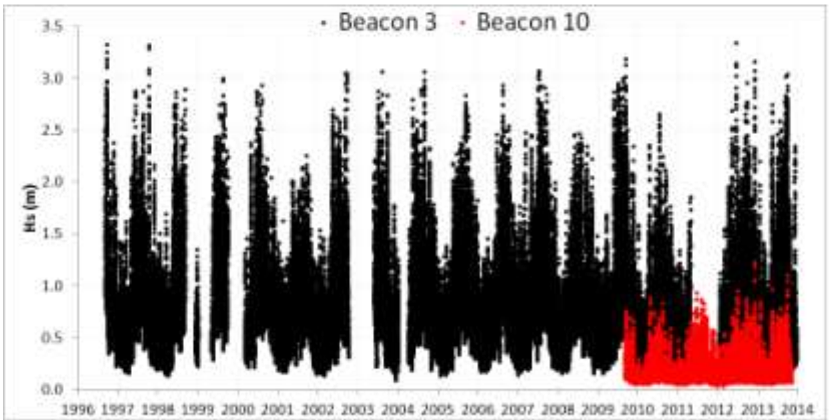


Figure 4-6: Observed Significant Wave Heights at Bunbury AWACs

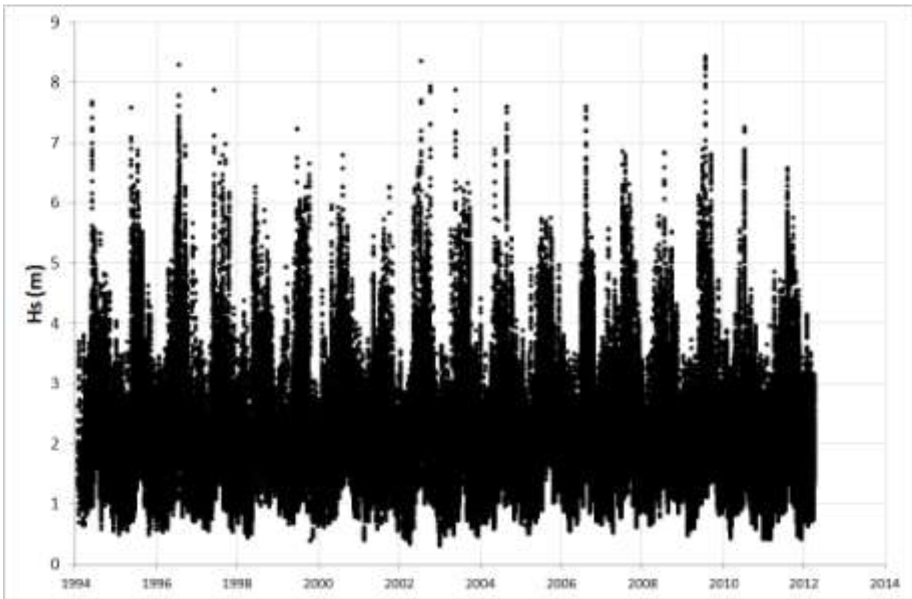


Figure 4-7: Rottnest Offshore Wave Height (1994-2006)

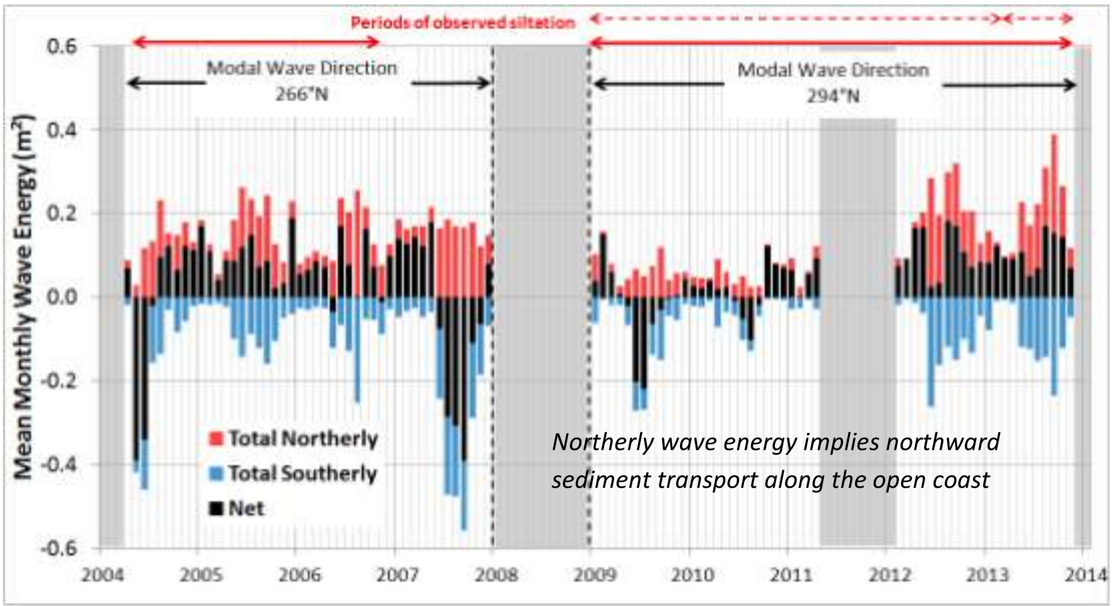


Figure 4-8: Evaluation of Mean Monthly Wave Direction
(BPA Beacon 3, modal wave direction varies due to instrument processing)

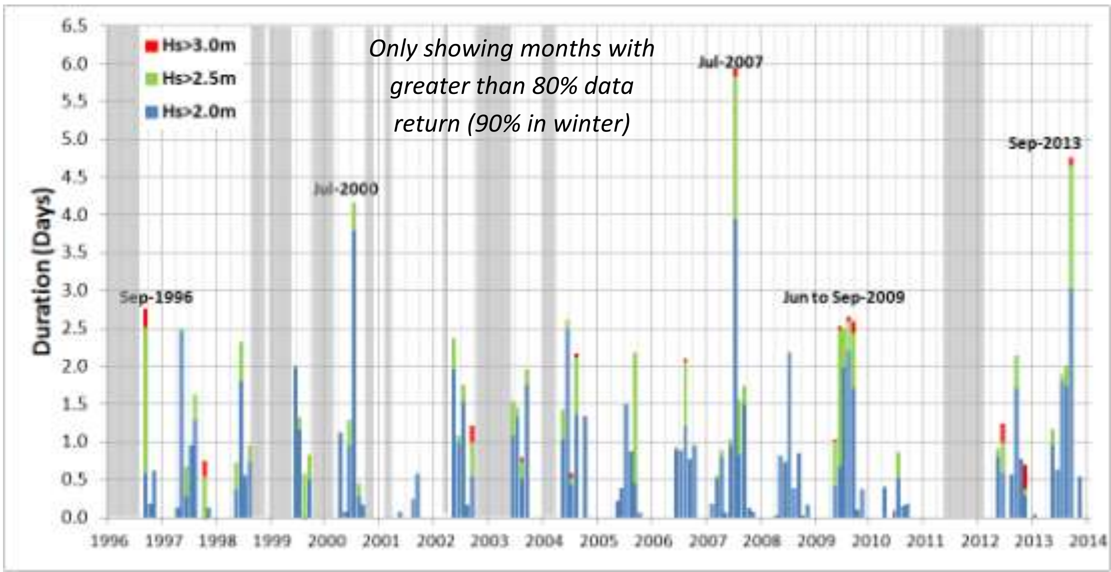


Figure 4-9: Monthly Wave Storminess (BPA Beacon 3)

4.4 Water Levels

Water levels on the Shire of Harvey coast are considered to be reasonably well represented by the record from Bunbury, which is one of the Standard Ports defined by the Royal Australian Navy Hydrographic Office [41]. Bunbury experiences a principally diurnal tide, experiencing a single tidal cycle on most days. It has a small tidal range, classified as microtidal, with a range of 1.4m from lowest to highest astronomical tide (Table 4-3), of which 0.3m is produced by the seasonal mean sea level cycle.

Table 4-3: Bunbury Tidal Planes

Tidal Level		Water Level (m CD)
Highest Astronomical Tide	HAT	1.3
Mean Higher High Water	MHHW	0.8
Mean Lower High Water	MLHW	0.5
Mean Sea Level	MSL	0.6
Mean Higher Low Water	MHLW	0.6
Mean Lower Low Water	MLLW	0.3
Lowest Astronomical Tide	LAT	-0.1

The tidal sequence is strongly affected by monthly, seasonal and inter-annual signals. It should be noted that the seasonal signal, which ranges approximately 0.3m and peaks in June, is believed to be the result of pressure, temperature and salinity variations rather than being an astronomic tide [42]. The tidal range varies on a bi-annual cycle, with peaks at the summer and winter solstice. It is further modulated by the 18.6-year lunar nodical cycle [43,44]. Analysis of the long-term Fremantle data set suggests peaks in 1987 and 2006, with the next peak due around 2025.

Water level observations have been made at Bunbury since 1930, originally using a Bailey drum tide gauge [45]. However, the reliability of early sea level records has been questioned, and it is considered unlikely the reference datum was stable prior to additional survey control instigated during the 1965 Australian mean sea level survey to establish Australian Height Datum [46,47]. Furthermore, the original gauge was largely constrained to measure from –0.3 to +1.8m relative to the gauge datum [45]. Higher levels have been recorded since the gauge type was upgraded in 1966.

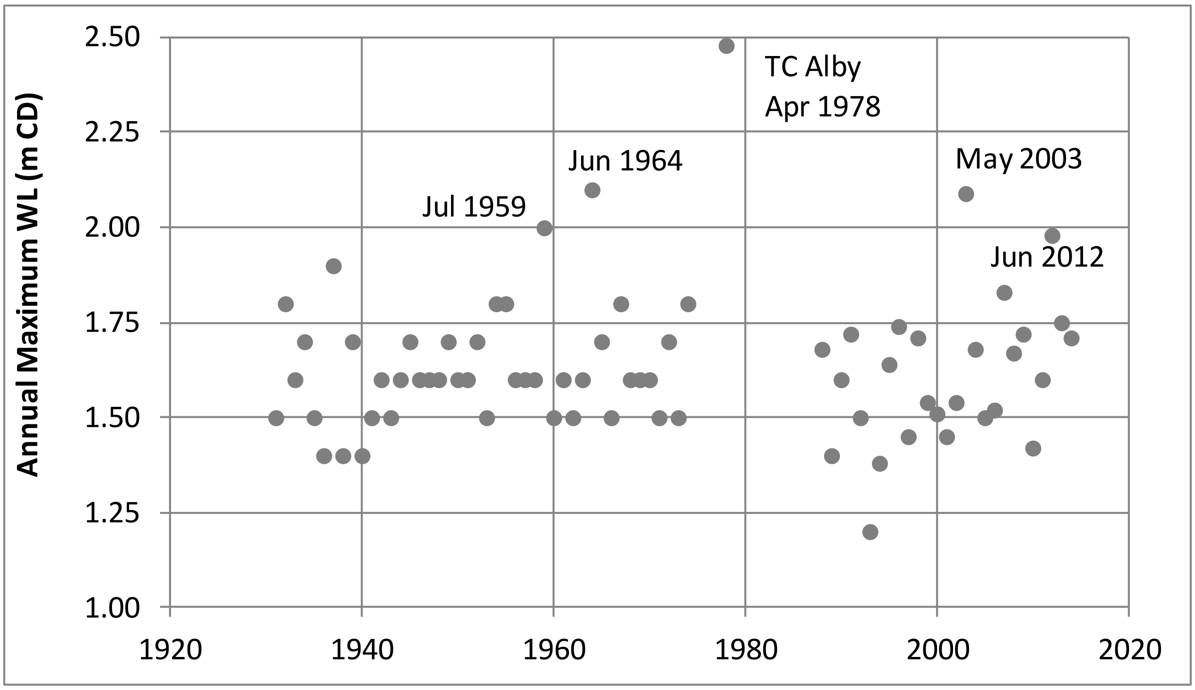


Figure 4-10: Annual Maximum Water Levels (1930-2014)

Several analyses of the Bunbury water level record have been undertaken, principally to define requirements for the flood protection system protecting Bunbury central business district, particularly subsequent to flooding that occurred during TC Alby [17,48,49,50]. Much of this analysis has recently been revised to incorporate recent data, following observation of an increased number of high water level events (DPI unpublished analysis).

A simple summary of the water level record is suggested by the submergence curve for Bunbury, showing the tidal planes and extreme observed water levels (Figure 4-11). It should be noted that this curve is schematised and does not represent the cumulative distribution of observed water levels.

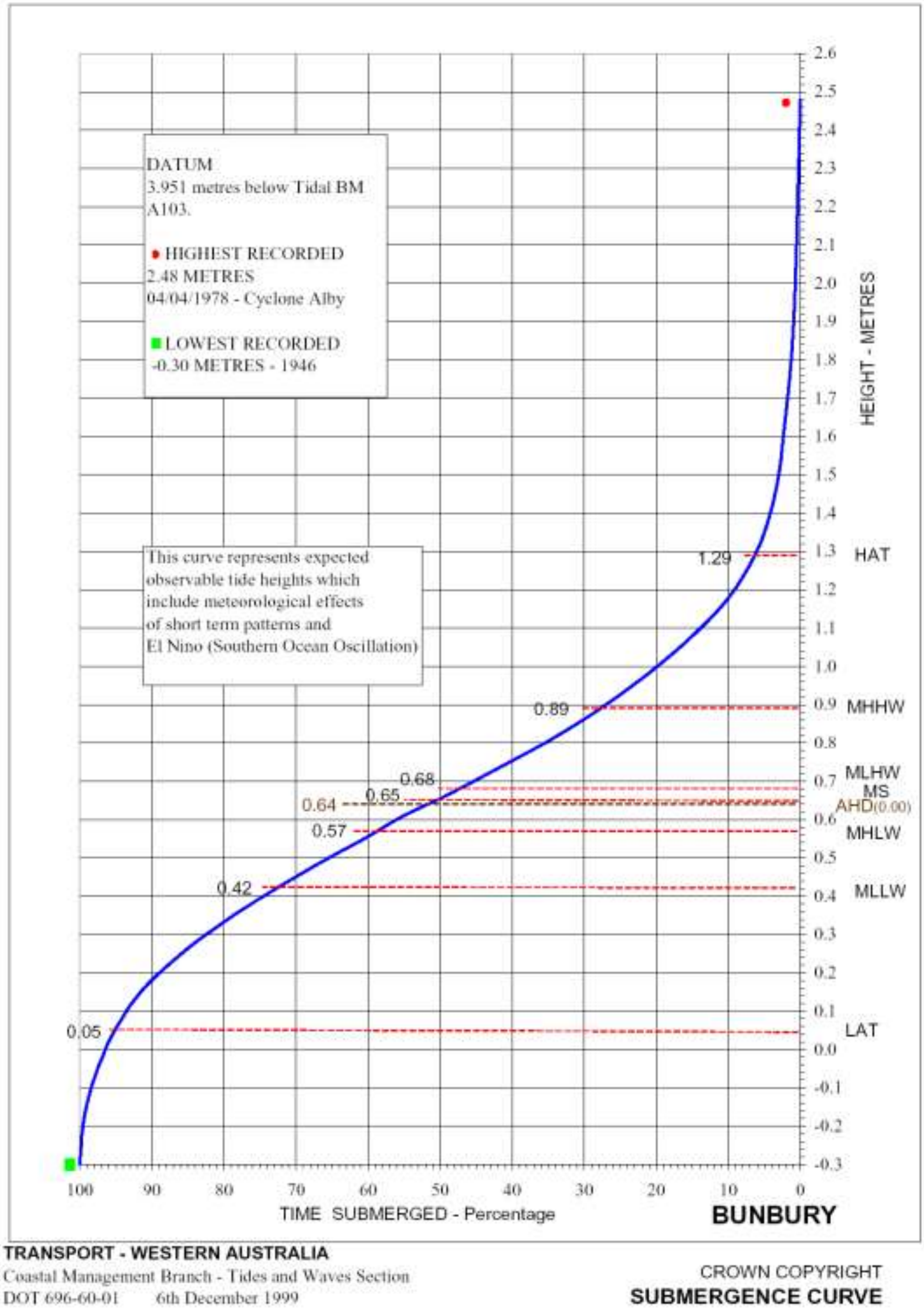


Figure 4-11: Bunbury Submergence Curve
[OBTAIN UPDATE]

Water level variability [51] also contributes to coastal dynamics, with daily, fortnightly, semi-annual and inter-annual tidal cycles interacting with storm surges, and annual and inter-annual mean sea level processes (Figure 4-12). The total range is small, at approximately 2.5m, but the range for 80% of water level observations (10-90% occurrence) is only 1.0m, indicating that short-term (<10% occurrence) high levels represent a substantial deviation from ambient and consistent 'landform building' conditions.

Inter-annual variability of mean sea level is strongly linked to the El-Niño / la Niña climate cycle, suggested by a strong correlation to the Southern Oscillation Index [52,53]. Variation of approximately 0.3m may be attributed to this relationship, with higher water levels occurring during the la Niña phase. The Bunbury record shows recent periods of unusually sustained high mean sea levels during 1999-2000, 2008 and 2011-2013, which correspond to extreme la Niña conditions [54].

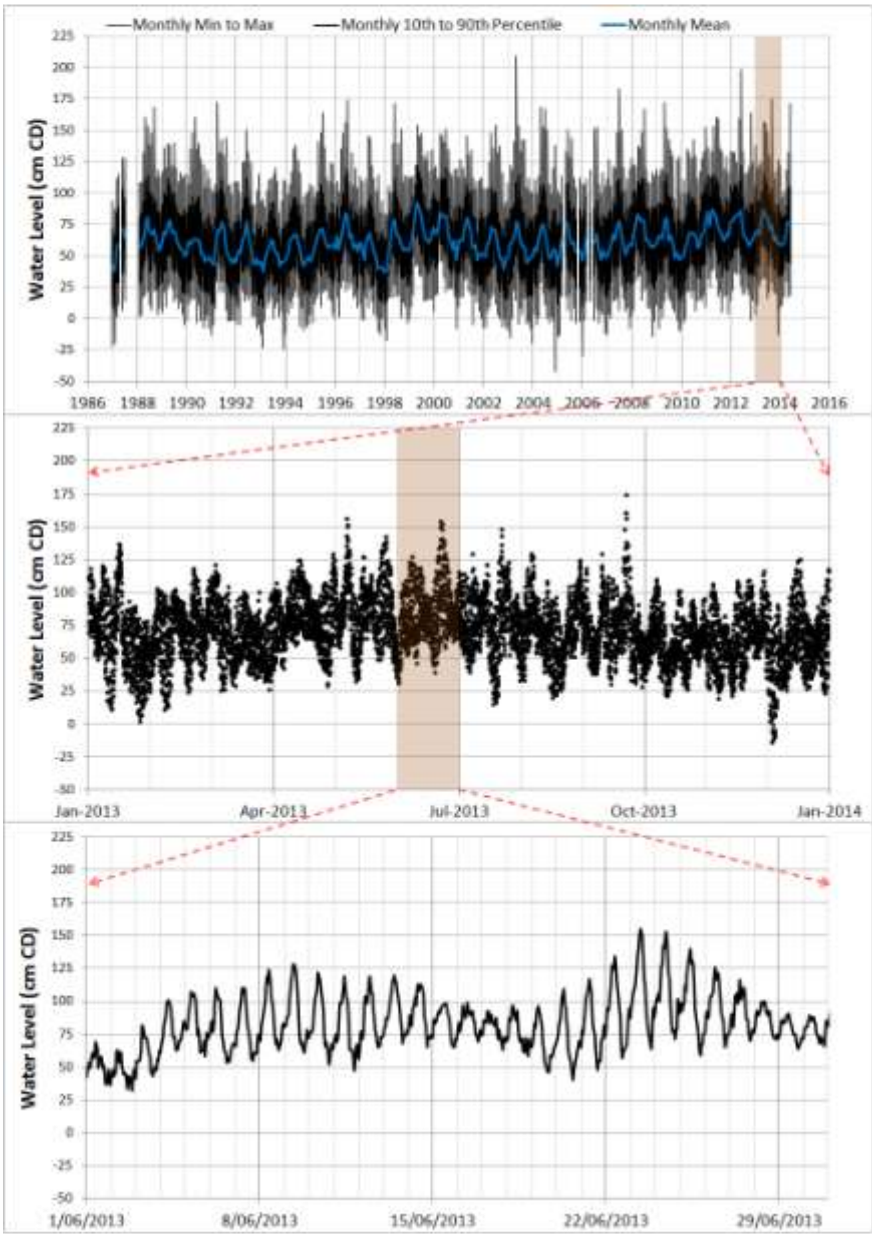


Figure 4-12: Bunbury Water Level Record 1987-2014
Scale cascade highlights contribution of different processes

The combination of water level processes active along the Harvey coast provides a significant change in the cause and recurrence of water levels over a relatively small vertical range. As the source and pathway of coastal flooding may influence the type of management options available, this is significant for a CHRMAP in the context of sea level rise and landform dynamics.

A classification scheme has been developed from modern water levels at Bunbury tide gauge, with different associated key processes for each class (Figure 4-13). Characteristics of the class include:

- Extreme water levels (>1.4m CD) require a severe storm surge to be reached. These events are most common during May to July when winter storms may coincide with high phases in the tidal (twice annual) and mean sea level (annual) cycles. Very occasional extremes may be caused by southward travelling tropical cyclones, which produce extreme surges, generally coincident with only moderate tide or mean sea level conditions;
- High water levels (1.0-1.4m CD) can occur through a combination of two or more moderately high water level components (tide, surge and mean sea level). These events are rare during January to March, but otherwise can occur year round, with the highest incidence from May to July, which is almost daily ;
- Ambient water levels (0.3-1.0m CD) include a number of events when one component of tide, surge or mean sea level was moderately high, but was not reinforced by either of the other two components. These conditions are experienced on a daily basis, and any level within this range is usually experienced at least once per month (i.e. subject to both emergence and submergence).

The very narrow difference between ambient and extreme conditions highlights the potential significance associated with projected sea level rise. Conditions considered to be extreme in the present day may occur on a daily basis with +0.4m of high sea level rise.

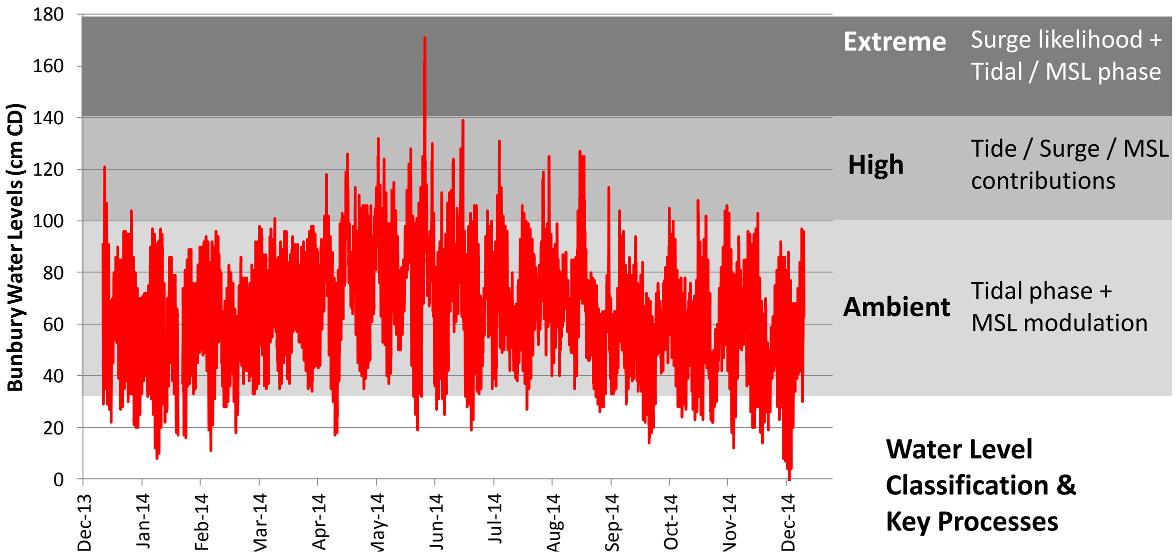


Figure 4-13: Water Level Classification Scheme

4.5 Projected Climate Change

Potential changes in climate due to global warming have been evaluated through global climate models [55] and down-scaled for the Australian sub-regions [56,57]. The range of projected changes, with the exception of sea level rise, contain both enhancement and depression of existing climate factors and therefore suggest increased climate uncertainty, rather than forecasting a clear trajectory of change. For most parameters modelled, possible change over the next 60 years is well within the existing historic variability, implying that historic coastal changes may help interpret future behaviour, although the frequency of events and longer-term means may vary over time. In general, modelled change to climate parameters is similar to a southward latitudinal movement of the climate belts, with the southwest expected to experience a warmer, drier climate, with a slight increase in the influence of tropical weather systems. For the coast, this suggests a slight reduction of southwest wave energy offshore – although contradicting a trend interpreted from satellite records [58]. Inshore, any offshore reduction of wave energy is more than offset by projected mean sea level rise, which allows a higher proportion of this energy to reach the coast.

In contrast to meteorological parameters, where the direction of change is not wholly certain, significant international consensus has been developed regarding the potential for future sea level rise associated with climate change [59]. Assessment of potential sea level rise has been undertaken using a range of global climate models, with consideration of different scenarios for human activities (greenhouse gas emissions) and different responses from the main elements of the global water balance (ocean, atmosphere, surface water and polar ice-caps).

Review of available knowledge and national practices was used to develop a recommended allowance for projected sea level rise in Western Australia, when undertaking planning projects [60] (Figure 4-14).

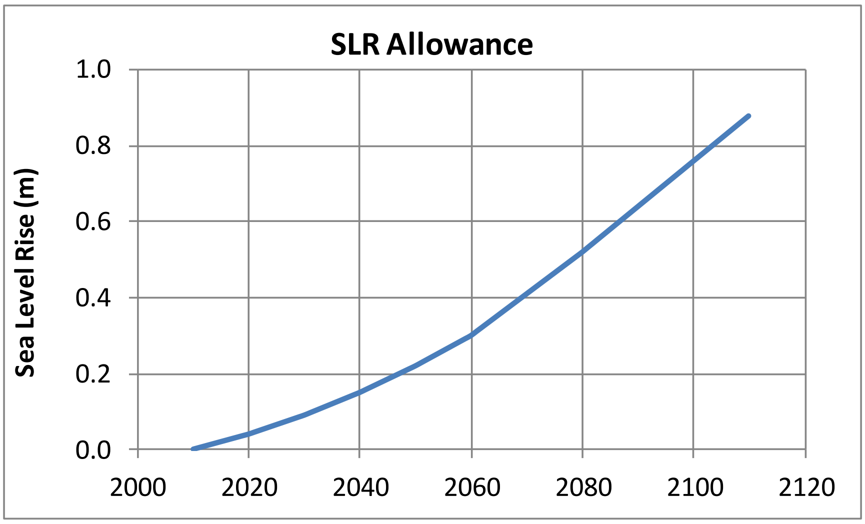


Figure 4-14: Recommended Allowance for Projected Sea Level Rise

5 OBSERVATIONS AND EVIDENCE OF COASTAL CHANGE

The Shire of Harvey coast has experienced significant changes over the historical period. Some of these changes have been consequences of human activity, although there is also stratigraphic evidence to suggest that this coast has been subject to progressive recession for millennia. Distinguishing between the sources and pathways of coastal change provides important understanding to the potential for management actions or interventions.

Coastal change assessment has been considered relative to the framework shown in Figure 5-1, with the objective to support a forecast of coastal change. The key piece of qualitative information is sensitivity to climate, which is inferred from historic coastal dynamics due to climate variability (Section 5.1). Due to the potential significance of long-term coastal trends and capacity for modern records to be biased by inter-decadal variability, historic coastal dynamics have been considered relative to the prehistoric coastal evolution, derived from stratigraphic assessment (Section 5.2).

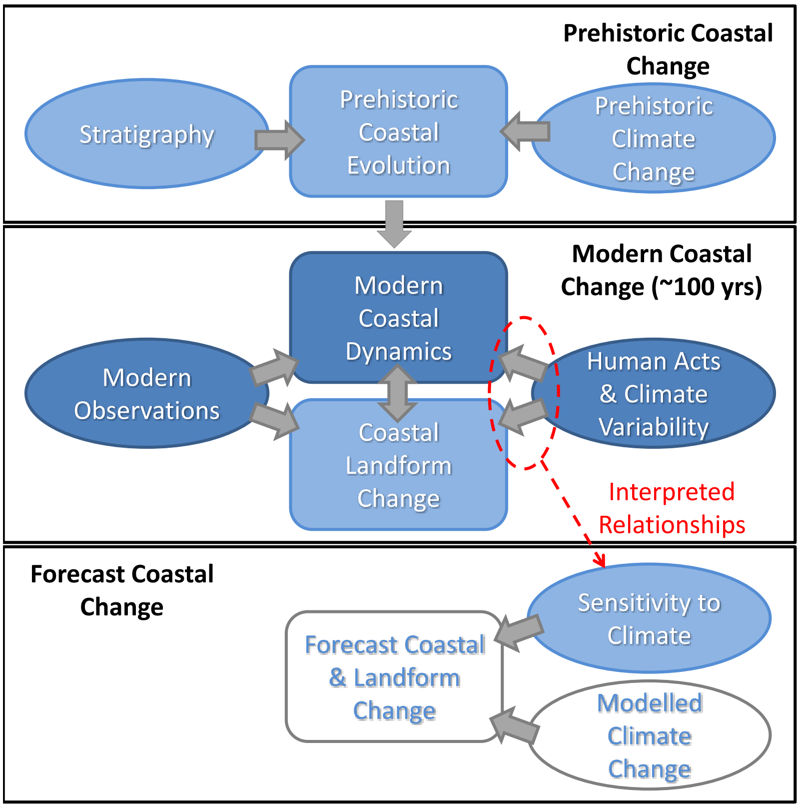


Figure 5-1: Framework for Coastal Change Assessment

Observations of coastal landform change have been assessed (Section 5.3), as they provide an indication of the pathway for coastal change, which potentially helps to select feasible management actions for hazard mitigation. Human interventions in coastal processes have been considered separately (Section 5.4), as they do not indicate climate sensitivity. However, substantial alterations such as excavation of The Cut provide clear illustration of coastal response to imposed change.

5.1 Coastal Dynamics

Dynamics of the Harvey coast include large seasonal variations, inter-annual and inter-decadal variability and net progressive coastal change. There is potential for the dynamic processes associated with each scale to contribute to any observed pattern of change.

Seasonal variation provides the largest amplitude of change, with beach width varying up to 50m due to changes in wave and water level conditions (Figure 4-9, Figure 4-12). The majority of seasonal movement is associated with cross-shore profile adjustment, although this is locally modulated by seasonal alongshore transport and sand retention by nearshore and onshore rock features.

Inter-annual variability is caused by year-to-year differences in meteorological and oceanographic conditions, including the effects of storminess, storm direction (Figure 4-9), mean sea level variation and tidal modulations [43,51] (Figure 4-12). Typically the majority of coastal change occurring due to anomalous driving conditions experiences almost full recovery when more typical conditions return. Inter-decadal coastal change is developed when complete recovery does not occur, typically because sediment has been moved (alongshore or cross-shore) outside the influence of ambient waves and water levels. This may include dune-coast exchange or a net imbalance of alongshore transport.

The Mandurah-Bunbury region is subject to moderate-high swell wave energy from the southwest (Figure 4-8), which supports a net northward littoral transport of sand 6[,61]. The transport rate varies seasonally, enhanced during summer months by the seabreeze, and occasionally reversed during the winter months by northwest storms. Sedimentation at Bunbury Power Station due to a short sequence of such storms prompted construction of the Power Station groyne.

Several exercises to estimate alongshore sediment transport rates on the basis of wave climate have been undertaken. The most studied area has been Bunbury Back Beach, due to ongoing coastal management issues [18,39]. However, the most relevant analysis has been undertaken along the Bunbury to Mandurah coast, as part of Dawesville Channel coastal process investigations [62] with effort made to tie modelling with vegetation line analyses and stratigraphic records, including an estimated erosion rate between 0.5 and 1m/yr since present sea level was reached 3,000 years ago [63]. The estimated net transport rates (Table 5-1) were based on coastal aspect and regional average wave power. The calculated potential for littoral drift was subsequently scaled to match the observed quantity of material accumulating at Bunbury Harbour [13]. These quantities are much greater than estimated for Bunbury Back Beach using similar modelling [18] (22-53,000 m^3/yr) and estimated for the Binningup desalination plant [64] (20,000 m^3/yr).

Table 5-1: Estimated Sediment Transport Rates Bunbury to Mandurah From Dawesville Channel Coastal Process Investigations [13]

Location	Modelled Transport (m^3/yr)	Scaled Transport (m^3/yr)
Bunbury	105,000 m^3	80,000 m^3
Leschenault	85,000 m^3	65,000 m^3
Preston	50,000 m^3	40,000 m^3
Dawesville	200,000 m^3	150,000 m^3
Roberts Point	100,000 m^3	75,000 m^3

The limitations of using wave power and coastal aspect to model alongshore sediment transport are recognised, as the approach cannot resolve local scale features, including the effect of barriers to exchange. Local evidence of this limitation is provided by:

- The alongshore differences of transport rate imply accumulation along Leschenault Peninsula, at Preston Beach and Roberts Point, with erosion from Bunbury and Dawesville. This is not consistent with the modern landforms or vegetation line movements;
- The long-term management of littoral transport at Dawesville is substantially less than the inferred rates [37].

An evaluation of coastal change has been conducted using vegetation line information available from the Department of Transport. This provides a proxy for coastal change, which theoretically reduces the influence of the seasonal variation on the perceived trend [65]. However, it is recognised that for this region, foredune and primary dune behaviour have not shown a direct relationship [21]. For much of the coast, vegetation line movement is considered likely to have been influenced by human activities, both due to industrial disturbance and later stabilisation works.

Despite the potential influence of human activities, a summary of the vegetation line change from 1955-2014 displays a spatial distribution that is more consistent with progressive net loss of sediment volume (Figure 5-2). In particular, the influence of rock features along the Harvey coast is apparent at a large scale:

- Vegetation line retreat has occurred for 22km north of Binningup, to a point south of Preston Beach where offshore rock ridges provide increased coastal shelter;
- Comparative stability of the vegetation line has occurred from Binningup to Buffalo Road, where the nearshore rock platform redistributes the erosive pressures acting in this area;
- Some retreat has occurred between Buffalo Road and Belvedere, although this is slightly less than movement further south, and is possibly due to the stabilising influence of the discontinuous reef ridge that runs at a slight angle to the coast;
- The area south of Belvedere has experienced significant retreat of the vegetation line, although some of this may be associated with bulldozing of the foredune as part of industrial clean-up; and
- Adjacent to the Leschenault Estuary entrance, the shoreline has been highly mobile, characteristic of year-to-year variations of net alongshore sediment transport.

Additional local scale sediment transport factors occur along the southern part of the Harvey coast, adjacent to the Leschenault Estuary entrance. Features that may affect the coastal dynamics include sheltering from the Bunbury main breakwater, onshore feed from the dredging dump ground and sediment fluxes to and from the ebb-tide sill at the Cut.

The importance of local scale features to coastal dynamics is suggested by the high resolution LIDAR bathymetry collected in 2008 by the Department of Planning. This shows a flat seabed gradient for about 7km north of Binningup, which offsets the change in coastal aspect (Figure 5-2). Under short-term erosion, the seabed gradient is less responsive (i.e. energy dissipating) than the area to the north, thereby providing an erosion hotspot north of Binningup. However, the transport potential is subsequently balanced alongshore, dispersing the erosion pressure along the 22km section of coast.

The pattern of behaviour inferred by this combination of beach grade and coastal aspect was observed following severe erosion in the 1970s, with partial recovery near to Binningup and a more prolonged phase of erosion occurring north of Myalup.

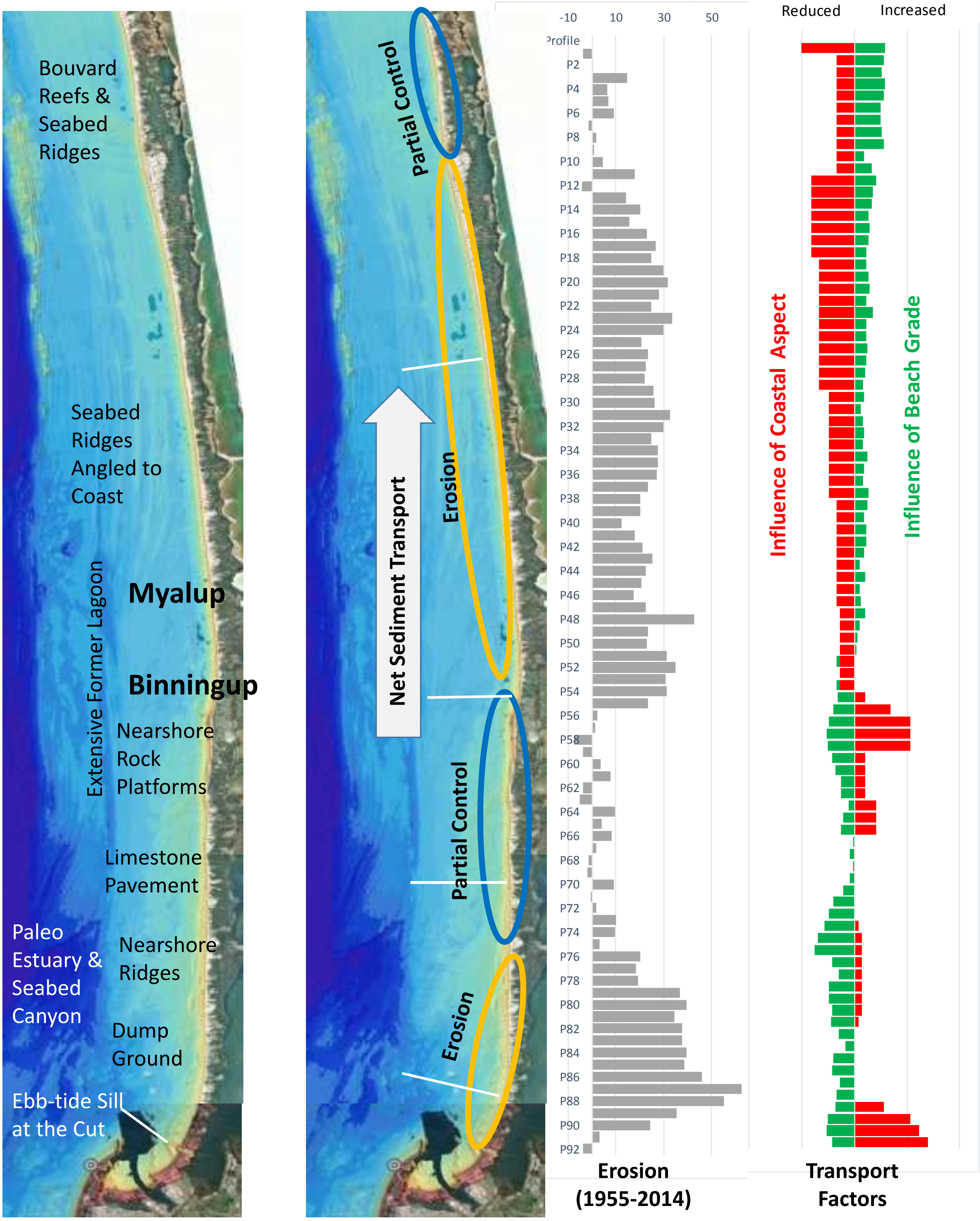


Figure 5-2: Summary of Historic Coastal Change

5.2 Coastal Evolution

The overall tendency for a section of coast to gain or lose sediment provides a crucial basis for long-term planning. Accrued over long time frames, even a small rate of loss can require substantial modification of coastal facilities, with the potential effects of projected sea level rise further pressuring effective long-term use of the coast. Identification of historic coastal change is required when establishing coastal setback allowances in Schedule One of SPP 2.6. However, identifying an overall trend may be obscured by inter-decadal variability, in an equivalent way to detecting inter-annual change may be obscured by storm events. For this reason, comparison of the historic observed behaviour (1955-2014) requires comparison to the change suggested by stratigraphy and geomorphology.

Progressive landward migration of the barrier dune system along the Harvey Coast has been inferred from stratigraphy at an approximate rate of 0.5m/yr over the last 6,000 years [66]. Migration has not been constant, but has occurred cyclically, believed related to periods of enhanced storminess [22]. This behaviour is also supported by the historic record, which displayed rapid retreat of up to 2m/yr of the coastal vegetation line between 1950 and 1970, with the position subsequently steady until around 2004, after which vegetation line retreat has been rapid for some parts of the Harvey coast.

Over the historic period, the majority of beach erosion events were followed by substantial or complete recovery, suggesting a cross-shore movement that is typical of many storm affected coasts [67]. However, this obscures the behaviour which followed severe erosion north of Binningup between 1950 and 1970, which perhaps indicates the way in which the Harvey coast has progressively eroded. Substantial erosion initially occurred for 7km of coast north of Binningup, with subsequent limited change, whereas the 15km further north eroded later and more gradually. This is characteristic of a transfer of erosive pressure, and corresponds to the relative role of beach gradient and coastal aspect indicated by the geomorphic analysis (Figure 5-2). An important characteristic is that there has been a secular change (i.e. permanent shift of beach position) which is distributed almost evenly for 22km north of Binningup.

Projected sea level rise provides a potential mechanism for the rate of erosion to increase in the future. The extent of erosive response due to sea level rise is highly uncertain, due to both uncertainty regarding how sea level will change and uncertainty regarding incremental change with sea level. Alternative scenarios for coastal response to sea level change include:

- Low response due to the existing geomorphic structure, with the presence of nearshore and offshore rock features limiting erosive response;
- Moderate response considered typical for sandy coast, following State government policy [2];
- Enhanced response due to the width of the continental shelf and the potential for reduced alongshore sediment supply under regional erosion pressure [3].

The relative significance of contributing processes to coastal erosion varies over time (Table 5-2). Within the next decade, short-term storm erosion is the most significant factor, unless there is enhanced response to a rapid sea level shift. By 30 years, storm erosion and 'natural' progressive erosion are similarly important, and by 100 years, progressive erosion and the additional response due to projected sea level rise are substantially greater than storm response. The potential (although unlikely) effect of an enhanced response to sea level rise is much larger than for a moderate response.

Table 5-2: Scales of Coastal Response

Process of Change	1-year Time Scale	5-year Time Scale	10-year Time Scale	30-year Time Scale	100-year Time Scale
Storm Impact	**20m**	**20m**	**30m**	**30m**	40m
Progressive Erosion	1m	5m	10m	**30m**	**100m**
Sea Level Rise					
- Local Response	0m	0m	2m	10m	45m
- Bruun Response	0m	0m	5m	20m	**90m**
- Extended Response	0m	0m	**40m**	**150m**	**750m**
Dune Mobility (uncontrolled)	10m	100m	400m	1000m	2000m

5.3 Coastal Landform Change

Coastal landforms may be significant for coastal planning where they:

(a) Modify the influence of coastal change (e.g. act as a source or sink of sediment);
(b) Directly provide hazard that affects receptors (e.g. smothering of buildings); or
(c) Have an intrinsic value themselves and are particularly sensitive to coastal change.

Each of these three reasons for coastal landform significance occurs along the Harvey coast. The most significant form of landform change is dune mobility (Section 5.3.1) as all three reasons for significance may be relevant. Flood and ebb delta formations have importance due to their potential to locally enhance coastal dynamics (Section 5.3.2) which is also historically enhanced by the artificial nature of The Cut (Section 5.4). The sedgelands located north of Myalup are an example of a landform with intrinsic value and high sensitivity to coastal change (Section 5.3.3).

5.3.1 Dune Mobility

Dune mobility provides an additional mechanism for coastal evolution, through dune blowouts, sand sheet formation and migration. These may effectively withdraw sediment from the coast, thereby enhancing erosion. At extreme rates, loss of sand into mobile coastal dunes may be a similar order of magnitude to alongshore sediment transport, although this is difficult to quantify.

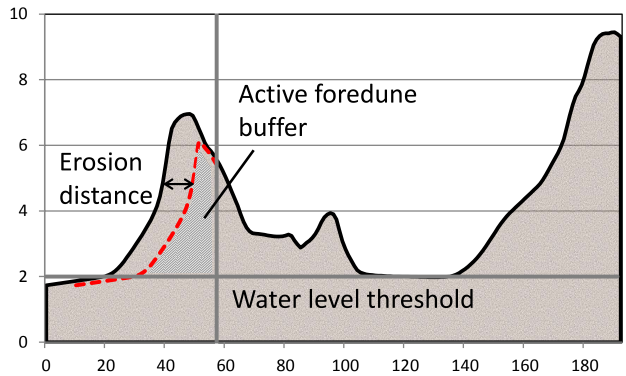
The existing dune structure (Figure 3-5) indicates that the Harvey coast has previously experienced substantial dune mobility, with deeply furrowed parabolic dunes extending from the coast to Leschenault Estuary and Lake Preston. Individual dunes run up to 2km, although the majority have shear faces between 400m and 1km in length.

Parabolic dune mobility is instigated when loss of vegetation provides a bare sand face that is exposed to the wind. Movement of the sand face then occurs, smothering adjacent vegetation and expanding in area to form a sand sheet. As the sand sheet continues to migrate, it deflates (lowers) on its windward side, forming a furrow, which acts to further concentrate winds and accelerate the process [68]. Ultimately the capacity for parabolic dune mobility is limited by the volume of sediment available, and therefore a highly deflated dune system, such as occurs south of Binningup, is potentially less mobile than a dune barrier that has experienced less disturbance. Possible causes for dune mobility include bushfires, uncontrolled coastal access by vehicles or pedestrians or the effect of coastal erosion. The latter mechanism will have increased occurrence if the rate of progressive coastal erosion increases.

It is worth noting some relative differences between coastal erosion and dune mobility:

- Coastal erosion causes effective loss of any coastal infrastructure or amenity that it reaches. It is a loss of coastal sand volume, and therefore although management may locally reduce erosion impact, it typically transfers erosive pressure, either alongshore, or through deepening. The effect is largely constrained to a comparatively narrow coastal margin;
- Dune mobility may affect a substantial distance to landward. However, its effects may be managed with moderate effort for revegetation and typically do not result in permanent loss of infrastructure or amenity (with smothering being clear exception).

An evaluation of the potential for increased dune mobility due to erosion has been undertaken by considering whether the coastal foredune has sufficient volume to act as a buffer against short-term erosion [69]. The analysis has been conducted using the 2008 high resolution topography collected by the Department of Water, and therefore does not represent an indication of present-day risk. The basis for foredune stability is determined by the cross-sectional area in the whole of the dune, or seaward of the foredune crest (Figure 5-3).



The foredune is considered **stable** when it has more than 50m^3/m cross-section in front of the foredune crest and above the 'design storm water level'.

If there is >50 m^3/m in the whole foredune, then there is opportunity for **breaching**.

If there is < 50 m^3/m in the whole foredune, then the **primary dune is susceptible** to reactivation.

Figure 5-3: Basis for Foredune Stability Assessment

Analysis of changing foredune stability due to individually assessed factors of mean sea level change and erosion has been undertaken (Figure 5-4). This indicates a spatial variation of the relative dune stability for both existing and potential future conditions. The southern coast is already substantially unstable, with potential for significant increase in dune instability along the central and northern parts of the coast. In general, there is greater sensitivity to erosion (which may occur within years) than mean sea level change.

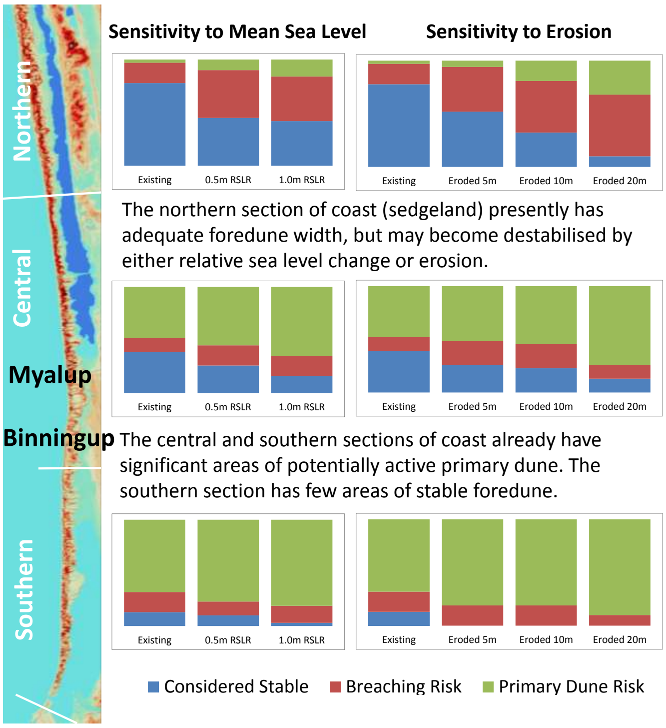


Figure 5-4: Foredune Stability Assessment

5.3.2 The Cut

An alternative entrance to Leschenault Estuary was constructed as part of flood mitigation works for Bunbury, with the estuary truncated and Preston River diverted. The new entrance cut through Leschenault Peninsula was unstable, leading to installation of rock armour training walls. Part of the geomorphic response to the Cut was formation of both ebb and flood tide shoals (outside and inside) adjacent to the entrance (Figure 5-5). A substantial volume of sand is located in each of these features, with growth of the flood tide shoal occurring simultaneously to erosion to either side of the Cut, suggesting infilling with marine sand [70].

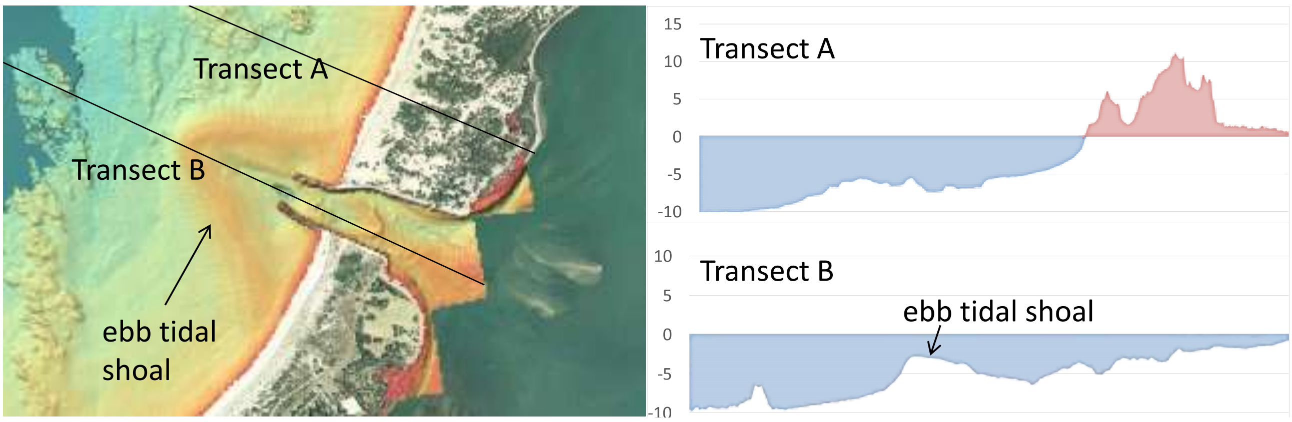


Figure 5-5: Ebb Tidal Shoal at Leschenault Estuary Entrance

Vegetation line movements adjacent to the Cut (Figure 5-6) display a high degree of inter-decadal variability, with a more complex time series than has occurred on the coast north of Binningup. Initially high rates of erosion were a result of sediment demand to form the shoals and adjust more generally to the presence of the training walls. Subsequent 'variable' behaviour is suggestive of Leschenault Peninsula being an endpoint for alongshore sediment transport. Although a time series relationship has not been established, it may be interpreted that erosion on the north side is likely to occur when northward transport is high and accretion if the transport is subdued. Behaviour is also likely to be influenced by the demand or availability of sediment from the shoals, and the rates of dredged spoil disposal as part of port operations.

Figure 5-6: Vegetation Line Change Adjacent to the Cut

5.3.3 Sedgelands

An area of particular environmental interest is the coastal sedgelands that are mainly located north of Myalup. These features are brackish seeps, intermittently holding freshwater, that occur in the depression between the linear coastal foredune and the larger aeolian primary dune (Figure 5-7). These formations develop due to dune blowouts when dry sand is pushed landward by wind, leaving the foredune (wet by the ocean) and the sedgeland (wet by groundwater).

Present-day pressures on the sedgelands include low rainfall, landward migration of the foredunes and disturbance by 4WDs. The land adjacent to the seeps is popular for vehicles use as it is typically flat, sandy and fairly compacted. The groundwater lens is unlikely to be connected directly to the highly exploited surface aquifer located landward of Lake Preston. Existing pressures are likely to be exacerbated by sea level rise.

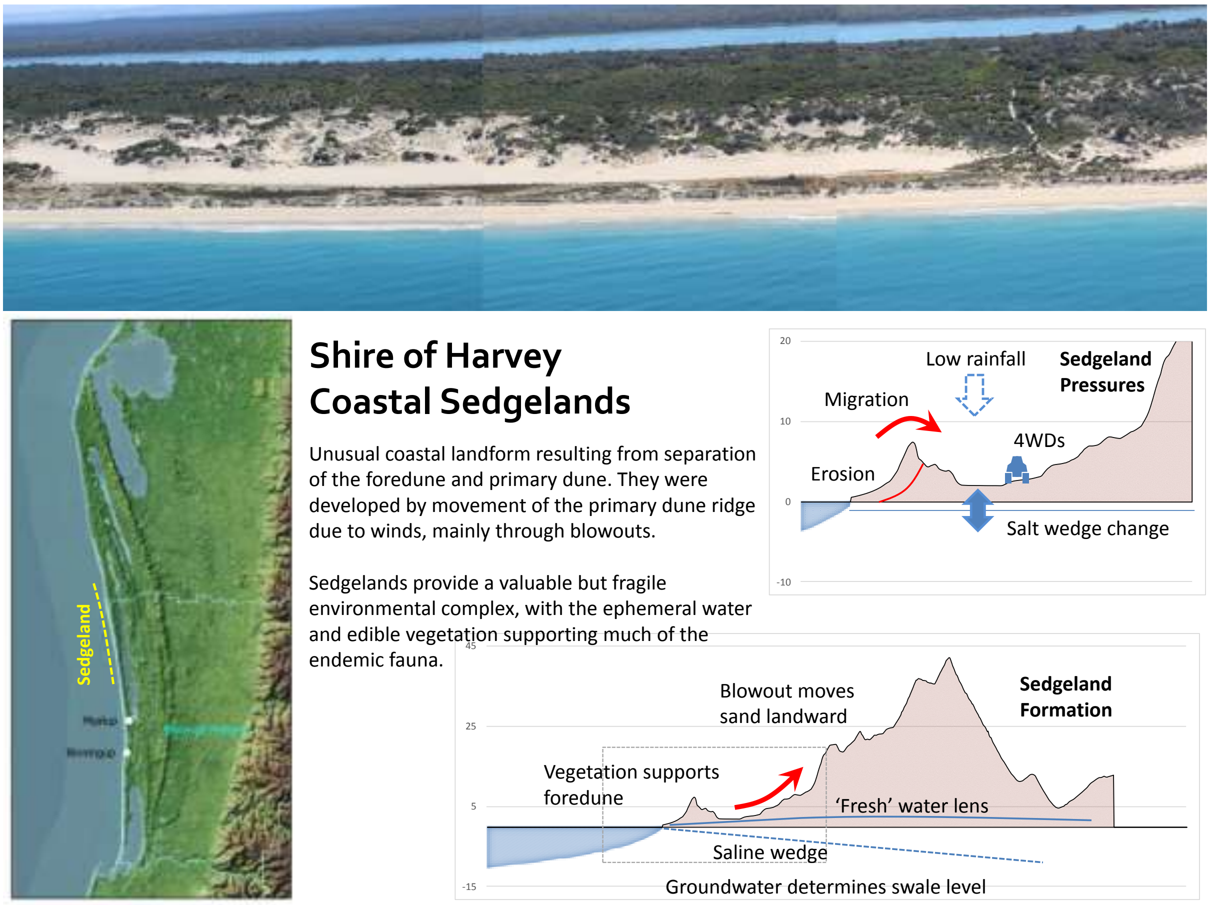


Figure 5-7: Coastal Sedgelands

5.4 Human Intervention in Coastal Processes

5.4.1 Coastal Structures

Coastal structures influencing the Shire of Harvey coast are limited, and include:

- Binningup 'Seawall', which is not apparently designed for beach scour. Dune erosion has occurred on either side of the structure, with downdrift beach erosion on the north side;
- Training walls at the Leschenault Estuary entrance. These cause large beach movements on the north side of the Cut, and the tidal flows have created a large ebb-tide sill offshore;
- Bunbury Power Station groyne, which defines the southern extent of the Leschenault Peninsula coast, now connected to the mainland after port reclamation works. This has created a largely stable beach;
- Bunbury breakwater at Casuarina Point, which interrupts sediment transport and provides swell wave sheltering affecting the southern part of Leschenault Peninsula.

These structures illustrate the role of alongshore transport on the coast via their interaction with the prevailing net northward sediment transport and occasional reversal. The resulting effect on the coast is a combination of the alongshore transport capacity (in both directions) and the capacity to impound sediment, which is normally a function of the structure size (Figure 5-8).

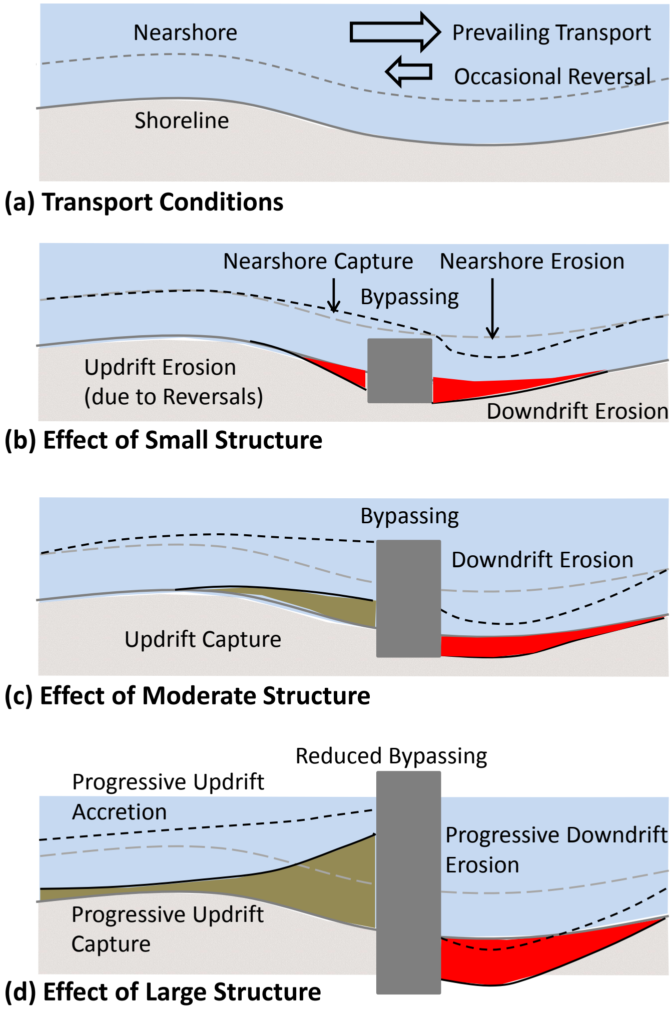


Figure 5-8: Response to Coastal Structures

The Binningup Seawall presently acts as a small structure, with dune erosion to either side. The Cut training walls act like the downdrift side of a large structure, but there is no corresponding updrift behaviour, as the alongshore supply is cut off by Bunbury Port and Koombana Bay. The training walls have also caused formation of a large ebb-tide sill, which may potentially contribute to shoreline fluctuations, as the sill's capacity to hold sediment will fluctuate with tidal conditions, river flows and mean sea level variation.

5.4.2 Dredging and Spoil Disposal

The Bunbury Port breakwater interrupts the alongshore sediment transport, capturing sediment in sand traps and in the port navigation channel. Maintenance dredging is undertaken to remove this accumulation, with material normally deposited on a dump ground 3km to the north and 2km offshore. Although this material may ultimately return to the shore and in effect bypass the port, there is a large offshore mound apparent from the high resolution bathymetry, indicating a net loss to the coastal system, along with material which occupies the sand traps. Historical analysis of past maintenance and capital dredging works suggests that the volume disposed offshore over the last 30 years may exceed the average rate of alongshore transport, although this is unlikely to have been the case previously [36]. The relative balance of sediment captured or effectively bypassed will have implications for the availability of sand along the Harvey coast.

5.4.3 Unmanaged Access

Uncontrolled pedestrian or vehicle access creates additional pressures on coastal stability [2]. This may:

- Introduce weeds, which out-compete native vegetation and reduce food stocks for native fauna. Weeds may also die back due to seasonal stress, allowing bare sand areas to form;
- Create scour-points on tracks, which form funnels to initiate blow-outs; or
- Affect foredune sand build-up or vegetation establishment due to beach use flattening the beach surface and trampling incipient growth.

6 HAZARDS

Assessment of the coastal features and processes acting along the Shire of Harvey coastline allowed for the identification of the historic and potential hazards capable of putting Shire of Harvey assets and their values at risk. Three main hazards were identified; Inundation, coastal erosion, and dune instability and mobility. These hazards, along with their drivers, pathways and receptors

6.1 Coastal Inundation

Coastal inundation has been evaluated by considering extreme ocean water levels relative to the Department of Water high resolution topography. Previous evaluation of extreme water level based on the Bunbury tide gauge identified +1.5m AHD as an upper limit estimate for the 100-year recurrence still water level and +1.8m AHD as an upper estimate for the 500-year recurrence still water level (Figure 6-1) [4]. As this represents the present-day still water level, additional factors were considered when reviewing sites that may potentially require adaptation for coastal flooding, including wave run-up, basin set-up within Leschenault Estuary and long-term sea level rise [60] (Figure 4-14).

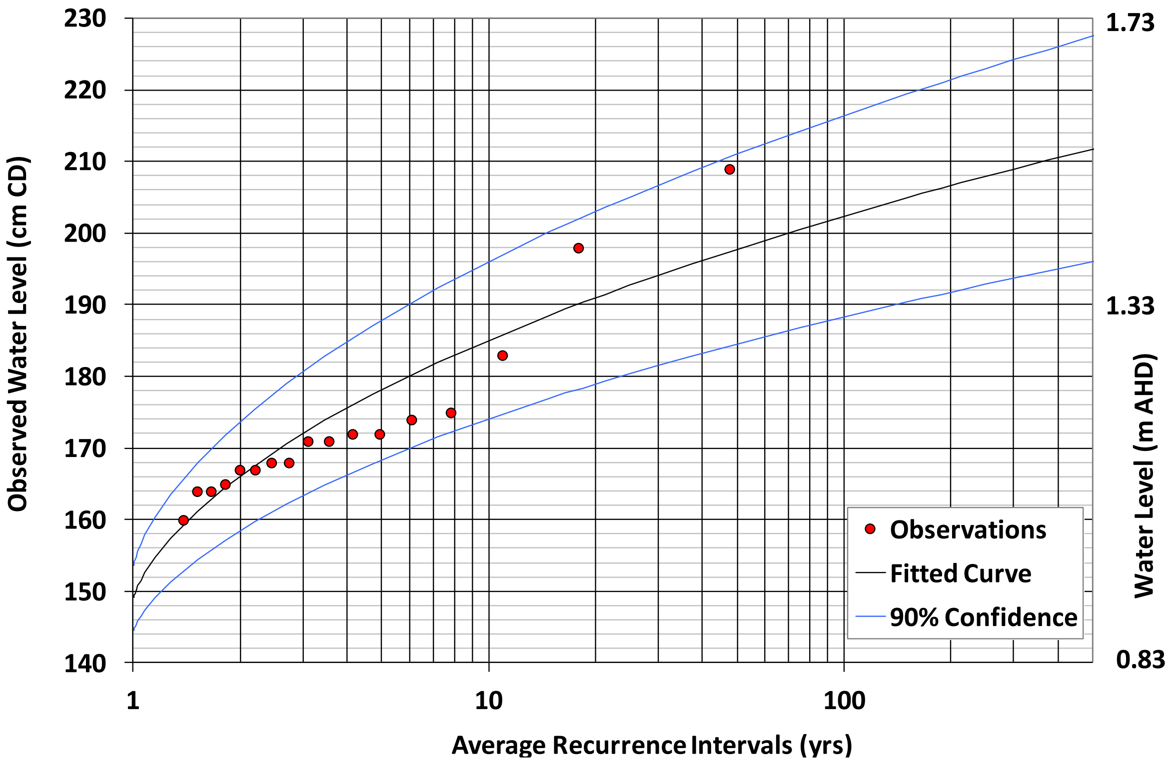


Figure 6-1: Extreme Water Level Distribution from Bunbury Tide Gauge

Areas potentially affected by coastal inundation in the long-term have been identified (Figure 6-2). In general, coastal sites require dune erosion to occur before there is present-day flood risk, whereas there is existing risk to infrastructure and agricultural land within Leschenault Estuary.

The capacity for wave run-up is significantly affected by the porosity and slope of the shore, but for a typical beach, run-up of around 1.5m can be expected. The coastal dunes present along most of the shore prevent inundation being a significant hazard along the coast.

The low-lying topography between Leschenault Estuary and Lake Preston provides a potential pathway for connection of the two water bodies during an extreme flood event, although truncated by a series of road causeways across the swampy land, and training bunds for the Harvey Diversion. Although the likelihood of flooding for this area is presently low, it increases substantially with projected sea level rise.

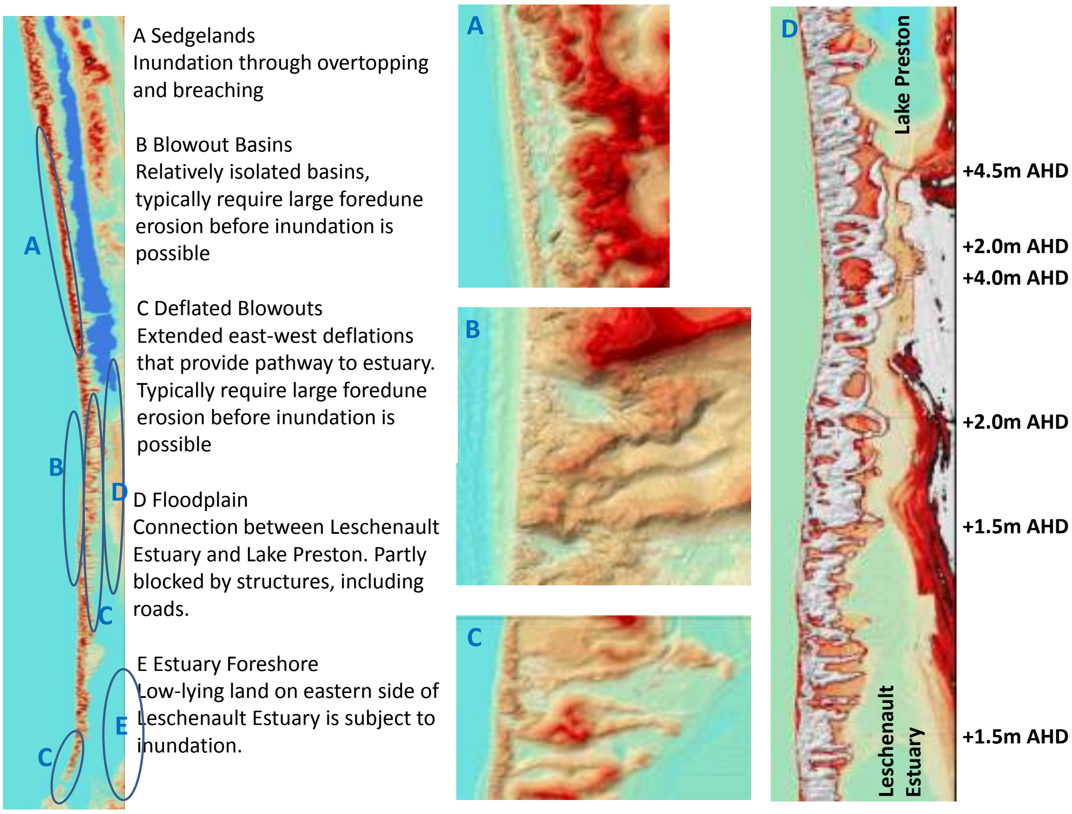


Figure 6-2: Summary of Coastal Inundation Hazard

6.2 Coastal Erosion

The Harvey coast is a barrier dune system, with stratigraphic evidence showing development and migration landward between 5,000 and 8,000 years ago, when sea levels were higher than today [71]. The barrier has eroded over the last 3,000 years [63], with coastal erosion continued to be observed in the modern record, dominated by a decade of acute retreat in the 1970s. Coastal erosion will continue to be a long-term coastal hazard for the Shire of Harvey and is likely to accelerate over the next 100 years due to projected sea level rise.

Evaluation of vegetation line changes along the Harvey coast suggests that historic erosion has mainly occurred north and south of an area of coastal rock to the south of Binningup (Figure 5-2). Interpretation of vegetation lines along the Harvey coast is partly obscured by extensive disturbance caused by industrial activities and the fragility of low linear dunes immediately adjacent to the beach. Subject to these limitations, inferred behaviour along the Harvey coast includes:

- The coast seasonally fluctuates in response to wave and water level variation. This typically includes net northward sediment transport in summer and slightly smaller net southward transport in winter, although reversal (both seasonally and annually) is common;

- Hotspot erosion occurs between Binningup and Myalup due to acute alongshore sediment transport, interacting with the transition from rocky to sandy inshore. Subsequent redistribution of erosion occurs, with recovery at the hotspot concurrent with erosion further north (i.e. net southward transport);
- Areas of weakly cemented beach rock are visible along the Harvey coast, typically comprised of a layer 0.1-0.4m thick. These features help to redistribute erosion stresses when they are in the active hydraulic zone, but typically break into rock plates when undermined, reducing their stabilising influence;
- Coastal instability has been observed at the mouth of Harvey Diversion Drain, as a result of variable runoff flows; and
- Coastal instability has been high at the manmade entrance to Leschenault Estuary (The Cut). Initial erosion was apparently related to formation of tidal shoals both within [70] and outside (Figure 5-5) the entrance. Subsequent coastal change has been variable, apparently related to 'end-point' behaviour in response to fluctuations in the net direction of alongshore sediment transport. Although variable, an overall net retreat is indicated by more sustained erosion several kilometres further north and the heightened stress on the Cut training walls, resulting in failure in 2013.

The sensitivity of the coast to installation of foreshore structures has also been illustrated by response to Binningup Beach Ramp and its associated walling. Erosion has been observed on either flank of the facility since 2010.

Indicative erosion setback allowances have been developed for the Harvey coast based upon Schedule One of the State Coastal Planning Policy [2] (Table 6-1). As identified in the regional erosion assessment [3] and its subsequent interpretation for the Peron-Naturaliste Partnership Coastal Adaptation Pathways project [4], there is considerable uncertainty associated with long-term changes. The theories underlying Schedule One allowances for chronic change (S2) and response to sea level rise (S3) are not considered to be applicable on the Harvey coast due to its coastal geomorphology, including its position at the southern end of a natural coastal sector [9,10].

Table 6-1: Indicative Erosion Setback Allowances

	North Sedgelands	North Myalup-Binningup	South of Binningup	South of Buffalo Rd	Near the Cut
Profiles *	P1-15	P16-55	P56-72	P73-83	P83-92
S1	30m	40m	20m	30m	50m
S2	20m	50m	20m	70m	120m
S3 **	90m	90m	90m	90m	90m
Total ***	140m	180m	130m	190m	260m

* Profile locations shown on Figure 5-2.
** Response to sea level rise is considered unlikely to correspond to the Bruun conceptual model for change, although regional change to littoral transport regimes is expected to occur
*** Additional local effects of foreshore structures upon adjacent coastal setbacks should be identified and incorporated into long-term planning and development setbacks. Major structures whose management is likely to influence setbacks include training walls at Leschenault Estuary and the coastal facilities at Binningup.

The projected acceleration of sea level rise is expected to increase the rate of coastal erosion along the Harvey coast. This continues (although in an accelerated fashion) existing behaviour, with characteristics indicating erosion already present in the coastal geomorphology (see section 5.1 and 5.2), such as scarps and foredune overtopping. These features will develop increased prevalence, along with the greater exposure of buried rock formations that are mostly apparent only during winter.

Anticipated coastal changes and corresponding pressures on coastal activity are described in Table 6-2.

Table 6-2: Coastal Changes due to Erosion

Coastal Change	10-30 years	30-100 years
Beaches	Exposure of rock (now seen during winter) will increase in frequency and duration *Reduced vehicle access on the beach*	Beaches will be discontinuous, with embayments formed between rocky sections *Increased use of overland tracks*
Foredunes	Increased overtopping and landward sand migration *Loss of sedgelands*	Widespread collapse of foredunes *Pressure on development setbacks* *No public foreshore reserve*
Primary Dunes	Increased occurrence of dune blowouts *Sand drift, increased dune planting*	Extensive marine scarping of primary dunes *Blowouts, limited beach access*

Human interventions and built structures along a coastline have the potential to exacerbate these erosion issues, as outlined in section 5.4. Figure 5-8 illustrates a built structures ability to trap sand, effectively removing it from the sediment pathway and starving downstream areas, creating further erosive pressure on the areas affected.

6.3 Dune Instability and Mobility

Harvey coastal dunes are comprised of a narrow and low coastal foredune ridge running along the coastal margin (not always present); and a wide and high primary dune ridge, which is comprised of nested parabolic dunes with crests running to landward (Figure 6-3). This dune structure is indicative of high mobility during an era of formation and evolution, which has been dated from 5,000 to 8,000 years before present.

In the modern period, the dunes are less mobile, due to both the vegetation coverage and reduced availability of sand supply. However, there have been a number of episodes of dune destabilisation due to loss of vegetation, including the effects of 4WD vehicles (ongoing) and the disposal of industrial waste (concluded in the 1990s). Dune instability is also be caused by coastal erosion, particularly where an erosion scarp intercepts the primary dune face. The consequences of vegetation loss are amplified if it causes dune blowouts resulting in sand sheet formation.

An evaluation of potential dune instability was undertaken by considering the relative stability of the coastal foredune structure (Figure 6-3). The cross-sectional area of the foredune and the active foredune buffer were determined relative to different beach erosion states or mean sea level conditions, to provide an indication of the relative change of dune instability with anticipated coastal responses to climate change. The analysis indicated that there was a greater sensitivity to coastal erosion, with approximately 50% increase in primary dune risk for a 20m erosion along the central section of the Harvey coast (Binningup-Myalup). There is a lesser sensitivity south of Buffalo Rd, where there is less foredune and the primary dune is already unstable; and a greater sensitivity north of Myalup, where the linear foredune provides almost a continuous buffer for the primary dune.

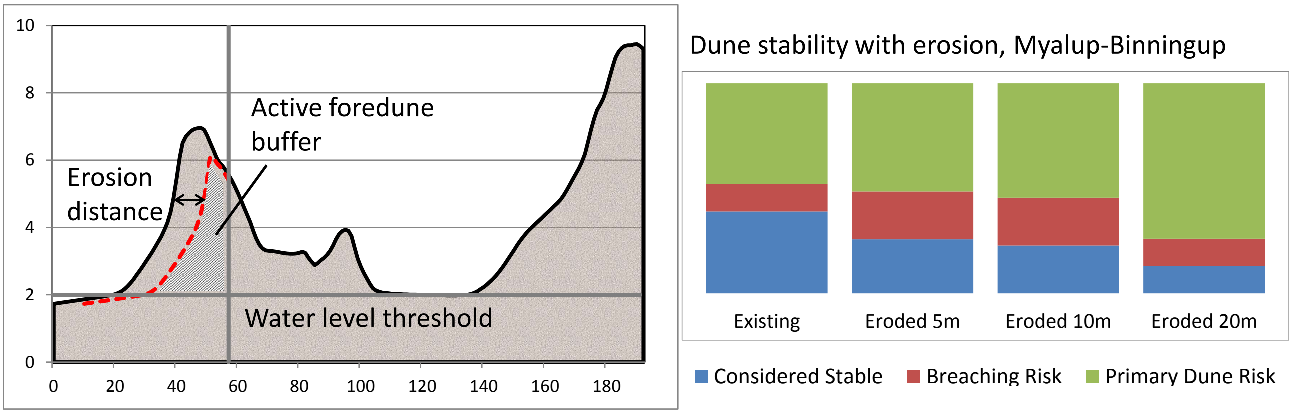


Figure 6-3: Evaluation of Foredune Stability

The landward distance of potential primary dune mobility, as indicated by sand sheets, is substantial along the Harvey coast, being 200-900m north of Myalup and up to 600m south of Buffalo Road. The section with the narrowest sand sheets is located adjacent to Binningup, which corresponds to the lowest and most deflated primary dunes (Figure 6-3), although it has also been the area of most active revegetation works.

Dune rehabilitation has been actively undertaken along the Shire of Harvey coast, and has been highly successful. However, it is anticipated that dune instability will increase due to increased population, pressure for additional overland tracks and more frequent episodes of primary dune scarping due to storm erosion. Evidence for this increase in instability due to higher frequency of storm erosion events is seen in Section 5.2, specifically illustrated in Figure 5-4. Evaluation of dune instability from marine scarping alone (Section 5.3.1) suggests that the required effort is likely to double within 10-30 years.

Dune instability may affect the entire width of the dune barrier if left unmanaged, causing sand to smother roads, houses and vegetation. Typically management or impacts occur across the entire (alongshore) width of a parabolic dune feature, which is typically 200 to 400m, although occasionally a wider area may be affected due to connectivity of multiple parabolic dunes through a single extended foredune swale.

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APPENDIX 1: PREVIOUS ASSESSMENT OF COASTAL HAZARD

Previous assessment for coastal hazard on the Harvey coast was undertaken as part of the PNP Coastal Adaptation Pathways (PNP-CAPS) project, which considered coastal inundation and erosion risks between Cape Naturaliste and Point Peron, Rockingham [5].

Coastal inundation hazard was assessed by developing extreme water level distributions from tide gauge records, interpolated along the coast, with additional allowance for local factors such as set-up within estuaries [4]. Four levels were identified at each site, with corresponding contours mapped from the 2008 LIDAR topography (Table A 1). Where no hydraulic connection to the ocean was identified, areas below the nominated contours were not included in the inundation hazard zones. The basis for water level selection did not include a component for wave runup and therefore neglected purely coastal areas which are subject to run-up and overwash, as these were deemed to be included in the erosion hazard assessment. This approach provided focus on areas where a substantial change to inundation recurrence is likely to require adaptation due to sea level rise.

Table A 1: Coastal Inundation Hazard Levels from PNP-CAPS for Harvey Coast

		2110	2030	2070	2110
	SLR Scenario	Present-day	+0.15m	+0.47m	+0.90m
High Event	100yr ARI	1.34m AHD	1.49m AHD	1.81m AHD	2.24m AHD
Extreme Event	500yr ARI	1.45m AHD	1.60m AHD	1.92m AHD	2.35m AHD
Exceptional Event	500yr+ ARI	1.57m AHD	1.72m AHD	2.04m AHD	2.47m AHD

Coastal inundation mapping showed limited direct influence on the ocean coast due to the elevation of the coastal dune barrier. More extensive flood hazard was identified across the lowlands between Leschenault Estuary and Lake Preston, with roadways at Buffalo Road and Binningup Road providing protection for low to medium scenarios, but overtopped by higher flooding scenarios.

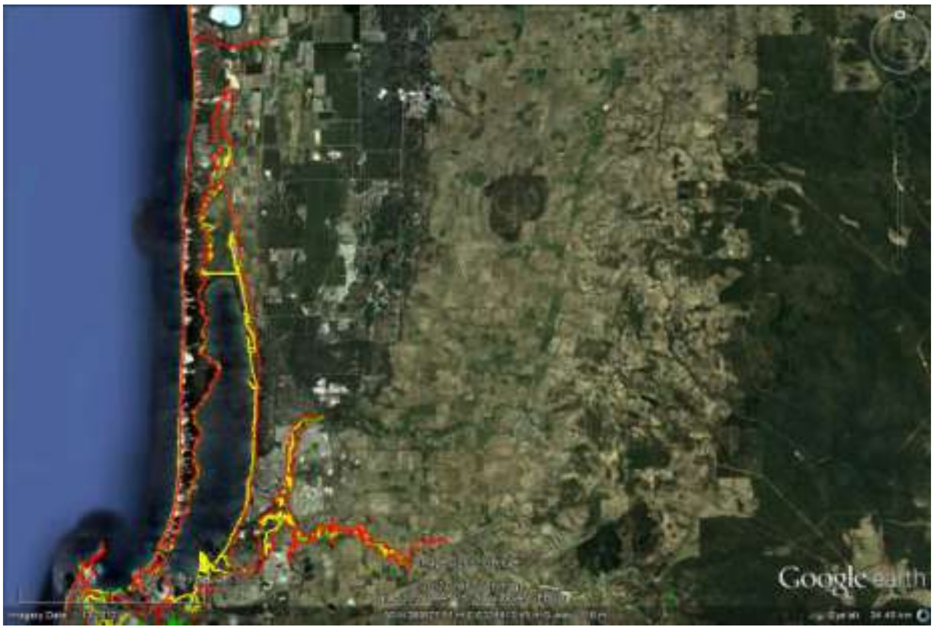

Figure A 1: PNP-CAPS Inundation Mapping for Harvey Coast

Mapping of erosion hazard along the PNP coast was derived from a regional recession study by the University of Sydney 3 to support hazard assessments by Geoscience Australia [72,73]. Technical review of the regional assessment identified that its application of uncertainty-based modelling dominated the assessment and provided extremely large estimates of forecast recession [74] (Table A 2). Two pathways for preliminary refinement were identified:

- Reducing the ratio of potential response to sea level rise, which had conservatively allowed for coast-shelf exchange equal to sea level rise across the full width of the continental shelf;
- Application of downscaling at approximately a secondary cell level (see Section 3.2), using the distribution of coastal landforms identified within the region [75].

Figure A 2: Probabilistic Recession Lines from Regional Study
Note that the recession estimates do not consider the presence of rock

The interpreted recession distances developed for PNP-CAPS were acknowledged to include a number of modelling simplifications inherent to the regional recession study that are not well-supported by the coastal geomorphology and coastal processes of the PNP region. Some key model representations with potential effect on the interpreted recession estimates include onshore sediment supply along the southern Geographe Bay coast and cell-scale aggregation of cross-shore structure. The latter representation effectively means that the increased exposure of rock features with recession has no influence on alongshore transport rates. This simplification provides a considerable restriction to interpretation of coastal behaviour at a sub-regional scale, and therefore a practical limit to the scale at which the regional recession study could be down-scaled.

The downscaling approach used for PNP-CAPS identified the significance of Casuarina Point and Cape Bouvard to the position and orientation of coastal landforms to the Shire of Harvey coast (Figure A 3). Maximum recession was modelled as a linear increase south from Cape Bouvard to Bunbury Port Inner Harbour (Figure A 4). Reduced recession estimates were considered for Koombana Bay due to its limited capacity to release sediment after it has moved into the sheltered waters of the Bay.

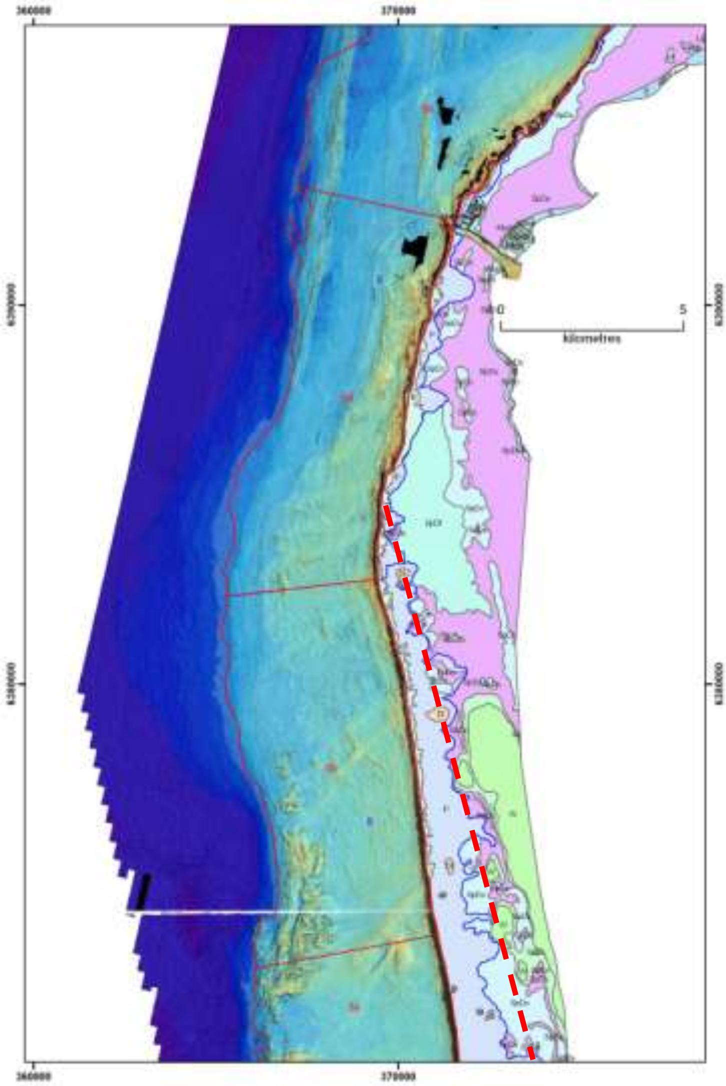

Figure A 3: Basis for Downscaling, with Control at Cape Bouvard

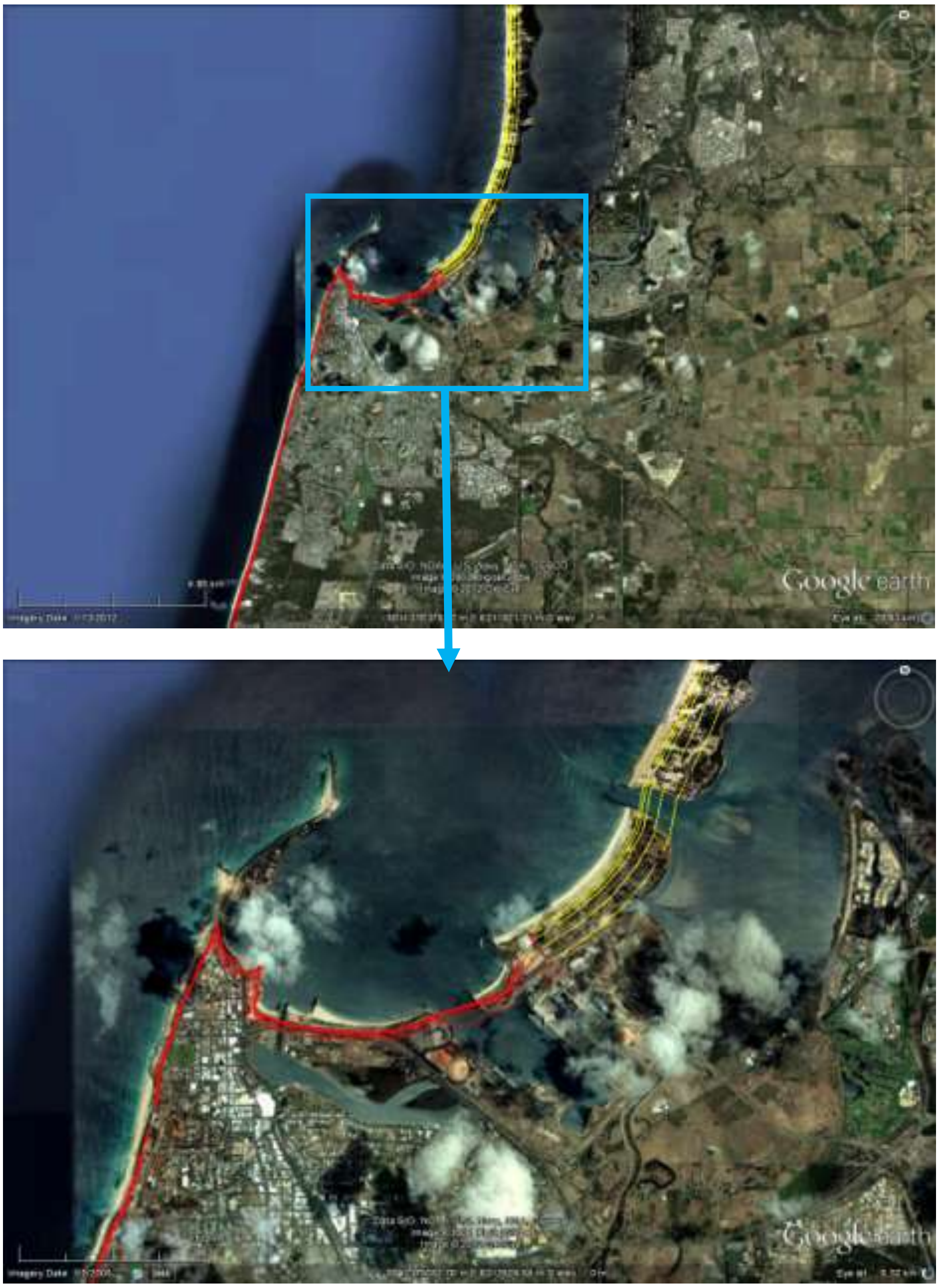

Figure A 4: PNP-CAPS Interpreted Recession Lines for southern Leschenault Peninsula

Re-interpretation of the regional assessment was presented as low, medium and high recession scenarios, with lines mapped for different time frames up to 2110 (Table A 2). Under the high scenario, the potential for erosion through Leschenault Peninsula by 2110 was identified, although this was considered to be a remote outcome, with its likelihood exaggerated by the limited down-scaling that could be applied to the regional assessment.

Table A 2: Regional and Interpreted Recession Estimates

Regional Recession Study	P = 0.10	P = 0.30	P = 0.50	P = 0.70	P = 0.90
2030	33m	44m	54m	65m	83m
2070	88m	121m	150m	182m	238m
2100	135m	187m	233m	289m	379m
Interpreted Recession (Maximum at Southern Leschenault Peninsula)			**Low**	**Medium**	**High**
Interpreted recession scenarios for L,M,H was based on P=0.5, 0.7, 0.9. Average recession across the whole cell is approximately half the maximum.			39m	51m	69m
			149m	183m	241m
			239m	293m	378m

Erosion Hazard Analysis at Finer Scales

The validity of the PNP-CAPS interpretation of erosion hazard was examined by considering the vegetation line information at finer temporal and spatial scales, in the context of the seabed features (Figure 3-3). Key findings included:

- Two additional structural controls were identified, being nearshore rock features from Binningup to Buffalo Road, and the substantial reefs offshore from Preston Beach. The influence of these controls is confirmed by changes to coastal aspect and landforms, which resulted in them being identified as secondary sediment cell boundaries (Table 3-1);
- The time sequence of observed erosion is not consistent with the model used for downscaling (recession increasing towards the southern end of the Bunbury-Cape Bouvard coast). Erosion of the Leschenault Peninsula coast occurred at a different time to the Binningup-Preston Beach section, and was apparently more strongly influenced by excavation of the Cut and subsequent development of flood and ebb deltas. This inconsistency was not apparent from net recession from 1955-2014 (Figure 5-2).

The apparent consistency of net recession along the wider coast (from 1955-2014) with the distribution of coastal landforms was used as a basis for applying the tertiary cells to downscale the regional recession estimate. Consequently, it is worth identifying whether this situation is likely to recur for subsequent applications.

The landform interpretation is based upon the structure of the dune barrier, which is largely determined by prehistoric shoreline position 1-2 kilometres seaward. As a result, offshore rock features from Preston Beach had greater influence on the dune barrier than they presently do on modern beach. Equivalently, the nearshore rock features south of Binningup, which apparently influence the modern coastal behaviour, were buried when the dune barrier was forming and migrating. Based upon available knowledge of coastal stratigraphy and evolution along the wider PNP coast, this situation is far more likely to occur along the Harvey coast than elsewhere. However, a similar outcome should be recognised as a possibility.

An interpretation of the coastal behaviour on a tertiary cell basis has been developed to support refined forecasting of future coastal dynamics (Table A 3).

Table A 3: Coastal Behaviour Relevant to Forecasting

Tertiary Sediment Cell	Coastal Behaviour Relevant to Forecast Recession
6b Myalup North to Preston South	Strongly connected to the cell to the south, but has lagged response due to difference in seabed grade and coastal aspect
6a Binningup to Myalup North	Subject to focused erosion (downdrift from rock features), but gradually transfers erosion pressure northward
5c Buffalo Road to Binningup	Partial stabilisation provided by extensive nearshore rock features
5b Leschenault South to Buffalo Road	Subject to high inter-annual variability, likely due to 'endpoint' behaviour, with possible influence from estuary entrance flood and ebb-tide deltas
5a Bunbury Harbour to Leschenault South	Isolated from main littoral sediment transport pathway by Bunbury Port breakwater and bypassing. May be subject to permanent recession after extreme northerlies

The regional recession study, even with the re-interpretation used for PNP-CAPS, is difficult to apply meaningfully at finer spatial scales. Further, the approach used is inconsistent with coastal planning policy SPP 2.6, making any form of planning decisions open to challenge. The implications of using a less conservative estimate of recession (e.g. SPP 2.6) are partly offset by the use of the CHRMAP framework, which incorporates monitoring and refinement of hazard assessment.

On the Harvey coast, the importance of coastal erosion is significantly outweighed by the potential for dune mobility, which has far greater spatial effect and immediacy than coastal erosion. The absence of significant policy guidance for the management of coastal landform mobility creates a challenge for the Shire of Harvey. Developing an effective strategy for the management of dune mobility and ensuring adequate in-house knowledge is considered to be an important step for the Shire's coastal management.