# Bluff Point Coastal Adaptation
# Chapman River Sand Bar Assessment

## Seashore Engineering
## May 2022

**Report SE127-01-Rev0**

Seashore Engineering

**Prepared for City of Greater Geraldton**

**Limitations of this Report**



# Document Control

| Index | Author | Date | Review | Date | Comment |
|---|---|---|---|---|---|
| **Draft A** | G.McCormack | 08.10.2021 | M.Eliot | 14.12.2021 | |
| **Draft B** | M.Eliot | 06.05.2022 | | | |
| **Draft C** | | | | | |
| **Rev A** | | | | | |
| **Rev B** | | | | | |
| **Rev O** | M.Eliot | 16.05.2022 | | | [Final Revision] |

# Executive Summary

The City of Greater Geraldton has developed a coastal adaptation plan for the long-term management of coastal hazards. Adaptation proposed at Bluff Point, Geraldton, involves a low crested GSC groyne with initial sand placement on its southern side, to locally protect assets south of Bluff Point identified as vulnerable to erosion by 2030. The groyne is expected to retain sediment on its south side due to prevailing net northerly sediment transport. The ocean entrance of Chapman River is located on the north side, and consequently modified beach dynamics could affect stability of the river entrance.

Environmental assessment for the proposed groyne identified potential for indirect impacts on saltmarsh communities near the mouth of the Chapman River, due to "altered hydrology/tidal restriction" (GHD 2021). This saltmarsh is recognised as a Threatened Ecological Community (TEC) under the Federal Environment Protection and Biodiversity Conservation Act 1999, and the City is required to demonstrate no impacts on the TEC. The scope of this investigation is to locally assess potential impacts of a groyne on stability of Chapman River entrance, supporting evaluation of indirect impacts to saltmarsh TEC.

Assessment of historic and recent behaviour has identified the Chapman River entrance has experienced discrete state changes, strongly linked to a substantial change in river flow that occurred around 2000:

- Prior to 2004, relatively higher river flow conditions determined that the entrance bar was low elevation, subject to overflow, deflation, and wave overwash.
- From 2004 onwards, the bar transitioned into dune behaviour, with permanent vegetation supporting growth.
- The bar has subsequently been subject to coastal erosion from 2010, as a southward extension of the wider erosion trend which has dominated Sunset Beach area since around 2000.

Behaviour of the entrance is highly seasonal, with the channel opening through the onset of winter river flow, and generally closing within a few weeks after flows have tailed off, through a combination of alongshore and cross-shore sediment movements.

Installation of a groyne at Bluff Point is expected to modify alongshore sediment transport. Evaluation of impacts has involved (i) consideration of tidal inlet stability; and (ii) evaluation of active coastal processes. Modelled impact to tidal inlet stability is marginal, with the general expectation that the channel will remain open for slightly longer each season, but that it will still close if a neap tide phase coincides with moderate wave conditions.

The anticipated impact of the proposed groyne to modify active coastal processes is substantial. Structures at Bluff Point will accelerate erosion between Chapman River and north Sunset Beach. The threat to Chapman River entrance bar is significant, as the bar was formed through a discrete development phase and has subsequently been exposed to ongoing erosion pressure. Installing a stabilization structure at Bluff Point will accelerate loss of this bar.

Overall, it is not recommended to conduct the proposed groyne as suggested, or to replace with a groyne field.

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# 1. Introduction

The City of Greater Geraldton has developed a coastal adaptation plan for the long-term management of coastal hazards (Baird 2019). Adaptation proposed at Bluff Point, Geraldton, involves a low crested GSC groyne (Figure 1-1) with initial sand placement on its southern side, to locally protect assets south of Bluff Point identified as vulnerable to erosion by 2030 (MRA 2020). The groyne is expected to retain sediment on its south side due to prevailing net northerly sediment transport.

Groynes use the process of wave-driven alongshore sediment transport. A groyne traps sediment on the updrift side, altering the beach angle, which in turn slows the rate of transport. However, performance of a groyne is not always straightforward, and it can potentially introduce greater shoreline variability, particularly on the downdrift side. The groyne proposed at Bluff Point is adjacent to the ocean entrance of Chapman River, and consequently modified beach dynamics could affect stability of the river entrance.

Environmental significance of changing river entrance dynamics is developed by the presence of coastal saltmarsh communities near the mouth of the Chapman River. This saltmarsh is recognised as a Threatened Ecological Community (TEC) under the Federal Environment Protection and Biodiversity Conservation (EPBC) Act 1999, with location and extents to be confirmed in a planned terrestrial flora and vegetation survey. Environmental assessment identified potential for indirect impacts on saltmarsh communities from the proposed groyne, specifically due to "altered hydrology/tidal restriction" (GHD 2021).

The scope of this investigation is to provide local assessment of potential impacts of a proposed groyne on stability of Chapman River entrance, to support assessment of indirect impacts to saltmarsh TEC. The scope includes comparison of channel and bar morphology for existing conditions (baseline), and with projected influence of a proposed groyne.

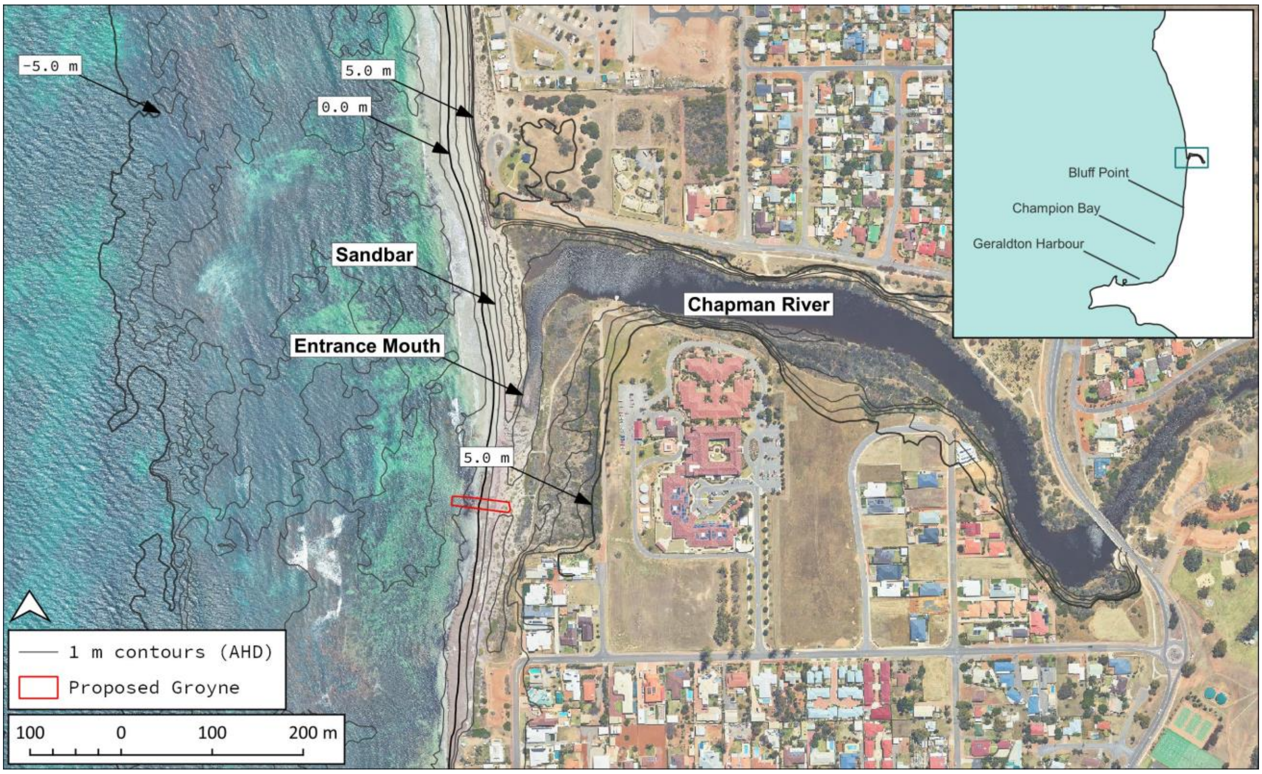


**Figure 1-1: Site Figure**

# 2. Chapman River Entrance Dynamics

Chapman River is a moderate-sized river system with a catchment of 1,160km$^2$, located in the semi-arid Midwest region of Western Australia, debouching into a micro-tidal region of southeast Indian Ocean. This combination of low tide and low/occasional flow leads to classification as a wave-dominated estuary (Heap *et al*. 2001), which is typically characterised by a sand bar partially across the river entrance (Ryan *et al*. 2005). This characteristic structure occurs at the mouth of the Chapman River, with a channel that has historically broken out south of the sandbar (Figure 2-1).

Entrance dynamics are developed through a combination of riverine, wave and tidal processes. Behaviour results from interactions of different geomorphic and structural features, suggested by the system interaction diagram (Figure 2-2). Active drivers vary for different features (Table 2-1), with behaviour of larger features generally providing "boundary conditions" for smaller component features. It is noted that effect of the proposed groyne is not directly related to bar and channel dynamics but occurs through the medium of beach change. Dynamics occur over multiple scales, with sediment moved around and over rocky features, including reefs and rock platforms (Figure 2-3). When resolving dynamic behaviour, it is also noted that change occurs over different time scales, with consideration given to seasonal, episodic, or inter-annual variability.

Examination of drivers and processes are reported in the Appendices:

**Appendix A: Meteorological and Oceanographic Drivers**
- A.1 Winds
- A.2 Water Levels
- A.3 Waves
- A.4 Chapman River Flooding

**Appendix B: Coastal Processes**
- B.1 Regional Scale Coastal Processes
- B.2 Local Geomorphic Overview
- B.3 Simulated Alongshore Transport & Groyne Influence
- B.4 Cross-shore Transport Considerations
- B.5 Tidal Prism Assessment and Entrance Stability


**Figure 2-1: Key Geomorphic Features Adjacent to the Site**
**Obliques Aerial from May 2011 Source: WACoast (Gozzard 2011) | Ground Photographs from September 2016**

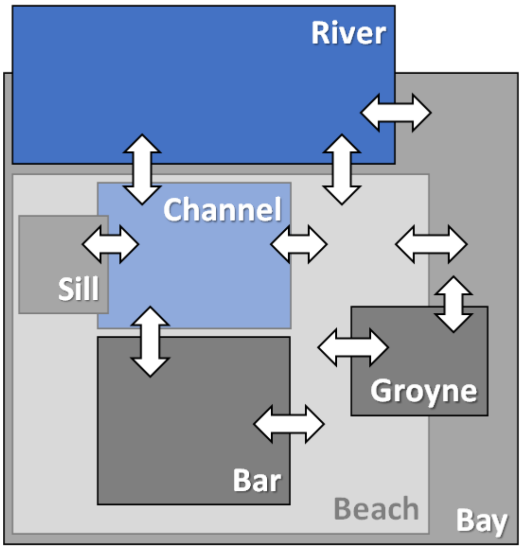


**Figure 2-2: System Interaction Diagram**

**Table 2-1: Drivers, Dynamics and Evidence**

| **Dynamic Feature** | **Drivers** | | | | |
|---|---|---|---|---|---|
| | **Wave** | **MSL** | **Tide** | **Flow** | **Evidence of Behaviour** |
| **Bay Dynamics** | | | | | |
| - Sediment Availability | | ✓ | | ✓ | Sediments |
| - Alongshore Distribution | ✓ | ✓ | | | Morphology |
| **Beach Dynamics** | | | | | |
| - Alongshore Transport | ✓ | | | | Vegetation lines |
| - Cross-shore Transport | ✓ | ✓ | ✓ | | Beach lines |
| **River Dynamics** | | | | | |
| - Sediment Supply | | | | ✓ | Sediments |
| - Flood Scour | | | | ✓ | Flow record |
| **Bar Evolution** | ✓ | | | | Aerial imagery |
| **Channel Dynamics** | | ✓ | ✓ | ✓ | Aerial imagery |
| **Sill Variability** | ✓ | ✓ | ✓ | | Not available (inferred) |
| **Effect of Groyne** | ✓ | | | | Not available (inferred) |

Available information for drivers and dynamics varies over time (Figure 2-4), creating windows to understanding behaviour. From 1941-2010, coastal change is informed by aerial imagery 'snapshots' and there is no directional wave data. Wave instrumentation became available from 2011 and frequent satellite imagery with sufficient resolution to look at the river entrance became available from 2015. Variation of drivers is outlined in Appendix A and coastal processes are outlined in Appendix B.

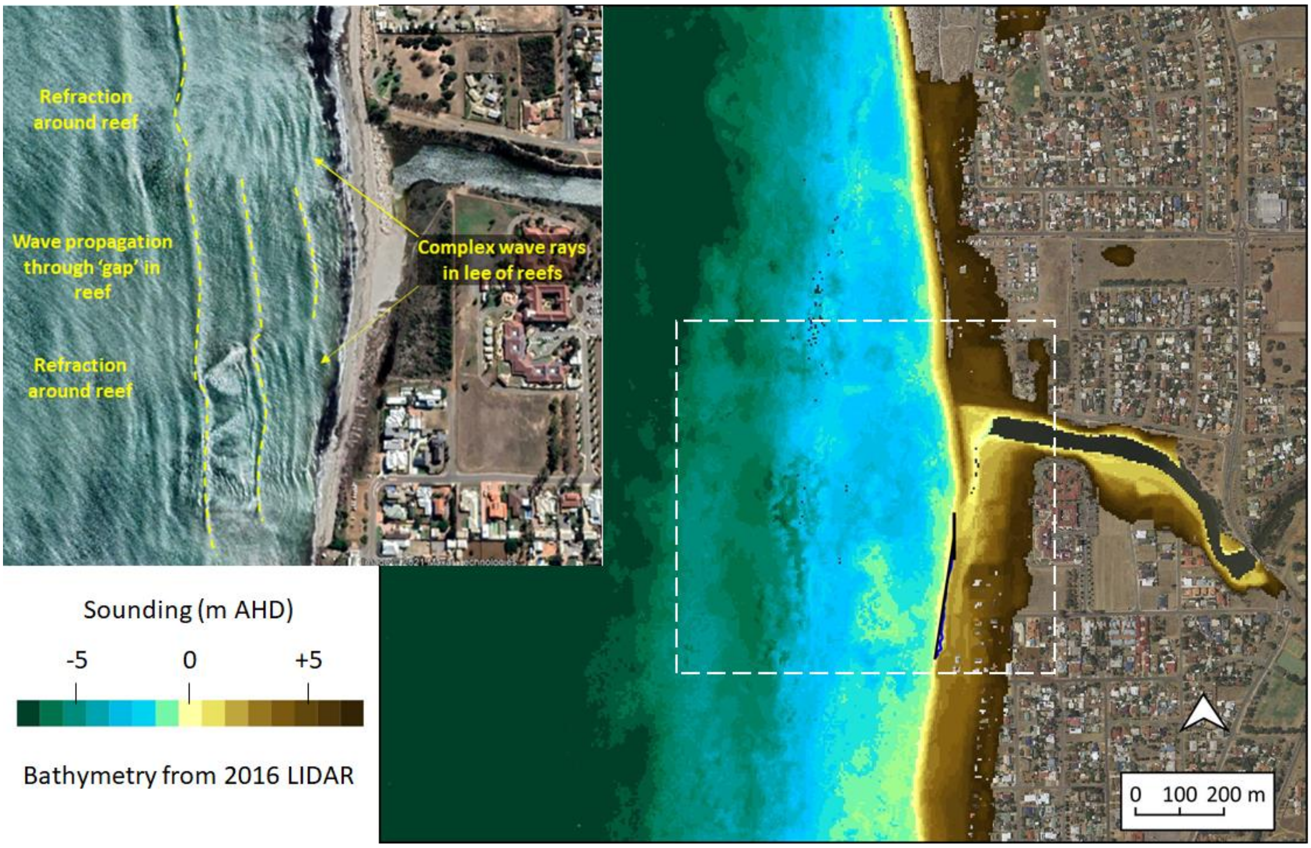


**Figure 2-3: Local Bathymetry and Influence of Reefs on Inshore Waves**

Information suitable for directly assessing seasonal behaviour is restricted to the period from 2015 to 2020, when there is both directional wave data and comparatively high frequency capture of suitable satellite imagery.

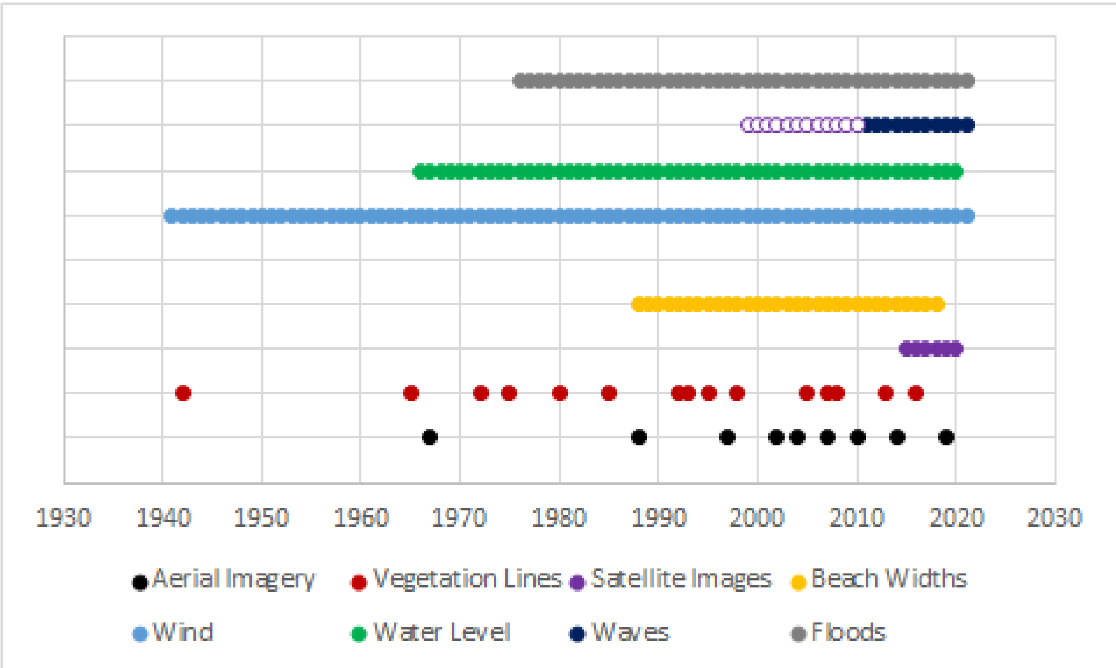


**Figure 2-4: Available Information on Drivers & Dynamics**

## 2.1. HISTORIC RIVER ENTRANCE VARIABILITY (1967-2014)

Variability of Chapman River entrance has been assessed visually from historic aerial imagery, with a time sequence illustrated by a selected subset of images (Figure 2-6). An open channel was captured on three occasions, in 1988, during a minor flood in 1997 and in 2002. Although these are sequential images, it is considered that this is largely coincidence, with more frequent observations (Section 2.2) suggesting a strong seasonal cycle, and hence the state of the entrance is affected by the month of imagery capture.

Observed position of the entrance mouth position ranges 450m, from a southerly position in 1967 to in line with the river channel in 1988, with subsequent breach points varying from 120 to 300m south of the 1988 position. It is noted that:

- The entrance bar was subject to occasional overwash and deflation until 2004, evidenced by a lack of vegetation, with overwash illustrated by the 2002 image.
- From 2004 onwards, the bar transitioned into dune behaviour, with permanent vegetation supporting growth. Lidar survey indicates heights of 3-4m AHD in 2016. A small area of dune also developed south of the channel mouth.
- The channel position behind the dune has remained largely stable, although the mouth has varied in position, intermittently truncating the southern part of the dune / bar, creating a denuded, lower elevation area.

Overall, this is a significant state shift, from an overwashing bar to a barrier bar across most of the ocean entrance.

Mechanisms associated with state shift from 2001-2004 include:

- River gauging indicates substantially lower flows since 1999 (Appendix A.4). Although this reduces opportunity for disturbance of the bar from the landward side, it doesn’t provide a mechanism for dune development.
- Total water levels generally increased from early 1990s to 2011, which were peak *el Niño* and *la Niña* climate phases. This period included mean sea level peaks in 1999-2000 and 2008, and a peak of the 18.6 tidal phase in 2006. From 2000 to 2004, mean sea level dropped by almost 0.2m, which is conducive to beach stability and dune development.
- Non-directional wave measurements from 2001-2008 indicate a shift from “steep” (wave height to period) and stormy wave conditions up to 2003, to “flatter” and calmer wave conditions (see Appendix B.4). Wave flattening provides an increasing ratio of spilling to plunging waves, giving tendency towards onshore sediment movement.
- The wind record suggests the 2000-2004 period was transitional in both summer and winter, with increasing westerly component to summer winds and increasing proportion of northwest and westerly winds during winter. Both suggest conditions likely to weaken northward alongshore transport. The fluctuation is typical of inter-annual wind variability.

Individually, wave and water level processes would not have supported a state shift, as they had previously occurred without causing the bar to develop into a dune. However, near-simultaneous occurrence, following a shift to low flow conditions, supported dune development, which subsequently prevented dune overwash and provided partial control to the channel.

It is worth noting that behaviour of the Chapman River entrance was not apparently associated with high rates of alongshore sediment transport following large-scale renourishment in 2004 of the beach north of Batavia Coast Marina, with material excavated during the Southern Transport Corridor construction. Northward dispersion of the renourishment material occurred over several years, causing a wide beach at Dean Street from 2005-2007 and at Hungerford Street from 2005-2012.

Variable sediment supply from the south has a relatively minor influence on beach behaviour between Bluff Point and Glenfield, which is dominated by a northward transfer of sediment, including progressive beach retreat of up to 1.6m/yr at Sunset Beach over 1988-2018 and accretion of 1.0m/yr at Glenfield Beach (Bishop-Taylor *et al*. 2021). Progressive beach retreat has occurred at the river mouth (Figure 2-5), with the present shore roughly 30-50m landward of the 1967 position (Figure 2-6). However, south of the mouth, a point of inflection linked to nearshore reef has eroded southward and straightened, indicating reducing influence of shelter, with the erosion rate delayed from 2000-2010, suggesting influence of supply from the south.

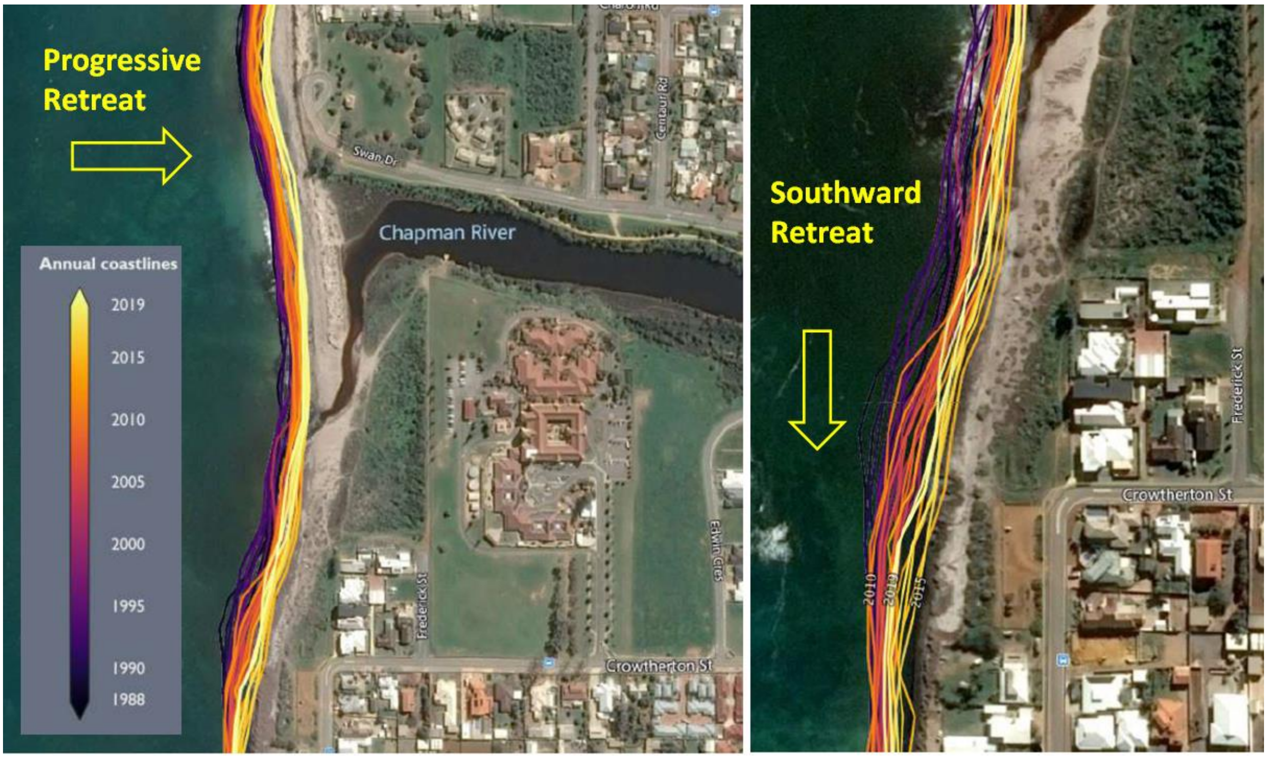


**Figure 2-5: Local Coastline Changes 1988-2018 (Digital Earth Australia)**
**DEA Coastlines derive the average annual beach position (Bishop-Taylor *et al*. 2021)**

Changing state of the river mouth has affected sediment movement within the entrance (Figure 2-6). High flow conditions prior to 1999 caused channel widening, apparent in 1967 and 1997 images. Channel infilling characteristic of tidal influx is evident in 1988 when the mouth was in line with the channel. From 2002 onwards, development of the bar into a dune has reduced sediment influx, with wind-blown drift towards the east side of the dune being irregularly scoured out by flow through the narrow channel behind the dune.

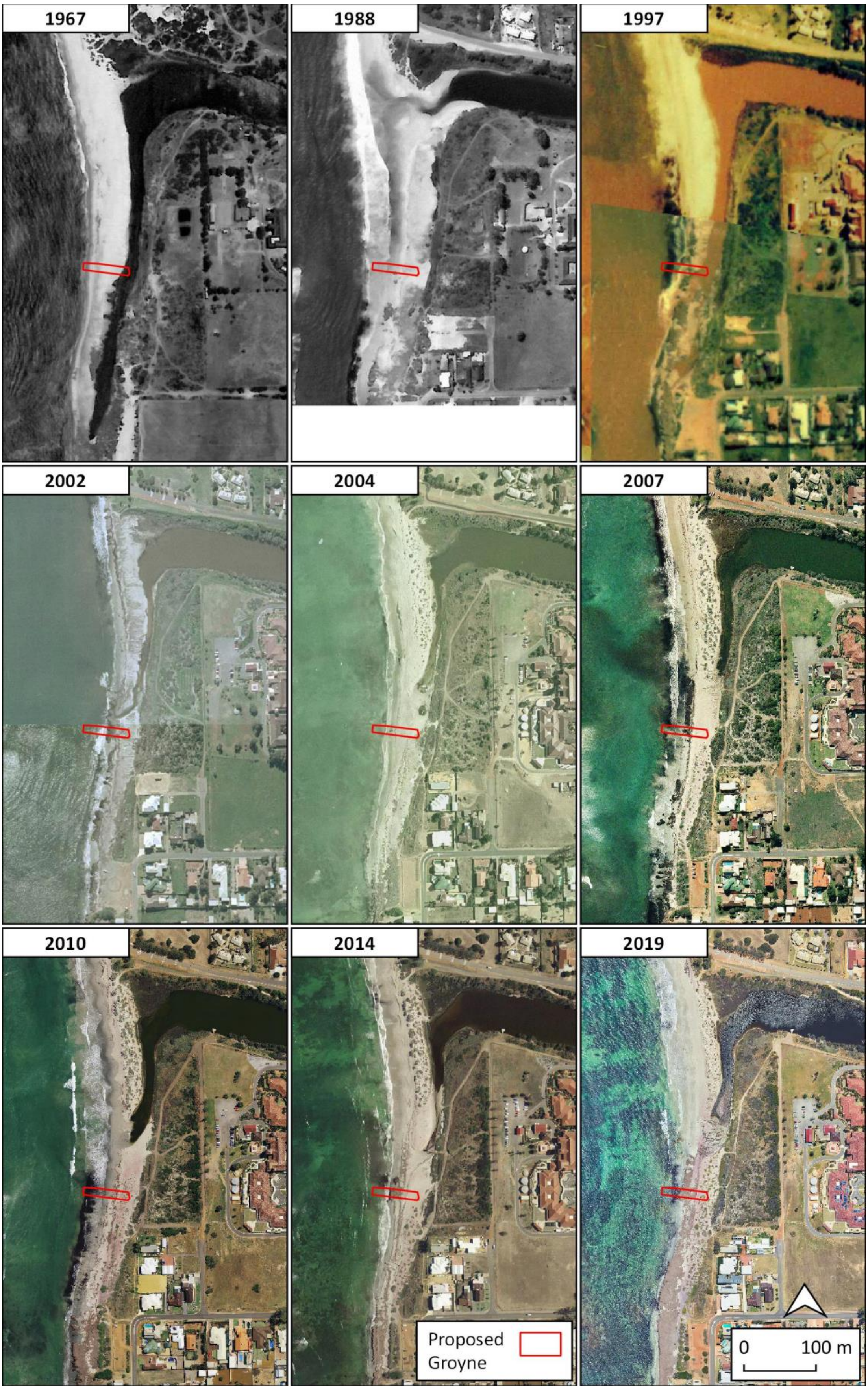


**Figure 2-6: Historic Variability at Chapman River Mouth**

## 2.2. RECENT CHANNEL AND ENTRANCE BEHAVIOUR (2015-2021)

Relatively greater frequency and quality of imagery available from 2015 supports evaluation of seasonal variability of the river mouth. This has been assessed using:

- Imagery available from Google Earth, which has increased frequency since 2018.
- Sentinel-2 satellite imagery, which has frequent capture since 2015, enabling up to weekly assessment.

Assessment is partly limited by Sentinel-2 image quality, which can obscure smaller channel openings and closure timing, particularly when the bar is narrow, if there is wave breaking or wrack coverage. It is highlighted that 2015-2021 is a period with limited variability of drivers, low flood flow and relative stability of the entrance bar and channel mouth. Seasonal dynamics are expected to vary with higher flood flows, bar destabilisation or channel migration.

An image sequence (Figure 2-7) and a timeline of high flow events with approximate dates of channel opening and closing indicate the general pattern of behaviour for 2015-2021 (Table 2-2). General results are:

- The channel opens during winter flows, with relatively minor flows (<1m$^3$/s) able to breach the entrance bar and form a channel. Over 2015-2021, this occurred during late June to mid-August, which is coincident with potential for high alongshore sediment transport, with declining tides and mean sea level from the May-June peak.
- Channel expansion occurred during larger flows, with the widest channel inside the mouth observed in August 2019, following the highest flow for 2015-2021 of 17.7m$^3$/s on 6/07/2019.
- Channel generally remains open through August and September, supported by winter flows and tidal exchange, but typically narrows and shallows at the mouth.
- Berm development at the mouth typically begins in September when winter flows subside, increasing in October as tidal exchange reduces, there is low mean sea level and increased tendency for spilling waves to cause beach rebuilding.
- Once the berm has been established, cutting off tidal exchange, the channel immediately behind the mouth begins to infill, plugging the entrance. Washover fans and progressive infill indicate this process occurs through landward transfer during wave overwash events or progressive wind-blown sand during prevailing seabreezes. It can occur from October right through to winter.

The channel was open for an extended duration in 2021, compared to the preceding five years.

**Table 2-2: Timeline Showing Flow Events and Periods and Channel Openings (Blue Shade)**

| Year | Month | Flow Event >1m³/s | | Flow >0m³/s | Total Dichage m³/s | Google Earth Assessment | Sentinel S2 Assessment | Duration Open |
|---|---|---|---|---|---|---|---|---|
| 2015 | Jan | | | | | | | |
| | Feb | | | | | | | |
| | Mar | | | | | | | |
| | Apr | | | | | | | |
| | May | | | | | | | |
| | Jun | | | | | | | |
| | Jul | 2.8 | 21/07/2015 | 21/07/2015 | 2500 | | | |
| | Aug | 7 | 1/08/2015 | 25/08/2015 | | | | |
| | Sep | | | | | | | |
| | Oct | | | | | | Closed - 28/10/2015 | |
| | Nov | | | | | | | |
| | Dec | | | | | | | |
| 2016 | Jan | | | | | | | |
| | Feb | | | | | | | |
| | Mar | | | | | | | |
| | Apr | | | | | | | |
| | May | | | | | | | |
| | Jun | | | | | | Closed - 24/06/2016 | |
| | Jul | 2.3 & 8.6 | .0 & 18/07/201 | 10/07/2016 | | | Open - 14/07/2016 | 100-130 days |
| | Aug | 1.8 | 29/08/2016 | | 5600 | | | |
| | Sep | | | 11/09/2016 | | | | |
| | Oct | | | | | | 22/10/2016 - likely open | |
| | Nov | | | | | | Closed - 21/11/2016 | |
| | Dec | | | | | | | |
| 2017 | Jan | | | | | | | |
| | Feb | | | | | | | |
| | Mar | | | | | | | |
| | Apr | | | | | | | |
| | May | | | | | | | |
| | Jun | | | | | | Closed - 19/06/2017 | |
| | Jul | | | | | | Uncertain | Uncertain |
| | Aug | | | 31/08/2017 | 400 | | Uncertain | |
| | Sep | | | 3/09/2017 | | | Uncertain | |
| | Oct | | | | | Narrow bar | Uncertain | |
| | Nov | | | | | No image | Closed - 01/11/2017 | |
| | Dec | | | | | No image | | |
| 2018 | Jan | | | | | No image | | |
| | Feb | | | | | No image | | |
| | Mar | | | | | No image | | |
| | Apr | | | | | | | |
| | May | | | | | | | |
| | Jun | | | | | | | |
| | Jul | 1.5 | 22/07/2018 | 6/07/2018 | | No image | Open - 9/07/2018 | 85-135 days |
| | Aug | 2.2 + 1.2 | 6 & 11/08/2018 | | 3100 | | | |
| | Sep | 1.5 | 1/09/2018 | 7/09/2018 | | | | |
| | Oct | | | | | No image | 2/10/2018 - likely open | |
| | Nov | | | | | No image | Closed - 21/11/2018 | |
| | Dec | | | | | | | |
| 2019 | Jan | | | | | | | |
| | Feb | | | | | | | |
| | Mar | | | | | | | |
| | Apr | | | | | | | |
| | May | | | | | | | |
| | Jun | 1.4 | 29/06/2019 | 26/06/2019 | | | Open - 29/06/2019 | ~115 days |
| | Jul | 17.7 | 6/07/2019 | | 5500 | No image | | |
| | Aug | | | 9/08/2019 | | | | |
| | Sep | | | | | | | |
| | Oct | | | | | | Closed - 22/10/2019 | |
| | Nov | | | | | | | |
| | Dec | | | | | | | |
| 2020 | Jan | | | | | | | |
| | Feb | | | | | | | |
| | Mar | | | | | | | |
| | Apr | | | | | | | |
| | May | | | | | | | |
| | Jun | | | | | | | |
| | Jul | | | | | | | |
| | Aug | 1.7 | 17/08/2020 | 10-24/08/202 | 1300 | | Open - 17/08/2020 | ~55 days |
| | Sep | | | | | Temp Closed, then open | 16/09/2020 - likely open | |
| | Oct | | | | | | Closed - 11/10/2020 | |
| | Nov | | | | | | | |
| | Dec | | | | | | | |
| 2021 | Jan | | | | | | | |
| | Feb | | | | | | | |
| | Mar | | | 30/05/2021 | | | | |
| | Apr | | | | | | | |
| | May | | | | | No image | | |
| | Jun | | | | 8600* | No image | Open - 28/06/2021 | |
| | Jul | | | | | No image | | >100days |
| | Aug | 6.6 | 2/08/2021 | | | No image | | |
| | Sep | | | 6/09/2021 | | No image | | |
| | Oct | | | | | No image | Open - 6/10/2021 | |
| | Nov | | | | | | | |
| | Dec | | | | | | | |

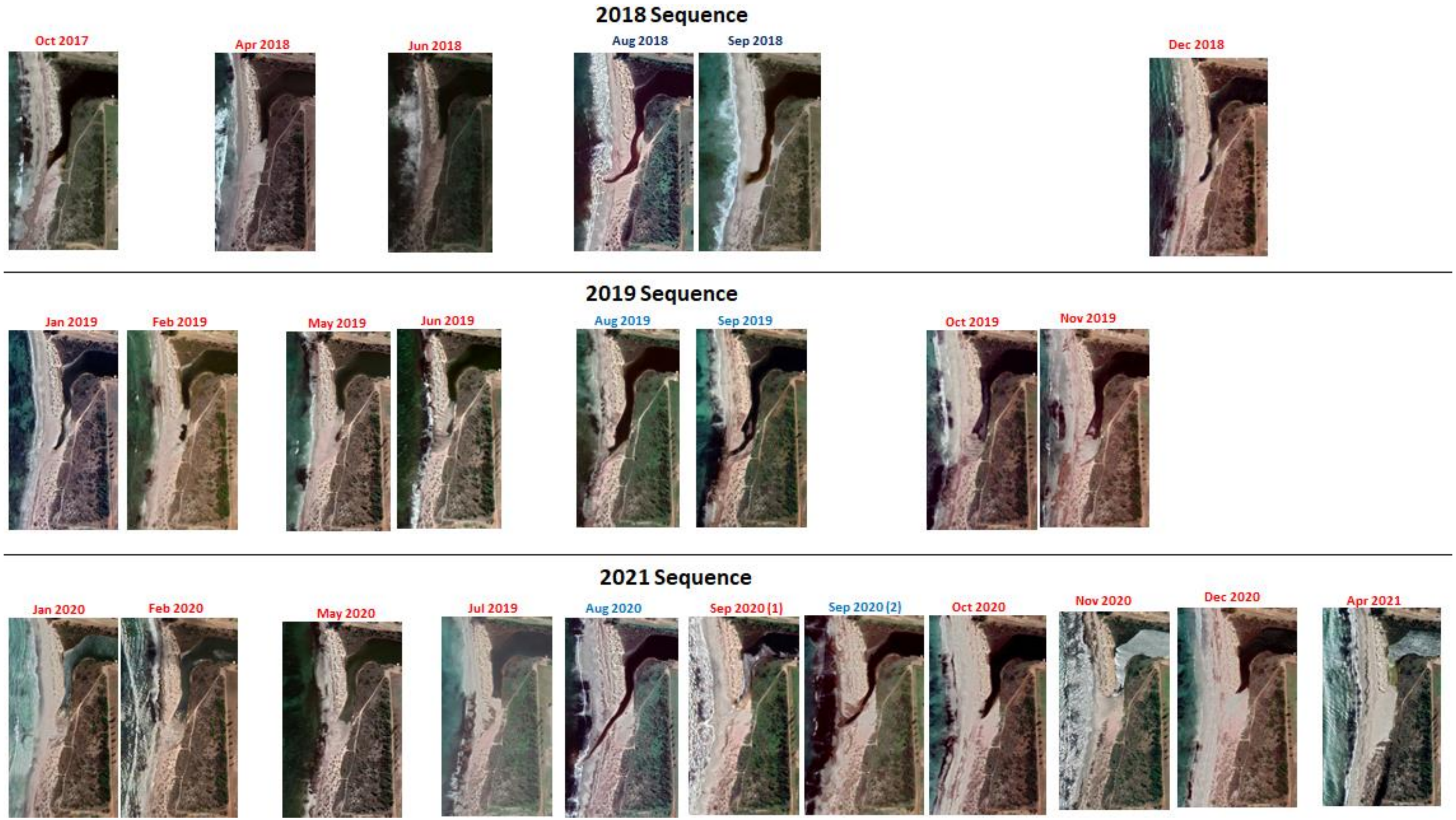


**Figure 2-7: Image Sequence showing seasonal behaviour at Chapman River mouth (source: Google Earth)**

Shoreline behaviour along the entrance bar and adjacent areas varies each year. There is a tendency for post winter sediment accumulation south of the channel mouth, apparently influenced by the nearshore reef system. This is subsequently redistributed north over summer months. This process will be interrupted by the proposed groyne.

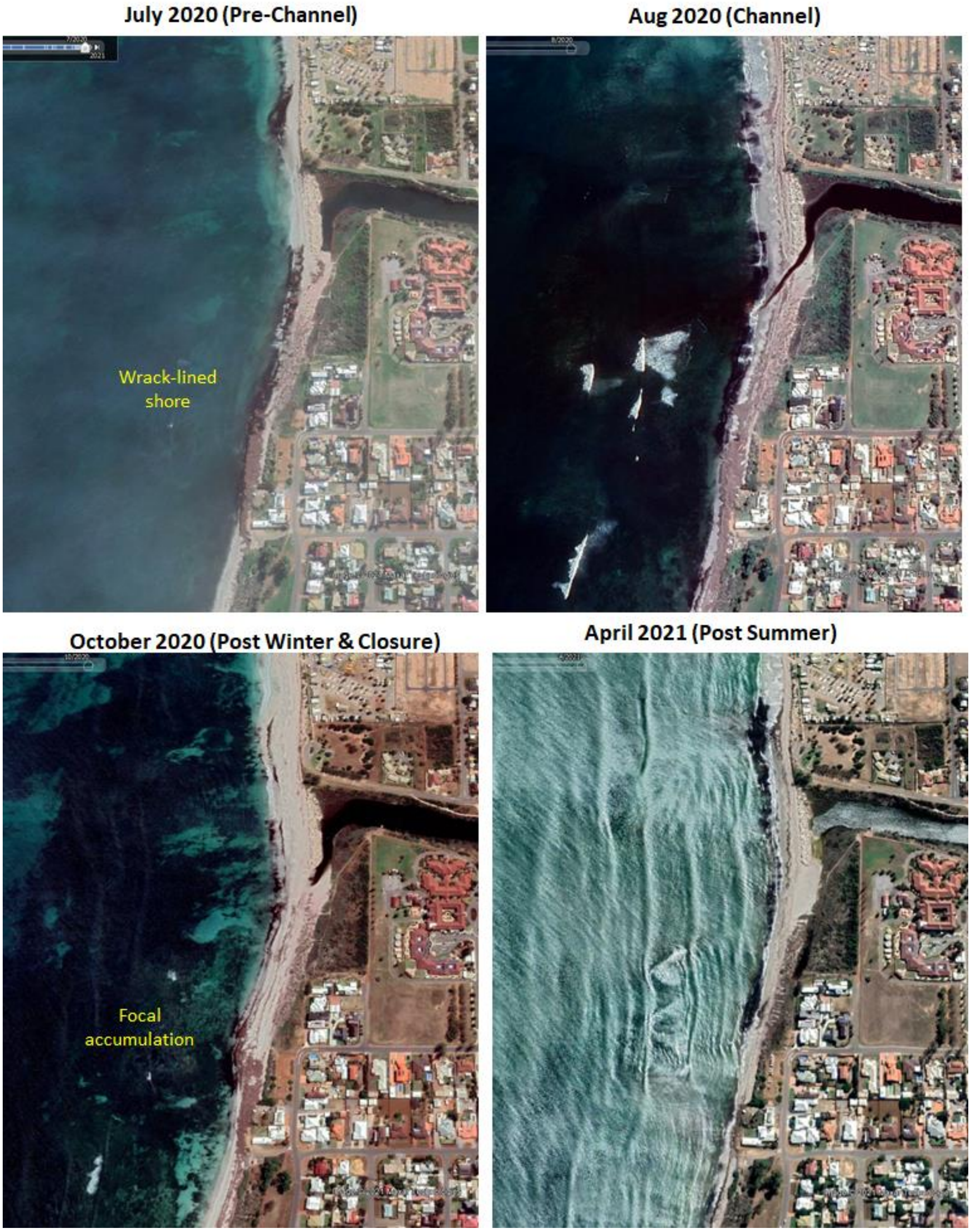


**Figure 2-8: Google Earth Imagery Sequences Showing Typical Seasonal Behaviour**

## 2.3. PROCESSES INFLUENCING CHAPMAN RIVER ENTRANCE

Processes likely to (separately) trigger opening and closing of Chapman River entrance have been interpreted based on historic and recent behaviour. A qualitative evaluation, considering timing of influential processes, describes seasonal pressures (Table 2-3).

- On a seasonal basis, the only mechanism causing channel opening is river flooding. This peaks though June to August.
- After opening, most of the conditions tending to enhance channel closure occur simultaneously during November to March, including both cross-shore and alongshore sediment transport. Once river flows have declined, the main process counteracting closure due to sediment movement is tidal exchange, provided flows are sufficient to keep the entrance scoured open (refer to Appendix B.5).

**Table 2-3: Seasonal Timing of Processes Influencing Channel Opening/Closure**

*Each process has been equally weighted, with a range from -2 to 2 corresponding on seasonal influence to open or close the channel entrance.*

<table>
<tr><th></th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td colspan="13">Key Seasonal Processes at Site</td></tr>
<tr><td>Typical Annual Flows</td><td colspan="2">-2</td><td>-1</td><td>0</td><td>1</td><td colspan="3">2</td><td>1</td><td>0</td><td>-1</td><td>-2</td></tr>
<tr><td>Flood Events</td><td colspan="2">-1</td><td colspan="2">1</td><td colspan="4">2</td><td>1</td><td>-1</td><td colspan="2">-2</td></tr>
<tr><td>Count (Peak: +2; Low: -2)</td><td>-3</td><td>-3</td><td>0</td><td>1</td><td>3</td><td>4</td><td>4</td><td>4</td><td>2</td><td>-1</td><td>-3</td><td>-4</td></tr>
<tr><td>Channel Opening Potential</td><td colspan="2"></td><td></td><td colspan="2"></td><td colspan="3">Peak</td><td></td><td></td><td></td><td>Low</td></tr>
</table>

<table>
<tr><th></th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td colspan="13">Key Seasonal Processes at Site</td></tr>
<tr><td>Typical Annual Flows</td><td>2</td><td>2</td><td>1</td><td>0</td><td>-1</td><td>-2</td><td>-2</td><td>-2</td><td>-1</td><td>0</td><td>1</td><td>2</td></tr>
<tr><td>Tide</td><td>-1</td><td>1</td><td>2</td><td>1</td><td>-1</td><td>-2</td><td>-1</td><td>1</td><td>2</td><td>1</td><td>-1</td><td>-2</td></tr>
<tr><td>MSL</td><td>0</td><td>0</td><td>0</td><td>-1</td><td>-2</td><td>-2</td><td>-1</td><td>0</td><td>1</td><td>2</td><td>2</td><td>1</td></tr>
<tr><td>Storm Surge</td><td>2</td><td>2</td><td>2</td><td>0</td><td>-1</td><td>-2</td><td>-2</td><td>-1</td><td>0</td><td>2</td><td>2</td><td>2</td></tr>
<tr><td>Total Wave Enegy - Onshore Transport (Berm Building)</td><td>2</td><td>2</td><td>2</td><td>0</td><td>-1</td><td>-1</td><td>-2</td><td>-2</td><td>-1</td><td>0</td><td>2</td><td>2</td></tr>
<tr><td>Gross Alongshore Transport Potential (north or south)</td><td>2</td><td>1</td><td>0</td><td>0</td><td>1</td><td>2</td><td>2</td><td>1</td><td>1</td><td>0</td><td>1</td><td>2</td></tr>
<tr><td>Count (Peak: >7; Low: <-5)</td><td>7</td><td>8</td><td>7</td><td>0</td><td>-5</td><td>-7</td><td>-6</td><td>-3</td><td>2</td><td>5</td><td>7</td><td>7</td></tr>
<tr><td>Channel Closure Potential</td><td colspan="3">Peak</td><td></td><td colspan="3">Low</td><td></td><td></td><td></td><td colspan="2">Peak</td></tr>
</table>

Seasonal pressures overlay substantial historic state shifts in the condition of Chapman River entrance bar, which has switched from a seasonal feature (river flow-dominated) to a vegetated dune, which has subsequently been subject to progressive erosion (ocean-dominated).

# 3. Assessment of Groyne Impact on Chapman River

Placement of the proposed groyne south of Chapman River entrance potentially modifies coastal dynamics influencing closure of the entrance channel. The most significant effect is introduced by any change to alongshore sediment transport (see Appendix B.3), with a reduction of transport potentially reducing the tendency for the river entrance to close. Notably, installation of a groyne will have limited influence on cross-shore sediment transport (see Appendix B.4), which contributes to seasonal closure – but there is insufficient information available to determine its importance compared to alongshore transport.

## 3.1. INLET STABILITY ASSESSMENT

Assessment of potential effect of installing a groyne south of Chapman River on entrance bar stability has been undertaken by considering the potential change to alongshore sediment transport and corresponding change to tidal inlet stability.

Effects of installing a groyne include intercepting a portion of alongshore sediment transport on the updrift side of the groyne (in this case on the south side) and realignment of the shoreline, locally modifying alongshore transport rates. The proportion of alongshore sediment transport trapped by the groyne reduces as the updrift storage area fills in, with much of the incoming sand supply eventually able to bypass the groyne as it becomes 'saturated'. Relative effectiveness of the groyne to bypass once the groyne is 'filled' is controlled by seasonal variation of the updrift storage volume.

Evaluation of wave-driven alongshore transport is outlined in Appendix B.3. Evaluation of seasonal wave variation suggests a 'stable' shore alignment [1] range of 8$^{o}$ occurs over a year, with an anti-clockwise rotation during winter (i.e. a groyne will hold less sediment on its south side). Released sediment is dispersed along the shore by high energy wave conditions.

Two main consequences of sediment storage by a groyne and its variability are:

- Initial storage volume should be matched by capital nourishment, otherwise it will cause downdrift erosion. For the estimated alongshore transport rates of 5,000-10,000 $m^3$/yr, it would take approximately 1 year to fill a groyne projecting 20-30m from the shore. A groyne projecting 40m from shore would take 2-4 years to fill without nourishment.
- Variation of sediment storage causes downdrift erosion. For a groyne projecting 20-30m from the shore, 1,200-2,900 $m^3$/yr of alongshore transport would be trapped in the groyne's storage cycle. A groyne projecting 40-55m from shore may effectively intercept the entire sediment supply, although this will cause net shoreline accretion on the updrift side and consequently its influence would reduce over time.

[1] This is a notional alignment, at which there would be net zero alongshore sediment transport.

The required length of the proposed groyne is not presently defined. However, its objective is to offset erosion pressure, primarily associated with projected sea level rise, for the housing and carpark between Frederick St and Fuller St, an alongshore distance of 300m. The required trapping length is approximated by:

$$L_G = L_A \times (\tan \phi'/2)$$

Where $L_A$ is alongshore length and $\phi'$ is the rotational angle to match the net zero alongshore transport angle. For the derived nearshore wave climate, this is 110m. Adding a distance of 25m for the 'root' of any groyne at the beach, indicating one very long groyne (135m), two long groynes (70m), three moderate length groynes (60m), or a set of five shorter groynes (50m). All options have an equivalent updrift storage volume, but they have different efficiency to intercept alongshore transport, with the shorter groynes experiencing greater bypassing. This means that for a field of shorter groynes, there is less impact on the downdrift zone (e.g. Chapman River mouth), but that a greater volume of ongoing sand supply would be required to maintain coastal position to the south.

**Table 3-1: Influence of Groyne Field on Alongshore Transport**

| **# of groynes** | 1 | 2 | 3 | 5 |
|---|---|---|---|---|
| **Groyne Length** | 135m | 70m | 60m | 47m |
| **Initial Trapping Efficiency** | ~100% | ~75% | ~40% | ~25% |
| **Initial Downdrift Supply Deficit** | 5,000-10,000 $m^3/yr$ | 3,700-7,500 $m^3/yr$ | 2,000-4,000 $m^3/yr$ | 1,200-2,500 $m^3/yr$ |
| **Estimated Updrift Nourishment *** | 0 $m^3/yr$ | 1,200-2,500 $m^3/yr$ | 3,000-6,000 $m^3/yr$ | 3,700-7,500 $m^3/yr$ |

* Updrift nourishment is based solely on balancing alongshore transport rates. This does not address the effects of storm losses, or longer-term erosion due to projected sea level rise.

The effect of downdrift supply deficit due to the groyne will only be partly transferred to Chapman River entrance, as outside the shelter of the groyne, the full alongshore transport will be reached. The spatial gradient of alongshore supply will cause downdrift erosion on the north side of the proposed groyne field, with a slowing rate of erosion as the trapping efficiency of the groyne field reduces. To estimate potential effect on Chapman River entrance bar, it has been *assumed* that the proposed groyne will reduce alongshore sediment transport by 50% - the reduction would be influenced by structure design.

Simulation of the tendency for the channel entrance to open or close has been undertaken using a 'deterministic' approximation for tidal prism and a 'random' approximation for daily alongshore transport, considering seasonal variation in wave energy and direction (Figure 3-1). The ratio of tidal prism to alongshore transport (approximations) has been used to characterise the tendency for tidal inlet opening or closing (see Appendix B.5). It is noted that this 'tendency' does not directly govern behaviour, as river flow is the key mechanism driving opening, and once an estuary entrance has closed, it does not experience tidal exchange. In addition, cross-shore processes may also create a tendency for closing the inlet.

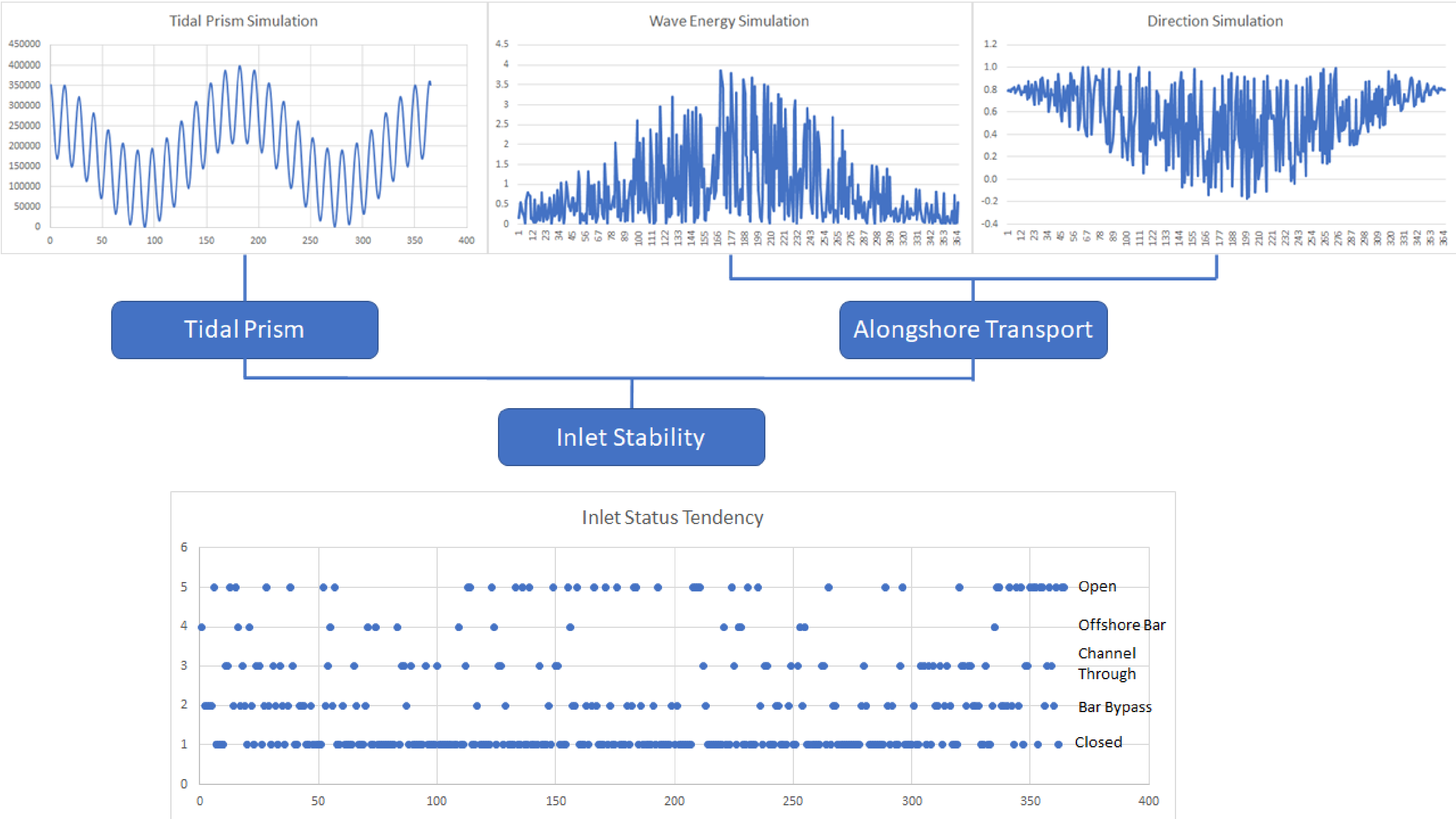


**Figure 3-1: Components of Entrance Stability Simulation**

**Outcomes**

Simulation of how the proposed groyne may affect Chapman River entrance have been evaluated through comparison of tidal inlet tendencies (towards open or closed) with undisturbed alongshore transport (Figure 3-2) or with a 50% reduction to transport (Figure 3-3).

Simulations suggest frequent switching between a tendency to open or close under tide-only conditions (i.e. when river flow doesn't keep the channel open), as well as seasonally variable tendencies. Strong closure tendencies occur during autumn and spring when the smallest tides occur.

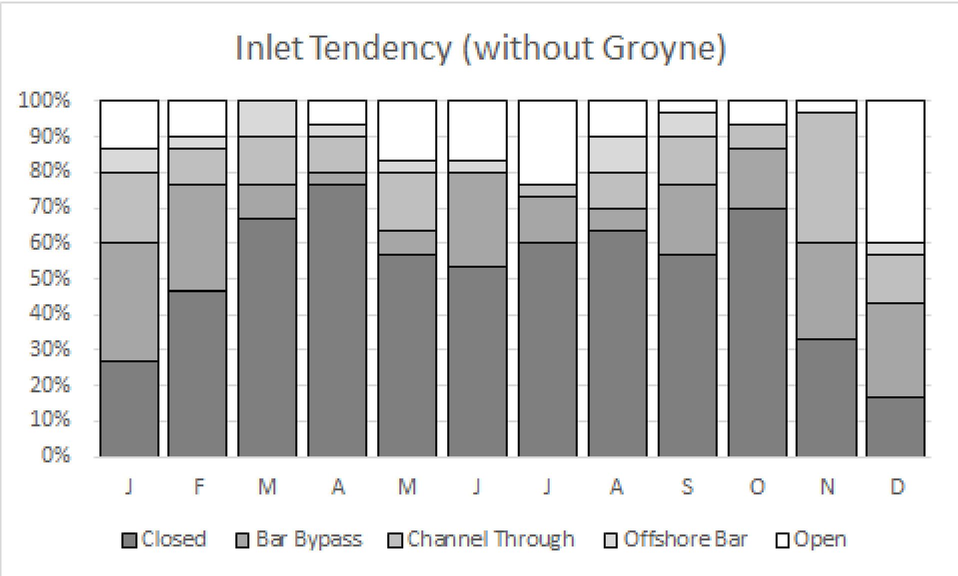


**Figure 3-2: Inlet Tendency Due to Tide and Alongshore Transport Simulation for 10,000 m$^3$/yr alongshore transport**

Reduction of the alongshore sand supply, following installation of a groyne, increases the tendency for the tidal inlet towards staying open and reduces the tendency toward closure. For a 50% reduction in transport, opening conditions are twice as frequent and closing conditions are half as frequent. However, as tidal exchange reduces if the channel narrows and ceases once the channel is closed, the influence of days with a tendency to close is greater than the influence of days with a tendency to open. Neap tide days continue to tend towards closure under typical rates of alongshore transport. Consequently, historic behaviour of the Chapman River entrance to be open while the river flows and to subsequently close within one or two neap-tide tidal phases is expected to continue. Overall, the proposed groyne may marginally increase exposure of the Chapman River estuary to marine conditions.

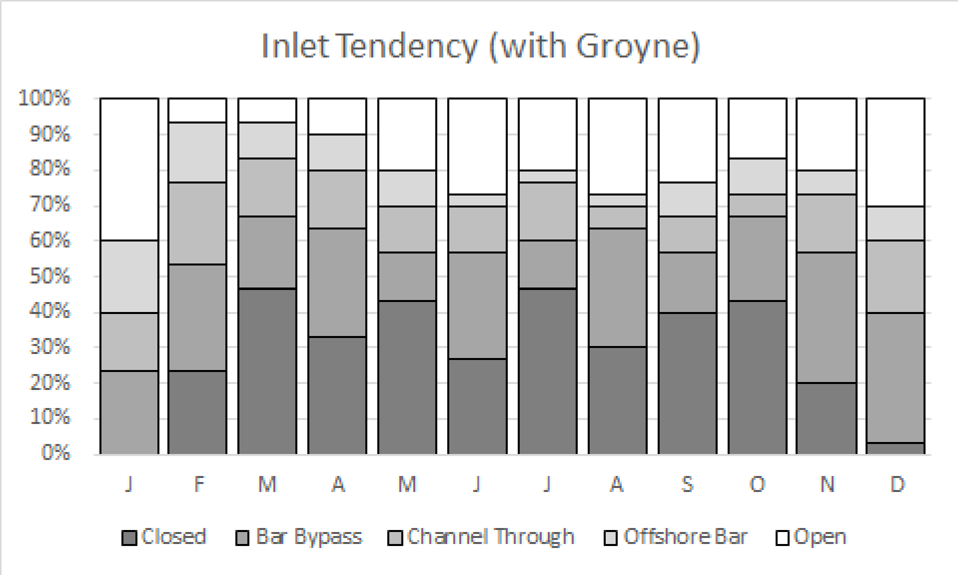


**Figure 3-3: Inlet Tendency Due to Tide and Alongshore Transport with Groyne A reduction of 50% alongshore sand supply has been *assumed***

## 3.2. IMPACT OF GROYNE ON COASTAL DYNAMICS

In addition to modification of alongshore sediment supply, installation of the proposed groyne will modify the wider-scale coastal dynamics. Over the last 30 years, Geraldton foreshore between Beresford and north Sunset Beach has experienced a substantial rate of erosion (Figure 3-4), partly due to modification of alongshore sediment supply due to installation of Geraldton Port structures from the 1920s and Batavia Coast Marina structures from the 1980s, and partly due to changing conditions, including substantially reduced river flow.

Erosion indicates a deficit between the sediment supply coming into an area and that leaving it. The area experiencing erosion between Beresford and north Sunset Beach is acting as a source of sediment, supplying the naturally occurring alongshore transport. Installation of a groyne at Bluff Point will divide the area of erosion in two. Consequently, sand supply to the area north of the proposed groyne is likely to be impeded.

Using historic rates of shoreline retreat as a guide [2], splitting the erosion area is likely to result in approximately 40% increase to the future rates of erosion. A greater relative response is anticipated to occur immediately updrift of the groyne, with erosion rates at Chapman River mouth estimated to increase from around 1.2m/yr to 1.8-2.4m/yr. This represents a substantial negative impact on stability of the entrance bar.

[2] The focal point of erosion has been progressively moving southwards, making this likely to be an underestimate.

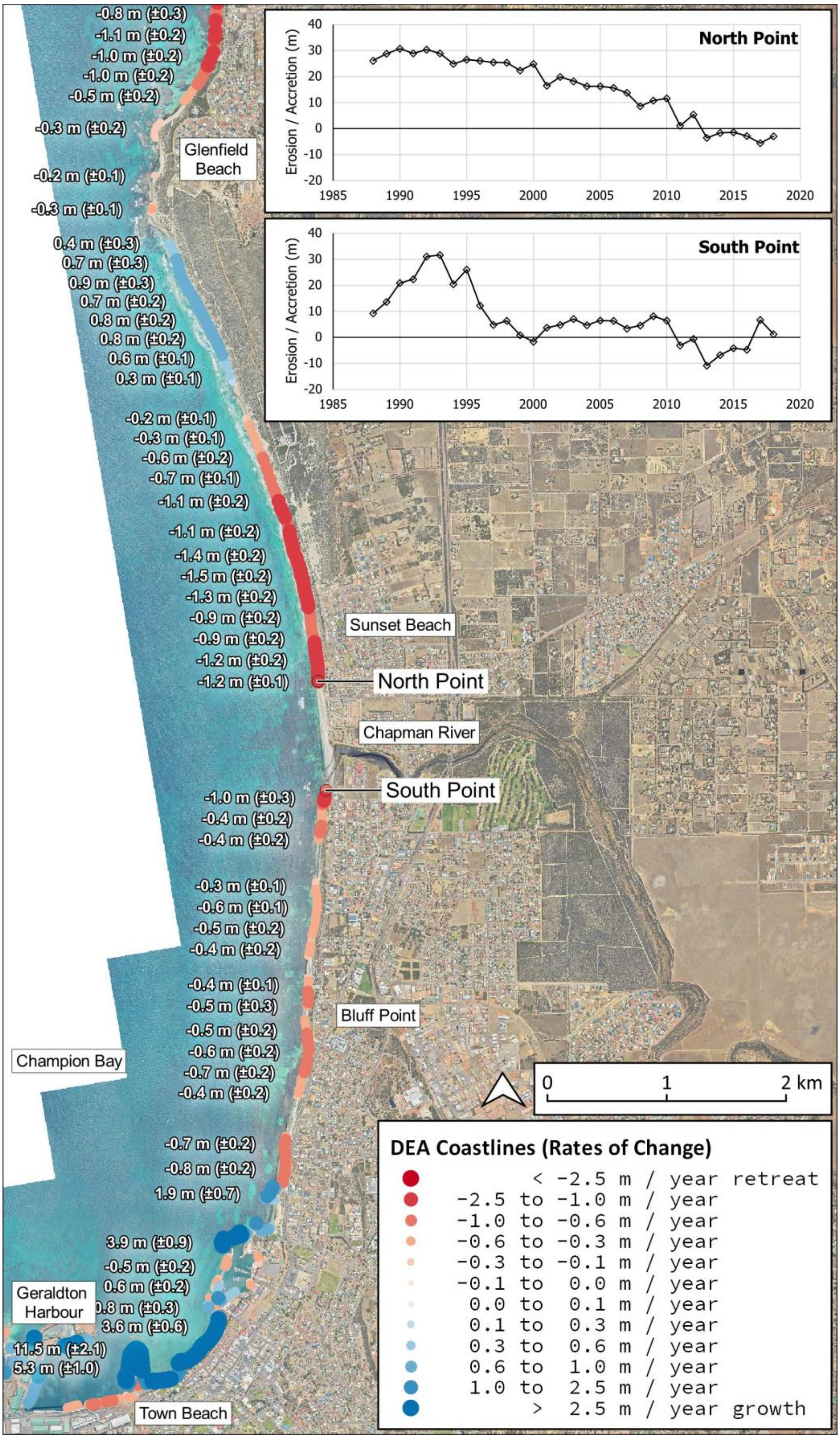


**Figure 3-4: Geraldton North Rates of Shoreline Change Between 1988 to 2018 From Digital Earth Australia Coastlines (Bishop-Taylor *et al*. 2021)**

# 4. Conclusions and Recommendations

Chapman River entrance has experienced a series of state changes:

- Prior to 2004, relatively higher river flow conditions determined that the entrance bar was low elevation, subject to overflow, deflation and wave overwash.
- From 2004 onwards, the bar transitioned into dune behaviour, with permanent vegetation supporting growth.
- The bar has subsequently been subject to coastal erosion from 2010, as a southward extension of the wider erosion trend which has dominated Sunset Beach area since around 2000.

Seasonal behaviour of the river entrance includes a tendency to open in response to river flow and close a few weeks after flow has tailed off, particularly once alongshore (and cross-shore) sediment transport is able to overwhelm the scouring effect of tidal exchange through the entrance.

Installation of a groyne at Bluff Point is anticipated to modify the alongshore sediment transport behaviour. This has potential to marginally increase the time the entrance channel stays open once winter river flows cease.

Installation of the proposed groyne is expected to reduce sediment supply to the Sunset Beach coast. This effect can be partly offset through initial placement of renourishment sand to 'saturate' the proposed groyne, but some fraction of the existing alongshore supply will be reduced, and the area south of the proposed groyne will no longer act as a sediment source. This will accelerate the historic erosion trend north of the proposed groyne and is anticipated to cause 1.8-2.4 m/yr erosion at the mouth of the Chapman River.

Relative behaviour is determined by groyne length and placement:

- A longer groyne creating a larger tendency for ongoing downdrift erosion.
- Locating the groyne further south reduces the size of groyne required and will move downdrift erosion effects away from the Chapman River mouth.

Although it is possible to reduce downdrift erosion using a field of smaller groynes, this will reduce effectiveness for the objective to enhance stability of the shore south of the proposed groyne.

Overall, it is not recommended to conduct the proposed groyne as suggested, or to replace with a groyne field as:

- Structures at Bluff Point will accelerate erosion between Chapman River and north Sunset Beach.
- Chapman River entrance bar was formed through a discrete development phase and has subsequently been exposed to ongoing erosion pressure. Installing a stabilization structure at Bluff Point will accelerate the loss of this bar.

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# Appendix A Meteorologic & Oceanographic Drivers

Meteorologic and oceanographic records have been assessed for key seasonal and inter-annual processes likely to affect behaviour of the river entrance and determine potential influence of the proposed groyne. Relevant datasets and instrument locations are summarised in Table A-1 and Figure A-1.

**Table A-1: Metocean Records for the Geraldton Region**

| Type | Location | Station Number | Depth/ Elevation | Data Start | Data End | Source |
|---|---|---|---|---|---|---|
| **Waves** | Geraldton Outer Channel Directional WRB | N/A | −16.3m | 20/06/2014 | 20/09/2021 | MWPA |
| | Geraldton Outer Channel Non-Directional WRB & AWAC | | | 1/03/1999 | 22/09/2021 | |
| | Chapman River Non-Directional WRB | | −13.3m | 5/08/2000 | 18/01/2001 | |
| **Waves/ Currents** | Geraldton Beacon 1 AWAC | | −15.8m | 30/10/2010 | 21/09/2021 | |
| | Geraldton Beacon 2 AWAC | | −16.6m | 2/12/2011 | 21/09/2021 | |
| **Wind** | Geraldton Airport Met. Station (Decommissioned) | 8051 | 33m | 18/08/1941 | 20/06/2014 | BoM |
| | Geraldton Airport Met. Station (Active) | 8315 | | 20/07/2011 | 14/01/2021 | |
| **Water Levels** | Geraldton Tide Gauge | 62290 | | 1/01/1966 | 31/12/2020 | DoT |
| **River** | Chapman River Utakarra River Gauge | 701007 | | 12/03/1976 | 18/09/2021 | DWER |

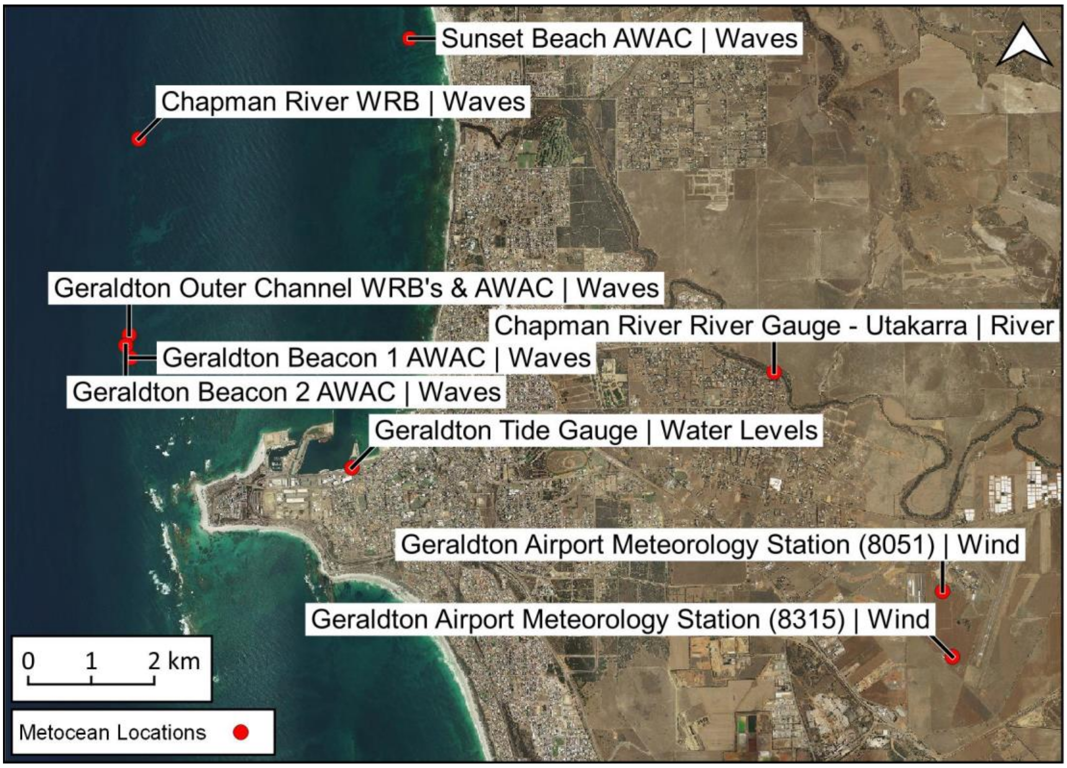



**Figure A-1: Metocean Instrument Locations**

## APPENDIX A.1 WINDS

The Commonwealth Bureau of Meteorology maintains long-term wind observations at Geraldton Airport, approximately 8km inland, with a ground elevation of 33m. This has included a station active from 1941 to 2014 (BOM Station 8051), with the present station installed in 2011 (BOM Station 8315). Mid-West Ports Authority has recorded over-water winds at the Outer Channel site since 2004.

Wind speed and direction frequencies derived from the active Outer Channel site demonstrate the coastal wind climate at the site (Figure A-2). The winds are dominated by one of the most energetic sea breeze systems in the world, which contributes the prevailing net northward sediment transport regime along the coast. Sea breezes in the region are characterised by wind in a predominantly alongshore direction (south to southwest), typically measured at the Airport in a 22.5° band width at 180°N. They begin to establish in October extending through to April, and peaks in December to February when around 60% of all wind observations occur from the south to south-west.

During winter months, the sea breeze system weakens under cooler conditions and winds become more variable. Typical winds include 'offshore' northeast winds associated with high pressure ridges, and strong winds from the westerly half during occasional winter storms, often swinging from southwest through to northwest during storm passage.

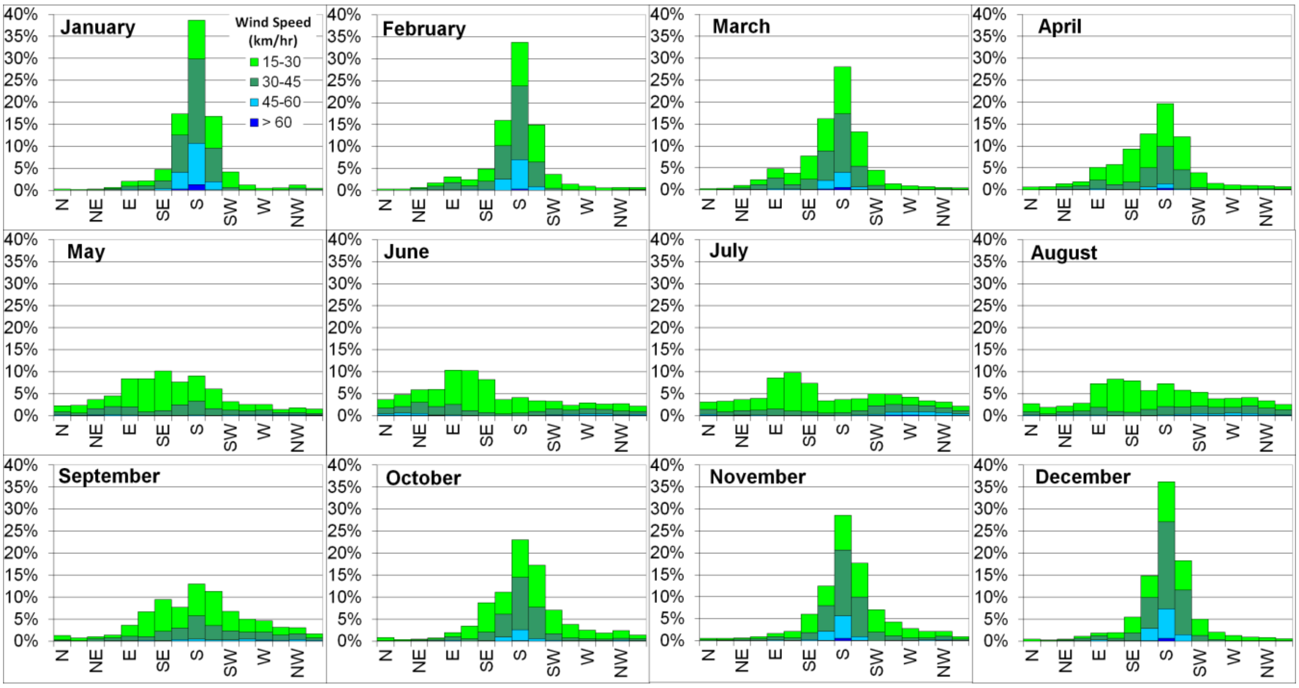



**Figure A-2: Monthly Wind Speed and Direction Frequencies (Outer Channel)**

Long-term variability in the onshore wind climate has been evaluated by considering 'summer' and 'winter' directional frequencies for each year in the long-term Bureau of Meteorology record. This demonstrates:

- Southerlies (S or SSW winds) are dominant throughout summer (Figure A-3). Southerly incidence includes cyclic variation (irregular, but approximately 20-year cycles) and some year-to-year variation. The most recent phase of greater southerly dominance occurred in the 1990s, with subsequent behaviour being variable between years. Incidence of winds in the 180° band (169°-191°N) progressively increased from the 1985 to 2013, which corresponds to a general transition from El Niño to La Niña dominance, although intermediate periods of strong La Niña (1995-1996, 1999-2000, 2008) were not associated with increased 180° winds.
- Wind directions are widely distributed during winter, with year-to-year variability, and limited cyclic behaviour (Figure A-4). Years with increased north-northwest wind incidence occur intermittently, including 1995 and 2011-2013, which were La Niña years, with relatively lower incidence of northwest winds over 2015-2021.

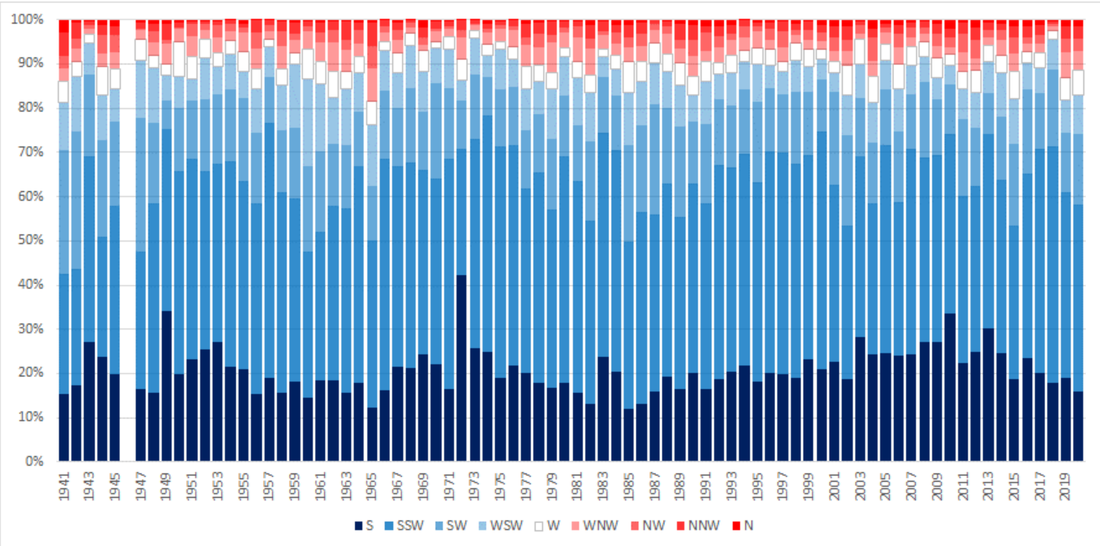



**Figure A-3: Summer Onshore Wind Distribution**

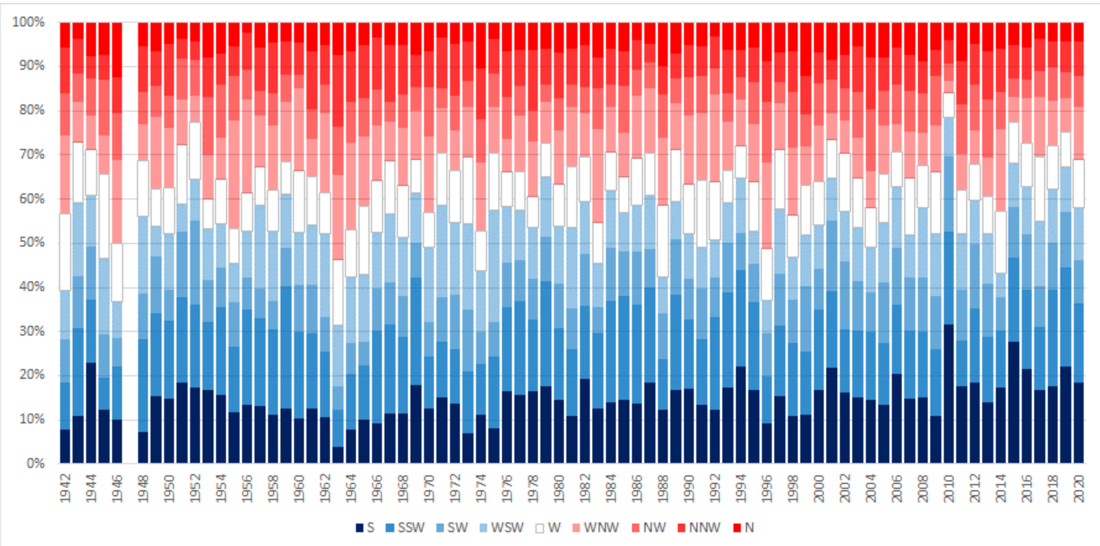



**Figure A-4: Winter Onshore Wind Distribution**

## APPENDIX A.2 WATER LEVELS

Water levels influence the height at which forces act on the beach and the degree of wave attenuation to the shore in the lee of reef systems and Islands. Digital water level observations are available from the Geraldton tide gauge since 1966 (Figure A-5). Key water level processes evident include tides, atmospheric surges, resonant phenomena, seasonal and inter-annual mean sea level variations.

Tides are mainly diurnal with a microtidal range of 1.2 m from LAT to HAT (DoT 2019). The tidal sequence is affected by monthly spring-neap cycles, bi-annual cycles with solstitial peaks in June and December. Due to the mainly diurnal tides, the 18.6-year lunar nodal cycle is influential in this region, affecting annual tide range by almost 20% (Eliot 2011). There is negligible influence from the lunar perigean cycle, which causes a 4.4 year subharmonic modulation of semi-diurnal tides, which are small in Geraldton.

**Table A-2: Tide Planes at Geraldton (DoT 2019)**

| Datum | HAT | MHHW | MLHW | MSL | MHLW | MLLW | LAT |
|---|---|---|---|---|---|---|---|
| m CD | 1.26 | 1.01 | 0.86 | 0.64 | 0.41 | 0.27 | 0.07 |
| m AHD | 0.71 | 0.46 | 0.31 | 0.09 | -0.14 | -0.28 | -0.48 |

Larger and more frequent surges occur in June to July during passage of winter low pressure systems and cold fronts. Infrequent surges may occur outside this period due to more unusual meteorological events, such as Tropical Cyclone Glynis in 1970 and 2004 Boxing Day tsunami.

The 30-day running mean shows seasonal and inter-annual variation each up to around 30cm, with relative high influence at Geraldton due to the small tidal range. Significantly, there have been two recent periods of unusually high mean sea levels in 1999-2000 and 2011-2013 linked to La Niña phase of the El Niño-Southern Oscillation cycle, correlated to the strength of the Leeuwin Current (Haigh *et al.* 2011). Transition from the El Niño phase in the 1990s to La Niña phase by 2013 created an accelerated period of mean sea level rise (White *et al*. 2014). High mean sea level in 2011-2013 in particular contributed to a succession of high water level events. A shift to neutral or El Niño conditions since 2013 has resulted in a drop in mean sea levels, with a low around 2015.

Overall, seasonal water level climate is characterised by a relatively narrow period of elevated water levels from late May to July, when peaks in seasonal mean sea levels, bi-annual tidal peaks (in June and December) and winter storm surge are all in phase (Figure A-6). Lowest water levels typically occur around October to November.

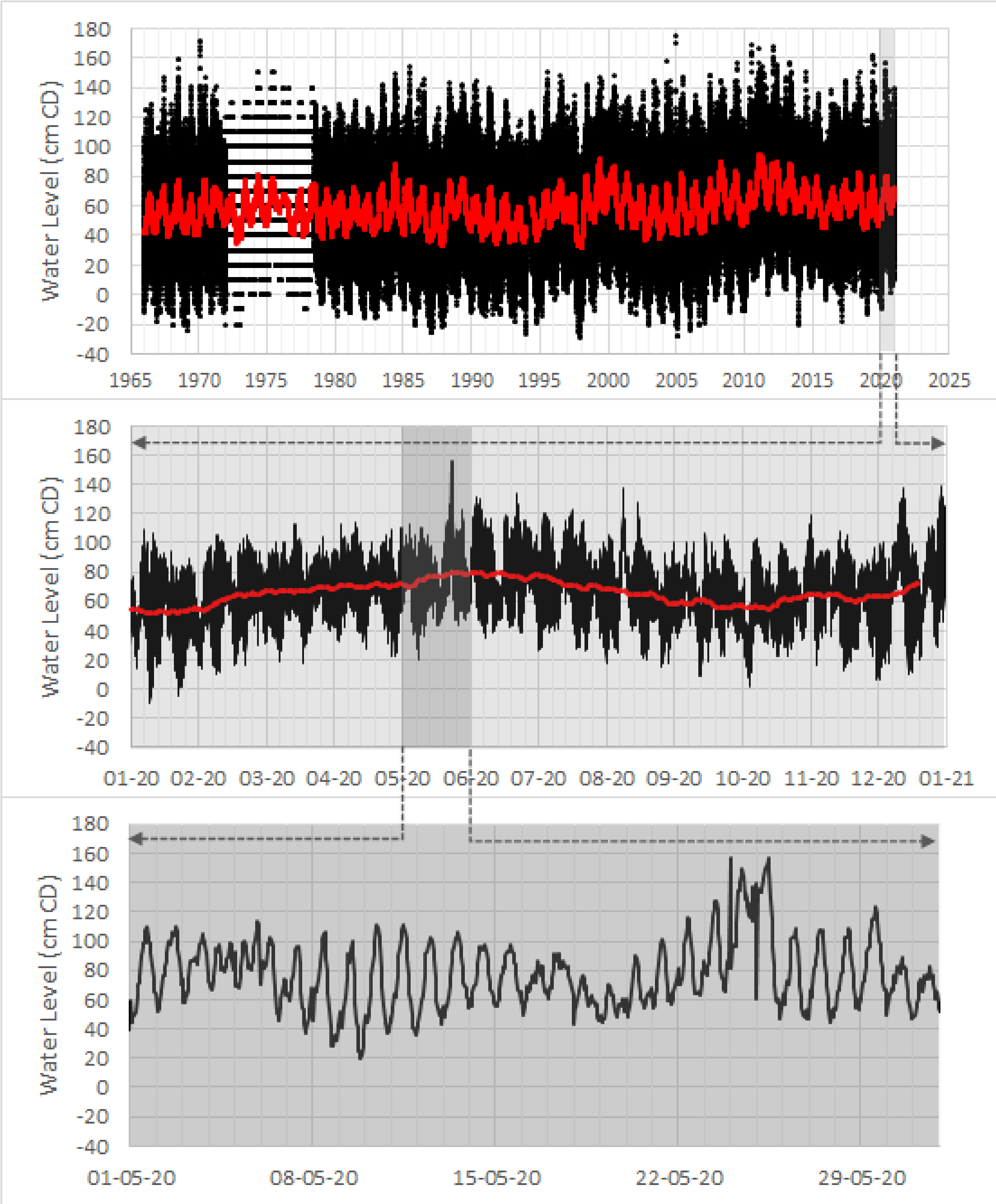



**Figure A-5: Observed Water Levels at Geraldton**

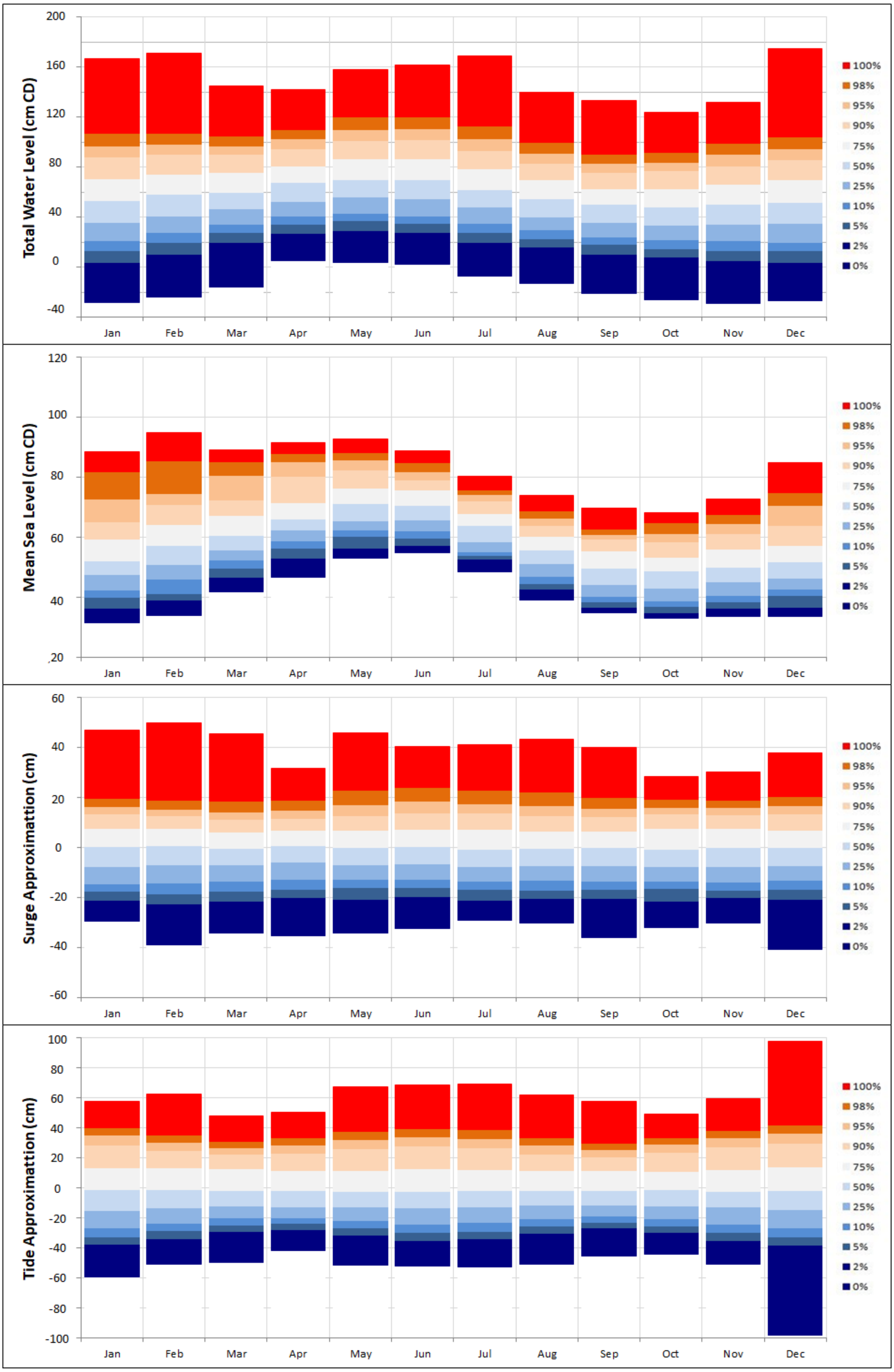



**Figure A-6: Seasonal Variation of Key Water Level Processes**

## APPENDIX A.3 WAVES

Waves are an important driver of sediment dynamics and landform variability along Geraldton coastline. The inshore wave climate in the region is heavily modulated from offshore conditions by wave damping and redirection due to wave breaking, refraction, diffraction, and frictional losses over Houtman Abrolhos archipelago. The degree of damping increases as offshore waves approach with a more westerly direction.

Wave conditions have been measured over a range of instrument deployments at Geraldton, with long-term deployments at the 'Outer Channel' by Mid-West Ports Authority used to describe Geraldton wave climate. This site is located on the north side of Point Moore, at the end of the Outer Channel at a depth of −16.6m AHD. Its position is outside the effects of nearshore reef systems, or shelter by Point Moore, with limited variation of bed contours to affect refraction. Inshore, the effects of reefs, sheltering from Point Moore and bed contours cause substantial spatial variability of waves reaching the shore, with alongshore sediment transport further significantly influenced by shoreline orientation.

Four key wave sources have been identified (Figures A-7 and A-8), summarised in Table A-3. Difference between offshore measurements and wave conditions along Geraldton coast are expected due to:

- Complex wave dissipation across a relatively wide and variable nearshore reef system. The nearshore reef system acts to reduce incident wave height and modifies wave direction. This process is highly dependent on coincident water levels, with shallower conditions causing wave crests to align almost parallel to the shore and greater dissipation of energy due to wave breaking.
- Shelter provided by Point Moore, particularly during south to southwest wave conditions.
- Wave shoaling and damping due to depth effects.

**Table A-3: Key Wave Sources for Geraldton Region**

| Source | Direction | Timing | Heights | Alongshore Transport Potential |
|---|---|---|---|---|
| **Prevailing Southern Ocean swells** | Narrow band, from SW to WSW. | Peaks in Jun to Sep | Typically <4m Max. 5.4m in Aug-2018 | Northward, but locally modified by sheltering/reef effects |
| **Winter westerly waves** | SW to NW | Peaks in May to Sep | Typically <3m | Both directions |
| **Locally generated short period seas** | South to south-west | Peaks in Nov to Feb | Typically <2m | Northward |
| **Tropical cyclone** | Variable | Rare events | Variable | Variable, but often southward (e.g. TC Seroja) |

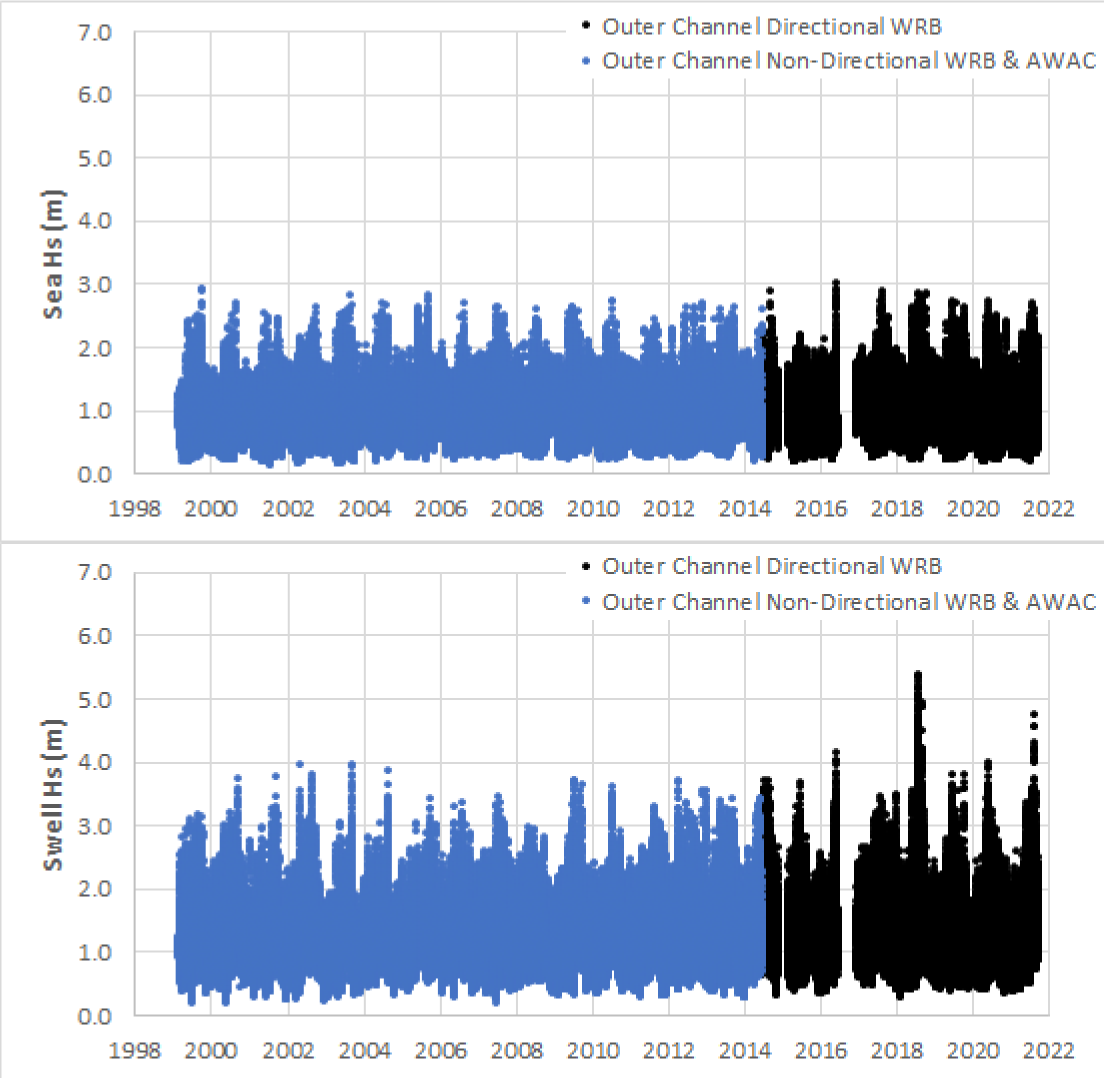



**Figure A-7: Timeseries Showing Sea and Swell Wave Heights at Geraldton (Offshore)**

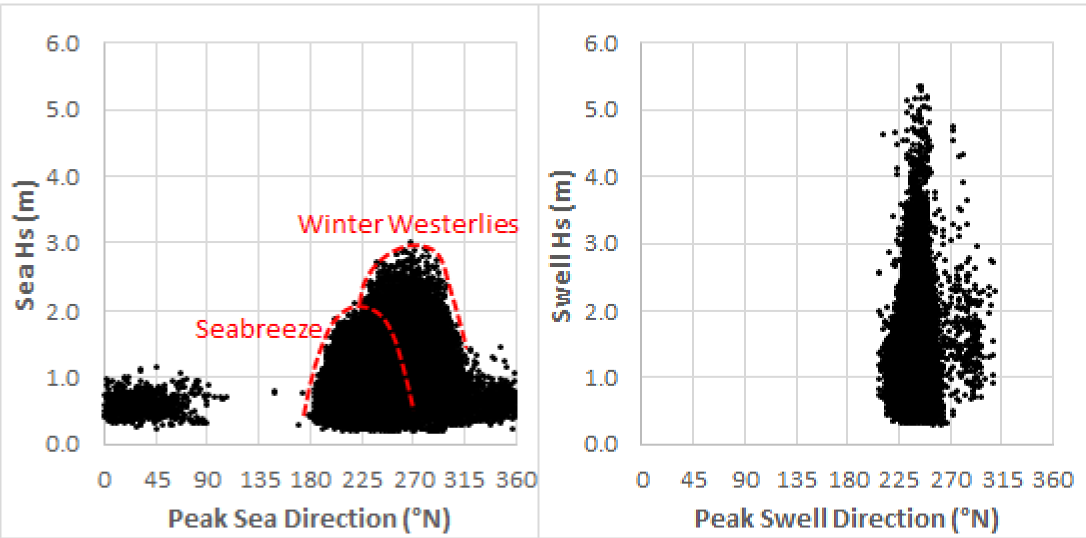



**Figure A-8: Sea and Swell Wave Height Versus Direction**

The Outer Channel WRB directional sea and swell record has been assessed to identify seasonal and year-to-year variability of the directional wave climate. This has involved approximating wave energy within 22.5° bands, by squaring the significant sea and swell wave height [3]. Average monthly directional sea and swell energy shows typical seasonal variability (Figure A-9), including:

- Onset of prevailing SSW-SW sea waves from October extending through to March/April, peaking in December/January. These conditions are associated with seabreezes.
- More variable sea direction between May to September, when winter storms can produce seas from SSW through to NW.
- Prevailing SW-W swell throughout the year, but with elevated energy and greater westerly component from May to October, peaking in July.

Sea and swell wave energy from the southwest quadrant are dominant throughout the year, creating a prevailing northward sediment transport regime along the coast. Transport potential is almost exclusively northward from October through to April, with occasional southward transport potential during northwest seas and swells between May to September.

The peak in wave energy occurs during elevated swell conditions in July. This coincides with relatively high seasonal water levels which allows for greater wave propagation across nearshore reefs (i.e. due to increased water depth).

[3] Wave Energy is proportional to $Hs^2$

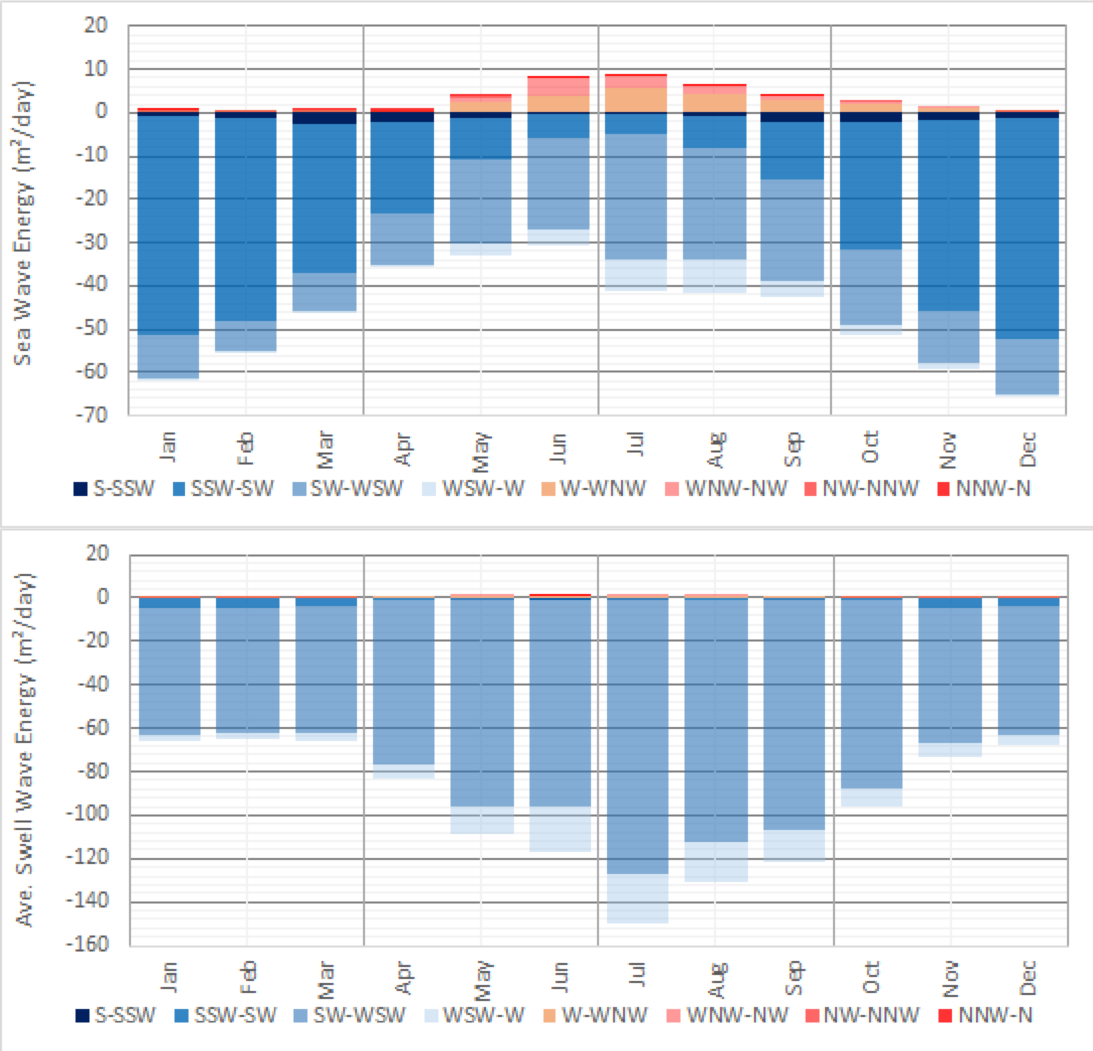
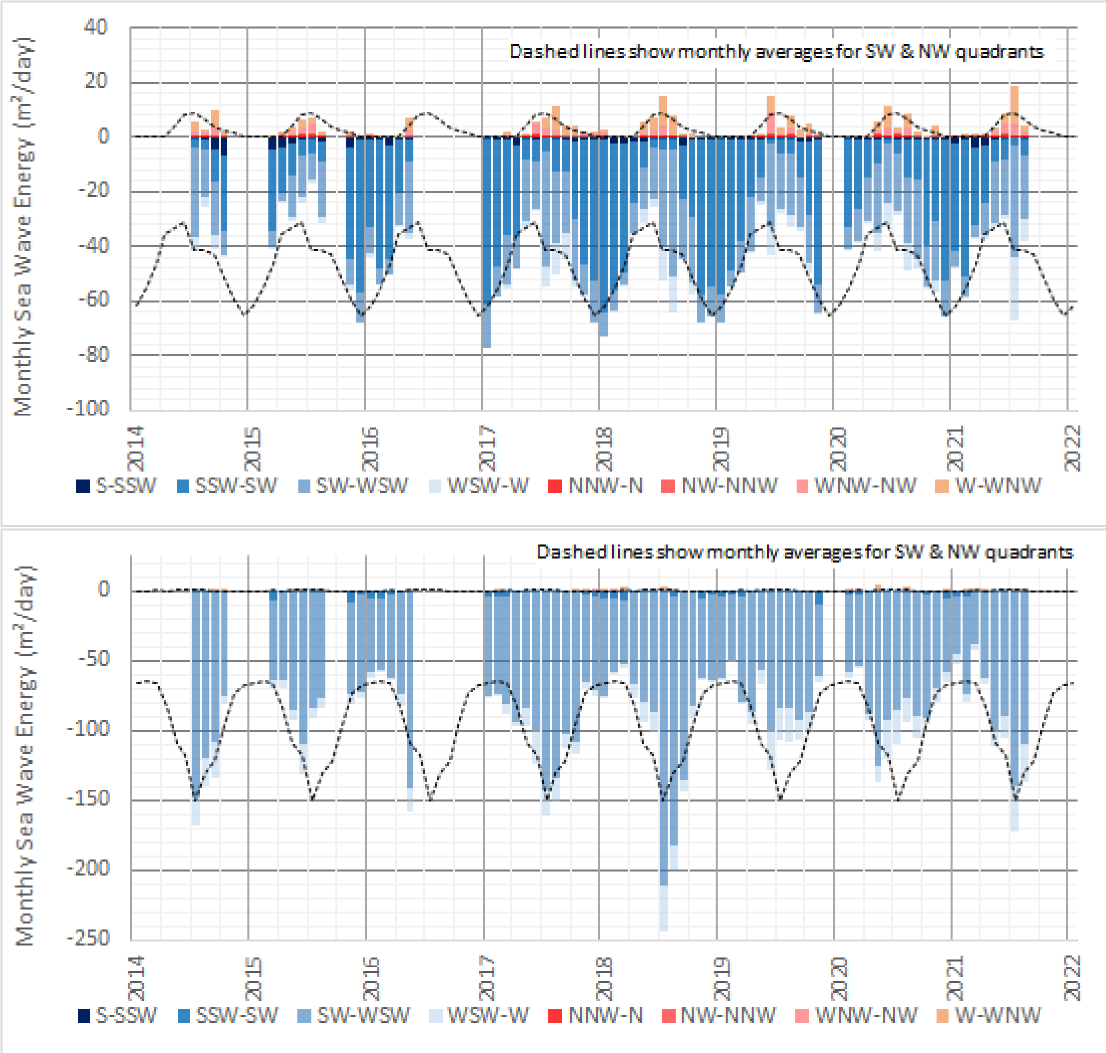



**Figure A-9: Average Seasonal Sea (Top) and Swell (Bottom) Wave Energy**

Variation of directional sea and swell energy over the available record has been considered through comparison of monthly average wave energy and the directional distribution for each month where data return was greater than 80% (Figure A-10). Anomalistic periods identifiable in the record include:

- Elevated southerly seas around January 2017 and January 2018, characteristic of strong sea breeze conditions.
- Reduced southerly seas in September 2019 suggesting extended ‘winter’ conditions.
- Elevated northerly seas in 2018, 2019 and 2021 winter periods.
- Elevated southerly swells July to September 2018.
- Reduced southerly swells in 2019 and 2020 winter periods.




(1) Only months with >90% data return shown.

**Figure A-10: Monthly Seasonal Sea (Top) and Swell (Bottom) Wave Energy**

## APPENDIX A.4 CHAPMAN RIVER FLOODING

Chapman River is 105 km in length with a basin extending to the northeast. The mouth of the river, positioned on the north side of the proposed groyne, is intermittently closed with a sand bar providing a barrier to the ocean. The mouth generally opens through breaching of the sand bar during peak winter flows, particularly coincident with high tide. When open, the estuarine reach extends approximately 1.5 kilometres upstream (WRC 2001).

Chapman River discharge and stage level has been measured by DWER since 1976 at Utakarra gauging station, located approximately 10 km upstream from the mouth. These records show it is subject to highly variable flow conditions (Figure A-11), with extended periods of low flow and short periods of intense flow during flood events. Flood events can carry suspended sediment load to the coast, and in strong flows, scours the river mouth, releasing sediments accumulated in the sand bar.

Major floods of Chapman River were reported in 1888, 1934, 1939, 1960, 1971, 1986, 1996, 1999 (Department of Agriculture 2005, Shire of Chapman Valley 2008), with the 1971 flood levels exceeding the 1999 levels. July 1996 and May 1999 (Figure A-12) represent standout flood events that have been measured, with three more moderate floods in the 1970s and 1980s. Since the 1999 flood, there has been an extended period with an absence of flood events, with the no discharge exceeding 20m$^3$/s or stage level above 1.2m. This is consistent with behaviour observed for other rivers on the south-west and mid-west of Western Australia.

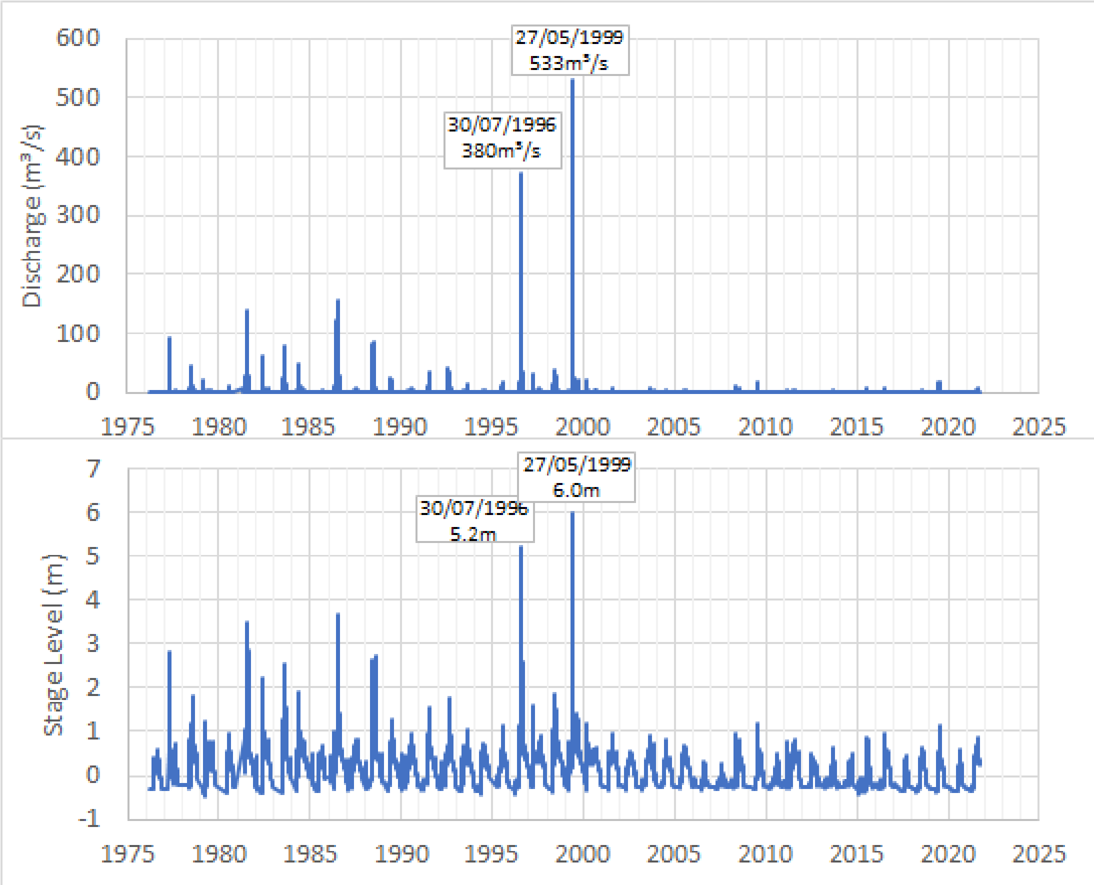



**Figure A-11: Chapman River Discharge (Top) and Stage Level (Bottom) at Utakarra**

The May 1999 flood was associated with a mid-latitude depression raining on a saturated catchment following TC Vance in March 1999.

**Figure A-12: Flooding at Chapman River Bridge in May 1999**
**From Langford (2001)**

Seasonal distribution of river stage discharge has been evaluated using average monthly occurrence of discharge thresholds over the record (Figure A-13). This shows typical winter flows peak in July-August, substantially decline in October, and have limited flow between November to April. In the period from 2015 to 2021, which correspond to available high resolution imagery for the river mouth, flows were generally lower, confined mainly to July and August, with negligible flow between November and May.

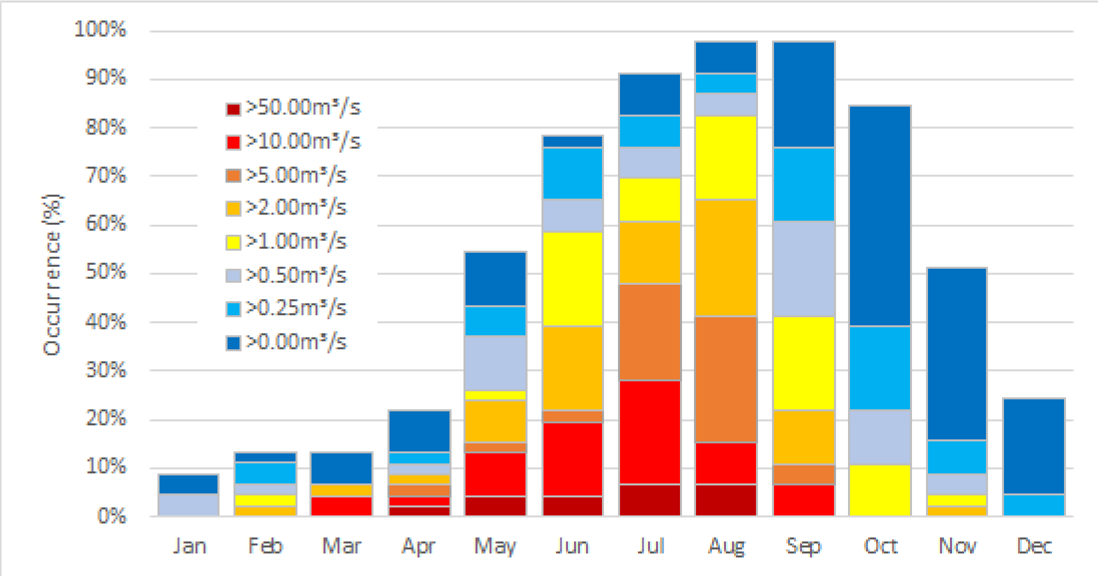



**Figure A-13: Monthly Discharge Occurrence at Chapman River**

Annual flow conditions have been summarised over the record in Table A-4, to identify year to year variability in peak flows, and timing and persistence of flows. This highlights the substantial change in streamflow which occurred after 2000.

**Table A-4: Summary of Annual Chapman River Flows**

| Year | Peak Conditions | | | Elevated Discharge | | | |
|---|---|---|---|---|---|---|---|
| | Annual Stage Max (m) | Annual Max Discharge (m³/s) | Max Discharge Day | Total Days Discharge >0m³/s | First Day Discharge >0m³/s | First Day Discharge >0.25m³/s | Last Day Discharge >0m³/s |
| 1976 | 0.58 | 1.6 | 15/08/1976 | 140 | 15/05/1976 | 15/05/1976 | 17/08/1976 |
| 1977 | 2.81 | 91.4 | 29/04/1977 | 80 | 28/04/1977 | 28/04/1977 | 16/08/1977 |
| 1978 | 1.81 | 42.6 | 16/07/1978 | 140 | 19/05/1978 | 19/05/1978 | 4/10/1978 |
| 1979 | 1.24 | 21.8 | 14/03/1979 | 165 | 14/03/1979 | 14/03/1979 | 26/08/1979 |
| 1980 | 0.98 | 10.0 | 16/07/1980 | 115 | 2/06/1980 | 2/06/1980 | 30/08/1980 |
| 1981 | 3.48 | 137.7 | 1/08/1981 | 208 | 23/05/1981 | 22/05/1981 | 6/10/1981 |
| 1982 | 2.23 | 61.1 | 14/06/1982 | 173 | 21/01/1982 | 22/01/1982 | 7/10/1982 |
| 1983 | 2.55 | 77.0 | 24/08/1983 | 175 | 18/06/1983 | 18/06/1983 | 17/11/1983 |
| 1984 | 1.90 | 46.0 | 28/05/1984 | 224 | 12/04/1984 | 12/04/1984 | 10/10/1984 |
| 1985 | 0.69 | 3.0 | 28/08/1985 | 142 | 11/02/1985 | 10/02/1985 | 24/09/1985 |
| 1986 | 3.66 | 156.5 | 23/07/1986 | 237 | 22/02/1986 | 22/02/1986 | 21/10/1986 |
| 1987 | 0.83 | 5.6 | 3/07/1987 | 209 | 11/02/1987 | 11/02/1987 | 5/09/1987 |
| 1988 | 2.71 | 85.7 | 24/07/1988 | 195 | 4/02/1988 | 21/05/1988 | 1/12/1988 |
| 1989 | 1.26 | 22.3 | 13/06/1989 | 173 | 30/04/1989 | 17/05/1989 | 23/08/1989 |
| 1990 | 0.93 | 8.4 | 3/08/1990 | 185 | 29/01/1990 | 29/01/1990 | 8/10/1990 |
| 1991 | 1.55 | 32.4 | 22/07/1991 | 183 | 4/06/1991 | 6/06/1991 | 15/11/1991 |
| 1992 | 1.79 | 41.5 | 10/08/1992 | 193 | 17/03/1992 | 13/06/1992 | 16/10/1992 |
| 1993 | 1.04 | 12.3 | 13/08/1993 | 195 | 4/05/1993 | 4/05/1993 | 25/09/1993 |
| 1994 | 0.73 | 3.6 | 2/07/1994 | 147 | 29/05/1994 | 31/05/1994 | 13/09/1994 |
| 1995 | 1.16 | 18.3 | 26/07/1995 | 153 | 26/05/1995 | 8/06/1995 | 13/09/1995 |
| 1996 | 5.22 | 369.9 | 30/07/1996 | 214 | 1/06/1996 | 1/06/1996 | 11/11/1996 |
| 1997 | 1.61 | 31.1 | 8/04/1997 | 240 | 2/01/1997 | 4/04/1997 | 26/09/1997 |
| 1998 | 1.84 | 37.9 | 18/06/1998 | 204 | 11/05/1998 | 11/05/1998 | 4/10/1998 |
| 1999 | 5.99 | 531.0 | 27/05/1999 | 287 | 20/03/1999 | 20/03/1999 | 1/11/1999 |
| 2000 | 1.20 | 19.5 | 11/03/2000 | 295 | 2/01/2000 | 10/03/2000 | 20/09/2000 |
| 2001 | 1.19 | 8.5 | 31/07/2001 | 202 | 8/05/2001 | 30/05/2001 | 25/10/2001 |
| 2002 | 0.53 | 1.1 | 11/08/2002 | 167 | 20/05/2002 | 1/07/2002 | 17/09/2002 |
| 2003 | 0.91 | 7.8 | 22/08/2003 | 190 | 19/05/2003 | 25/06/2003 | 22/11/2003 |
| 2004 | 0.82 | 5.3 | 8/07/2004 | 146 | 3/06/2004 | 13/06/2004 | 26/09/2004 |
| 2005 | 0.70 | 3.1 | 18/06/2005 | 164 | 16/05/2005 | 9/06/2005 | 23/09/2005 |
| 2006 | 0.46 | 0.2 | 23/08/2006 | 40 | 3/08/2006 | 3/08/2006 | 3/08/2006 |
| 2007 | 0.26 | 0.1 | 9/08/2007 | 13 | 6/08/2007 | 6/08/2007 | 6/08/2007 |
| 2008 | 0.96 | 9.5 | 29/04/2008 | 144 | 18/04/2008 | 18/04/2008 | 12/08/2008 |
| 2009 | 1.17 | 18.7 | 12/07/2009 | 118 | 29/06/2009 | 29/06/2009 | 3/10/2009 |
| 2010 | 1.09 | 0.8 | 19/08/2010 | 46 | 17/07/2010 | 14/08/2010 | 3/09/2010 |
| 2011 | 0.81 | 5.1 | 15/08/2011 | 177 | 20/02/2011 | 20/02/2011 | 28/10/2011 |
| 2012 | 0.52 | 1.0 | 21/06/2012 | 115 | 13/06/2012 | 13/06/2012 | 10/08/2012 |
| 2013 | 0.71 | 2.1 | 29/08/2013 | 75 | 1/08/2013 | 26/08/2013 | 18/09/2013 |
| 2014 | 0.54 | 1.0 | 24/09/2014 | 81 | 13/07/2014 | 10/09/2014 | 26/09/2014 |
| 2015 | 0.89 | 7.0 | 1/08/2015 | 64 | 21/07/2015 | 21/07/2015 | 25/08/2015 |
| 2016 | 0.94 | 8.6 | 18/07/2016 | 105 | 6/07/2016 | 10/07/2016 | 11/09/2016 |
| 2017 | 0.47 | 0.7 | 31/08/2017 | 51 | 13/08/2017 | 31/08/2017 | 3/09/2017 |
| 2018 | 1.01 | 2.2 | 6/08/2018 | 89 | 6/07/2018 | 6/07/2018 | 7/09/2018 |
| 2019 | 1.14 | 17.7 | 6/07/2019 | 99 | 24/06/2019 | 26/06/2019 | 9/08/2019 |
| 2020 | 0.59 | 1.7 | 17/08/2020 | 65 | 22/07/2020 | 10/08/2020 | 24/08/2020 |
| 2021 | 0.87 | 6.6 | 2/08/2021 | 129 | 30/05/2021 | 30/05/2021 | 6/09/2021 |

(1) Formatting used to demonstrate high (red) and low (blue) years for individual parameters

# Appendix B Coastal Processes

## APPENDIX B.1 REGIONAL SCALE COASTAL PROCESSES

The sediment cell framework defined by Eliot *et al*. (2011) identifies a hierarchy of sediment cells (primary, secondary, and tertiary) for the Western Australia coastline, defining natural management units based on their physical characteristics, within which sediment transport processes are expected to be strongly related. The framework provides important context for local scale coastal assessments.

Chapman River mouth divides the *Geraldton West to Chapman* and *Chapman to Glenfield* tertiary sediment cells, which are part of the wider *Point Moore to Glenfield* secondary cell (Figure B-1). The rationale for setting the boundary at Chapman was the river mouth providing a geomorphic feature which interrupted sediment transport; the change between shoreline alignment to the north and south; and presence of rock structures restricting sediment transport at a seasonal scale (Stul *et al*. 2014). Tecchiato *et al*. (2012) interpreted surface sediment composition and distributions throughout Champion Bay, finding the contribution of sediment from Chapman River to be a minor component of overall sediment supply to the Bay.

Two adjacent cells are dominated by a net northward sediment transport regime, driven predominantly by south-westerly swell waves throughout the year, combined with a strong south south-westerly summer sea breeze. There is some reversal over winter with passage of northerly storms, and on occasion over summer with passage of tropical cyclones.

Sediment transport around Chapman River mouth is complex, with the entrance bar and shoals fluctuating between acting as a source or sink of sediment. This complexity is illustrated by large discrepancies between previously derived sediment budgets, due to differing timescales and methods (Figure B-2), with:

- MRA (2001) showing a possible zone of nearshore accumulation at Chapman River, with convergence of southward and northward transport.
- Worley Parsons (2010) showing sediment input from Chapman River, with shoreline accretion to the south and erosion to the north.
- Tecchiato & Collins (2011) showing net northward transport to the south and transfer offshore at Chapman River. It was noted the "Chapman River is supplying quartz sand into Champion Bay, probably during high discharge winter flows. This sediment may also be redistributed southward by occasional storms and northward by littoral currents."

Net northward sediment transport pathways around Point Moore are interrupted by Geraldton Point facilities and Batavia Coast Marina, which commenced in the 1920s and 1980s respectively. Subsequent erosion to the north has been partly mitigated by sand bypassing, including substantial placement of 89,000m$^3$ north of Batavia Coast Marina in 2004 derived from the excavation works for the Southern Transport Corridor (Tecchiato & Collins 2011). More recently, stabilisation works have been conducted along Beresford foreshore, south of Chapman River mouth (Royal Haskoning DHV 2015).

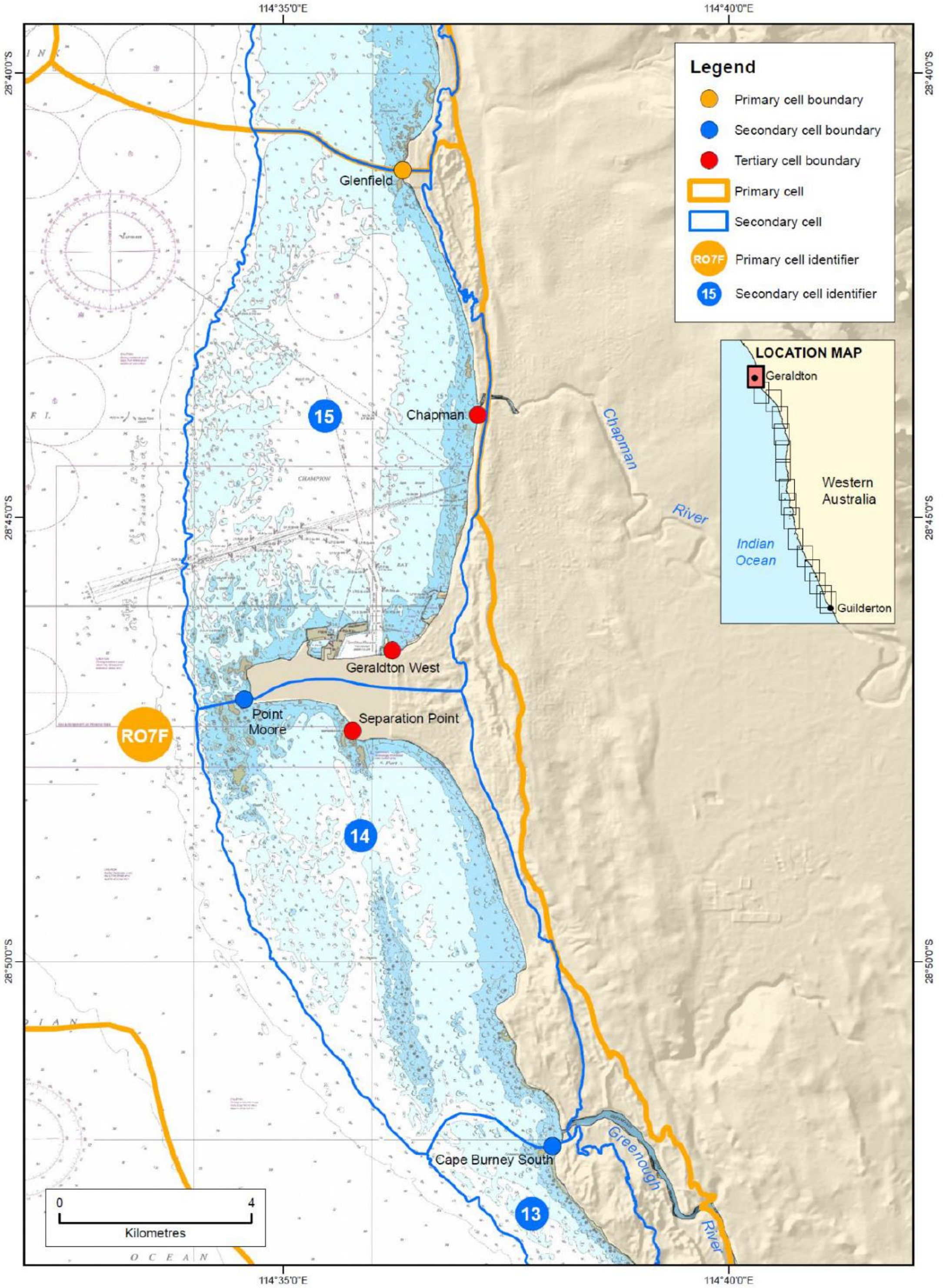



**Figure A.16: Secondary cells and tertiary cell points of the Mid-West Region**

Figure is at scale of 1:100,000 at A4. A primary cell point is also a secondary and tertiary cell point. A secondary cell point is also a tertiary cell point. This map should not be used for navigation purposes. Bathymetry information supplied by Department of Transport. Shaded relief model supplied by Geological Survey of WA, Department of Mines and Petroleum.

**Figure B-1: Sediment Cells Incorporating Chapman River Mouth**

Vegetation line analysis since 1952 (Worley Parsons 2010; MRA 2016); and annual rates of shoreline changes identified in the Digital Earth Australia Coastlines dataset since 1988 (Figure B-3) demonstrate most of the shore within the two cells adjacent to Chapman River has experienced erosion pressure. Factors influencing this tendency for erosion are described in Tecchiato & Collins (2011), including:

- Interruption of net northward sediment transport around Point Moore by the Geraldton Port.
- Net northward sediment transport leading to a zone of accretion south of northern cell boundary at Glenfield.
- Nearshore reefs acting as a barrier for the sediment supply from offshore to the shore, but not entirely obstructing the sediment from flushing offshore, especially during storms or strong swell events (Tecchiato & Collins 2011); and
- Development of the large dune blowout to north of Chapman River (evident in 1967 aerial imagery). This feature would have acted as a sediment sink during its early formation and propagation, removing sediments from the littoral transport zone.

Elevation differences between 1998 and 2016 has been used to identify behaviour of offshore and nearshore regions (Figure B-4). It is acknowledged that differences in method and resolution of the two surveys means that some local changes do not represent reality, particularly for reef systems which are mapped in detail by lidar but coarsely captured or excluded during vessel-based surveys.

This demonstrates a general pattern of accretion outside the nearshore reef system, extending northward of the Batavia Coast Marina to Glenfield Beach. This behaviour is likely influenced by northward sediment transport along the edge of the reef systems under a dominance of wave energy from the south.  Transport has likely been enhanced by:

- Placement of sand north of Batavia Coast Marina (e.g. in 2004).
- Transfer offshore at Chapman River during the 1999 flood.
- Supply from shoreline erosion over wider Champion Bay, with the reef system acting as a barrier to sediment moving back towards shore.

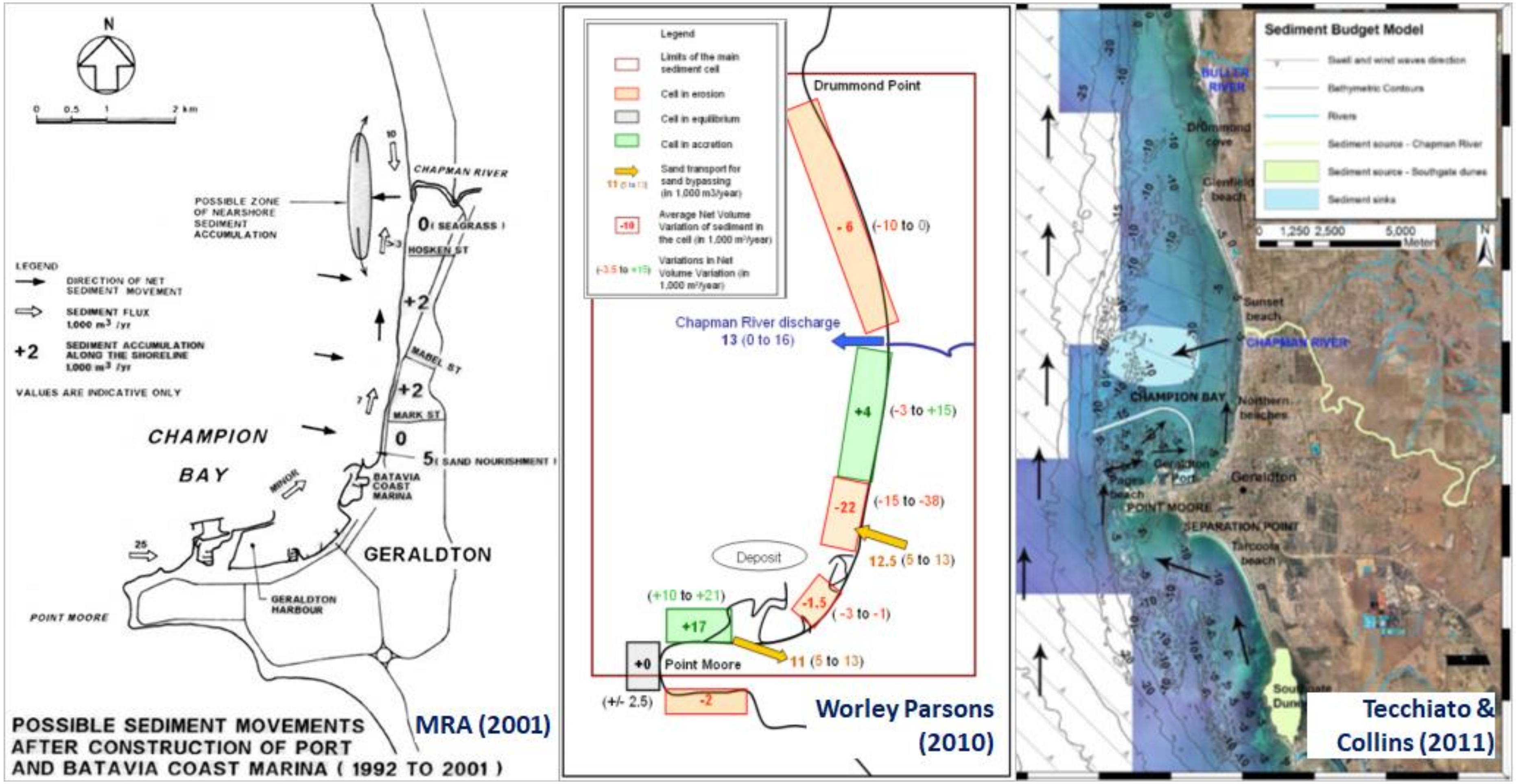



**Figure B-2: Previously Derived Sediment Budgets**

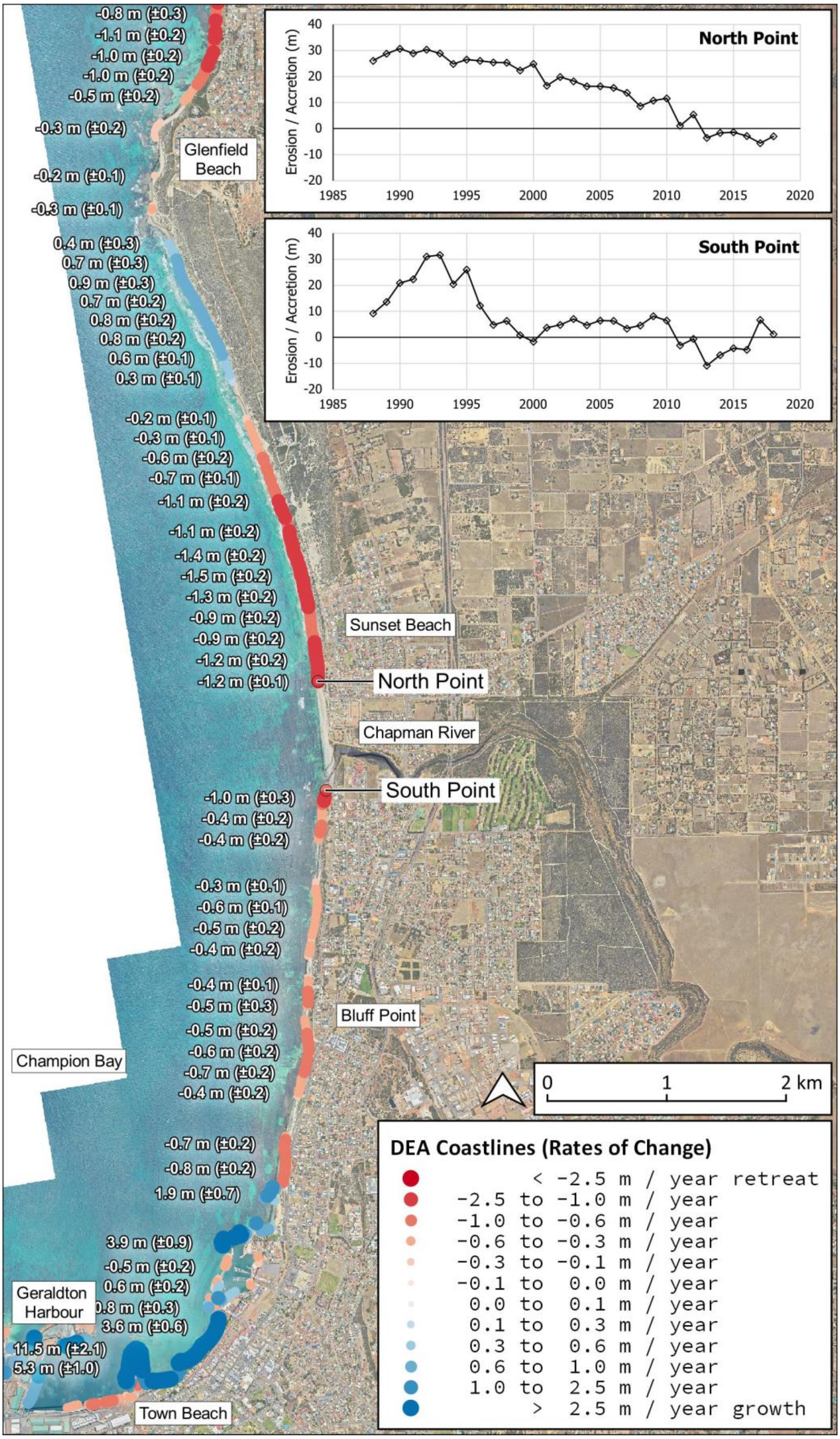



**Figure B-3: Geraldton North Rates of Shoreline Change Between 1988 to 2018 From Digital Earth Australia Coastlines (Bishop-Taylor *et al*. 2021)**

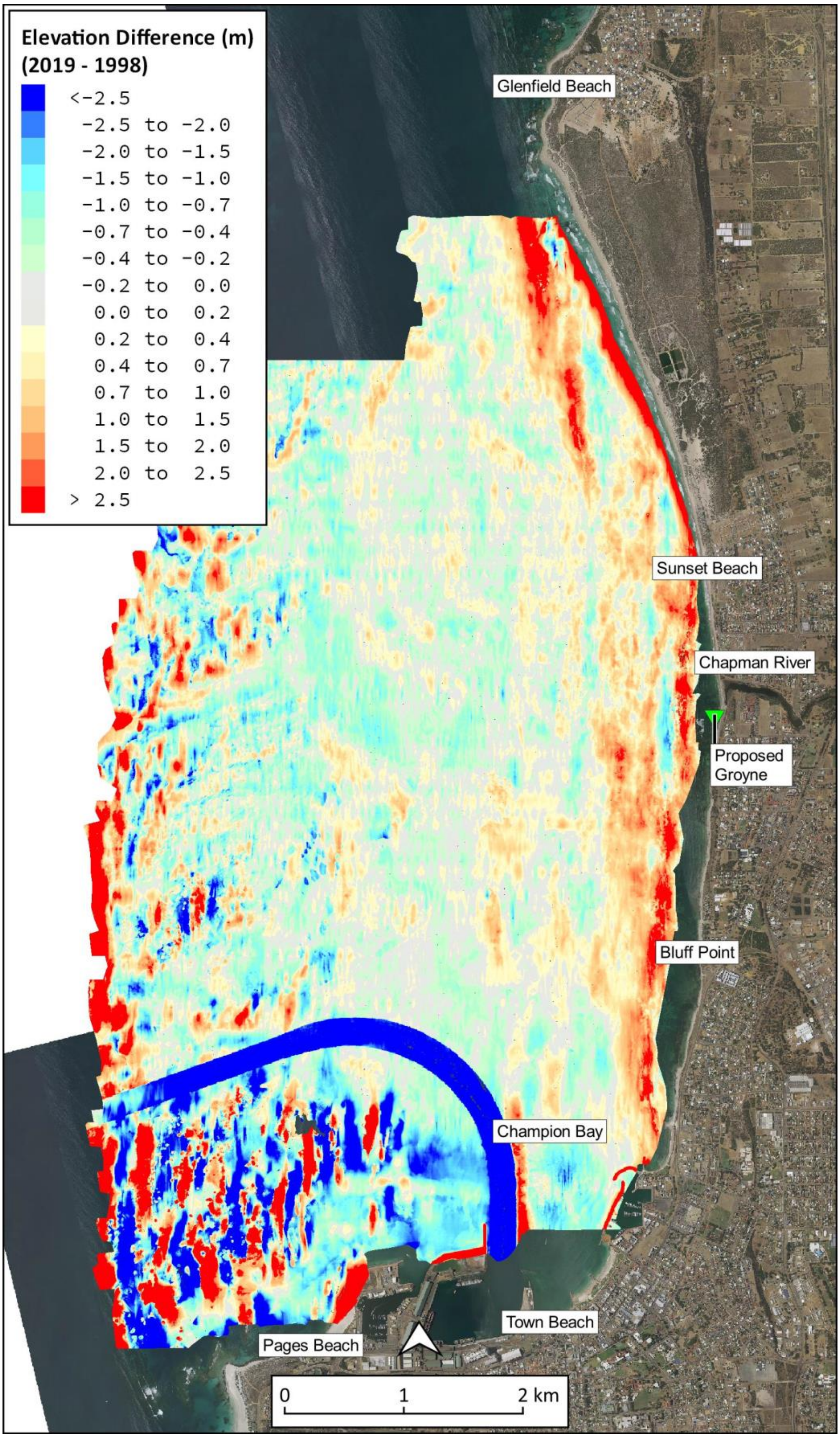



**Figure B-4: Elevation Difference Analysis – 1988 Single Beam Survey to 2016 LIDAR**
**Source: Department of Transport**

## APPENDIX B.2 LOCAL GEOMORPHIC OVERVIEW

The site is situated towards the centre of the 10km long embayment between Point Moore and Glenfield, largely the shelter provided by Point Moore from prevailing southerly sea breezes and southwest swells. Local site geomorphology is complex (Figure B-5), with Chapman River mouth and associated sand bar, variable nearshore reefs, exposed rock on shoreline to the north, and frequent wrack accumulation (see Figure 2-1). The proposed groyne positioned on the south side of the present-day entrance bar and channel mouth.

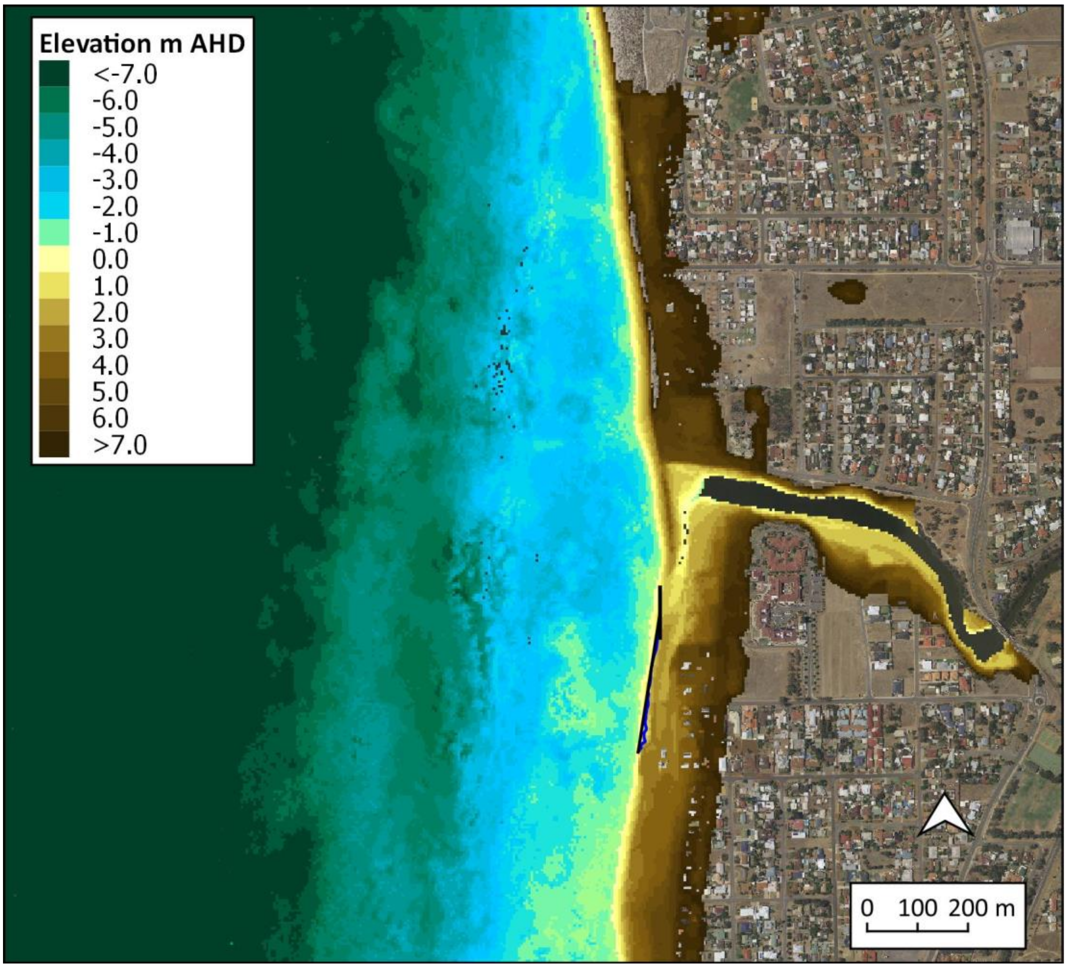



**Figure B-5: Bathymetry and Nearshore Topography from 2016 LIDAR**

The Chapman River channel is geomorphologically controlled by adjacent dunes, with mouth position generally orientated towards the low-lying area to the south. The mouth is intermittently opened by peak winter flows and coincident with high tide breaching the entrance bar (WRC 2001b). This causes sand stored in the entrance bar and river derived sediment being is transported offshore, with the amount of sediment likely to be transported offshore during a flooding event estimated to be 13,000 $m^3$/year on average (Worley Parsons 2010). The last known significant flood occurred in 1999 (Appendix A.4).

When open, the estimated reach of tidal exchange extends approximately 1.5 km upstream (WRC 2001), varying with water level processes (e.g. the twice annual cycle of tides) and degree of entrance channel opening. The channel tends to close under the combined influence of sediment supply from alongshore and nearshore (i.e. recovery); reduced river flows; and ocean water level fluctuations.

The sand bar feature across the river mouth varies with channel position, river flooding and rates of alongshore sediment delivery from the north and south (refer to Appendix A.3). The bar is prone to deflation and loss offshore during significant flood events, with dune development during periods with relatively low floods.

Rock is evident in the nearshore beach area immediately to the south of the river mouth, which provides local erosion protection to private property from approximately 270m north of the groyne. The rock can locally modify delivery of northward sediment transport towards the entrance bar, by promoting capture on the updrift side (south). It also effectively controls the southern limit for potential channel mouth position (e.g. 1967 aerial imagery).

The area adjacent to the Chapman River represents the widest point of the nearshore platform within the Champion Bay (<10 m water depth), with narrowing apparent to the north as the platform declines beneath the sandy substrate. Lidar survey (Figure B-5) indicates the reef system generally consists of two reef ridges, separated by a 100-200m wide gutter.

- The ‘offshore’ ridge is at around −5.0m AHD can trigger wave breaking as far as 500m from the shore.
- The ‘inshore’ reef is variable, with shallowest depths typically between −2.0m and −1.0m AHD.

The nearshore reef system acts to reduce incident wave energy and modifies wave direction. A local reef high point extends south from the proposed groyne’s position at approximately 200m from the shore. This system provides additional shelter to the shoreline, with the zone of shelter varying with wave direction. Shelter will likely contribute to periods of enhanced updrift accumulation (e.g. during sea breezes) and enhanced downdrift erosion to the north where greater wave exposure can occur.

## APPENDIX B.3 SIMULATED ALONGSHORE TRANSPORT & GROYNE INFLUENCE

A major process determining the influence and effectiveness of coastal groynes is alongshore sediment transport. This is a relative movement of sediment along the coast, developed mainly through sand being stirred up by waves breaking on the coast, which is transported by nearshore flows, which includes alongshore currents generated by wave breaking.

Alongshore sediment transport potential has been examined using a combination of the Outer Channel Directional Waverider Buoy dataset (2014-2021) and the Sunset Beach AWAC deployments (2020-2021). These represent comparatively short datasets, unsuitable for parameterising long-term shoreline dynamics. However, they are suitable for identifying seasonal patterns and illustrating the effects of synoptic (weather) variability. To combine the nearshore information provided by the Sunset Beach deployments with the longer-term information from the directional waverider, a basis of wave height and direction transformation was developed from the overlapping record and used to synthesise nearshore conditions when only the offshore data was available (Figure B-6).

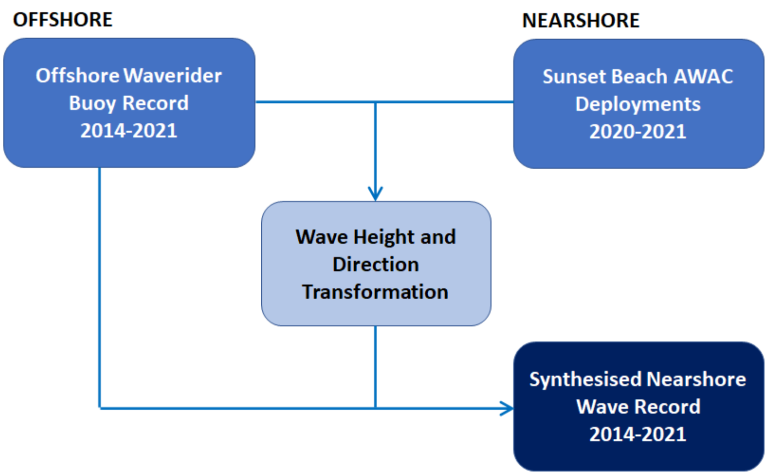



**Figure B-6: Schematic for Process of Wave Date Interrogation**

Comparison of wave conditions offshore and closer to shore indicates:

- Reduction of wave height from offshore to nearshore (Figure B-7).
- Modifications to wave direction (Figure B-8).

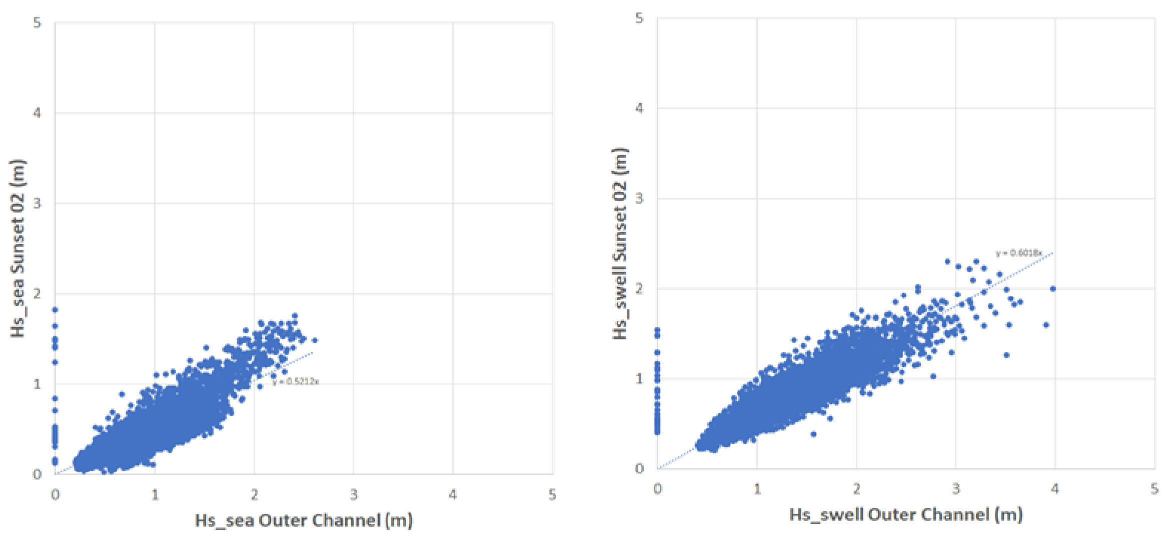


**Figure B-7: Cross-plot of Offshore and Nearshore Wave Height**

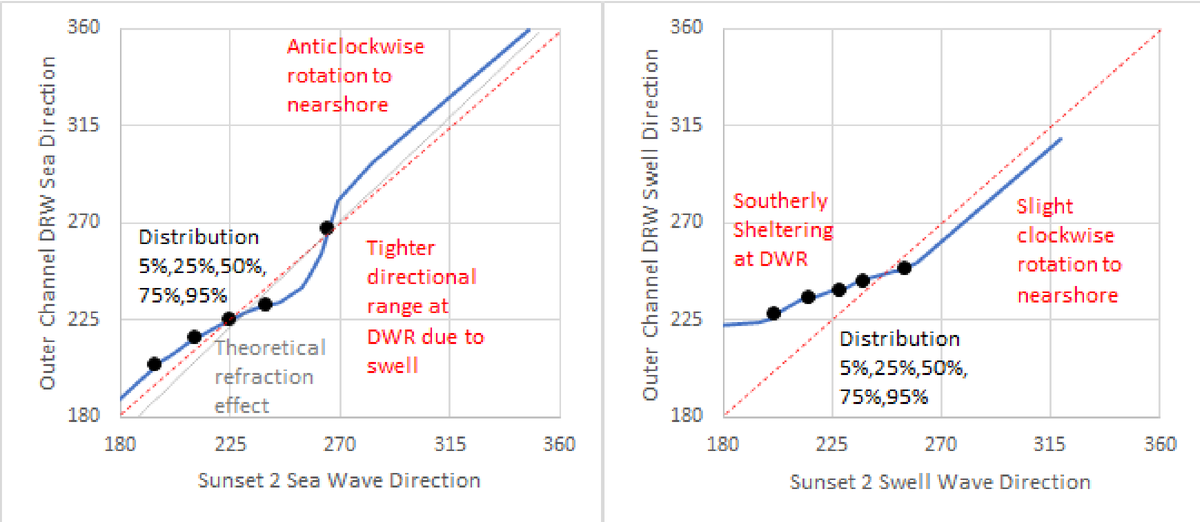



**Figure B-8: Comparison of Offshore and Nearshore Wave Direction Distributions**

There is an average reduction of sea and swell waves to 52% and 60% (respectively) of offshore conditions. The greater reduction for sea waves indicates that loss is not dominated by friction, which is more substantially experienced by swell. Further, the directional distributions (Figure B-8) suggest that swell waves are sheltered at the location of the directional waverider buoy (i.e. the higher nearshore to offshore ratio is a reflection of less shelter rather than proportionally lower energy loss).

The theoretical effect of refraction, which generally bends waves 'towards' a shore-normal approach, produces an anti-clockwise rotation for more northerly waves and a clockwise rotation for more southerly waves. This pattern was not apparent in the directional distributions (Figure B-8). However, subsequent evaluation of the reduction of sea waves from offshore to nearshore indicated the refraction is active (Figure B-9). A distribution was fitted to describe the relationship between sea wave damping and offshore wave direction.

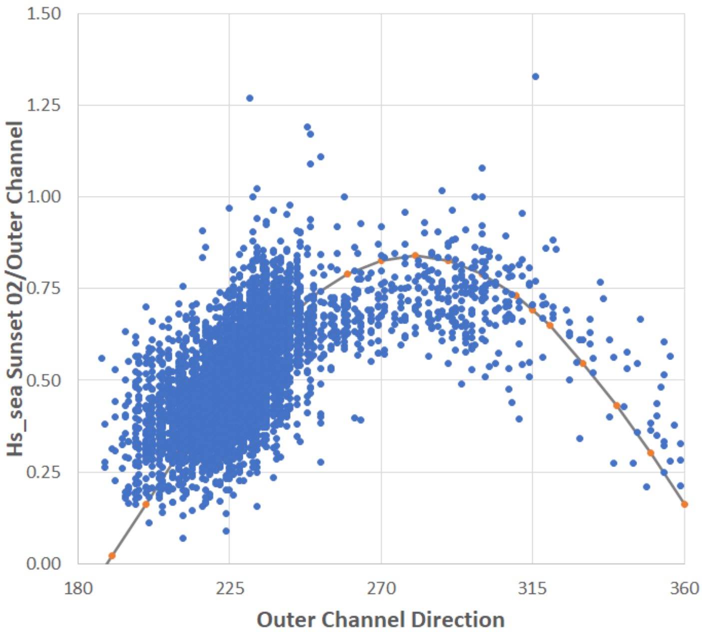


**Figure B-9: Variation of Nearshore to Offshore Sea Wave Height Ratio with Offshore Direction**

Directional cross-plots (Figure B-10 lower panels) do not show a clear relationship between the DWR and AWAC data sets. Direction measurements, for both sea and swell are apparently dominated by swell energy. No clear connection between offshore and nearshore was identified, with the point cloud suggesting a 'reverse' slope – this is possibly a function of instrumentation differences, or local bed structure.

Comparison between offshore and nearshore wave conditions has been used to simulate a nearshore wave history, based on the offshore wave measurements (2014-2021). Assumed relationships include:

- Swell waves have been assumed to be 60% of their offshore amplitude, preserving their direction and period.
- Sea waves have had their reduction calculated as a function of their offshore direction, but otherwise preserve their direction and period.

The simulated nearshore wave history was then used to estimate alongshore transport potential, using the formula

$$Q \sim H^2T \cos(2(\theta-\theta_0)) \, \text{sign} \, (\theta-\theta_0)$$

This equation estimates the potential capacity for waves to drive alongshore sediment transport. However, actual sediment transport is modified by a range of factors, including beach slope, sediment size and presence of rock.

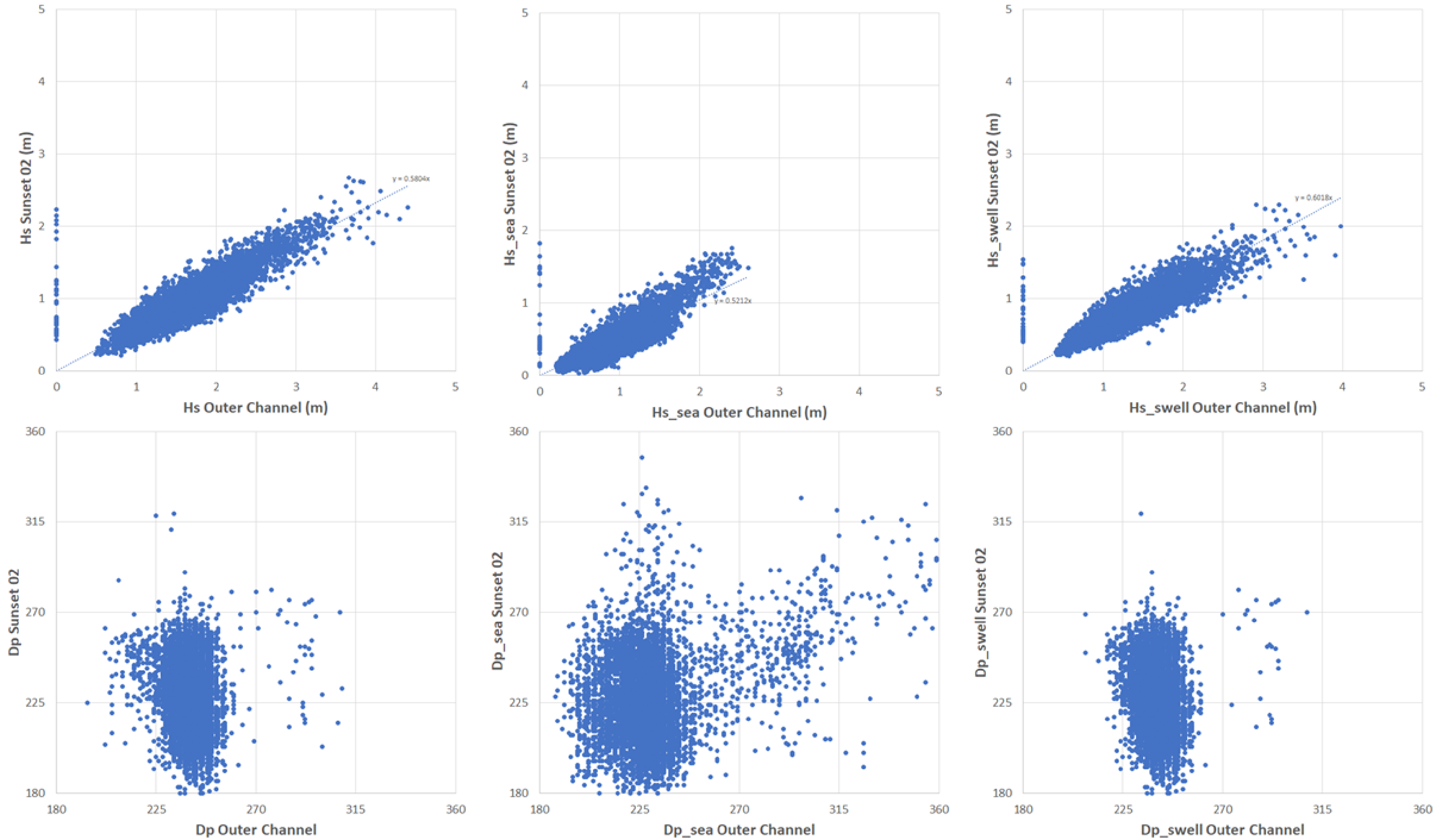



**Figure B-10: Cross-plots of Offshore and Nearshore Wave Height and Direction**

Alongshore sediment transport potential determined for the sea and swell wave components indicates the dominance of the swell waves, with approximately 85% of the transport potential derived from swell.

Transport potential from sea waves (Figure B-11) indicates that the northward transport is dominant for the west-facing coast, with sporadic occurrence of southward alongshore transport potential. Note the ‘upper limit’ of the sea waves is determined by the 8 second sea-swell cut-off, and wave steepness.

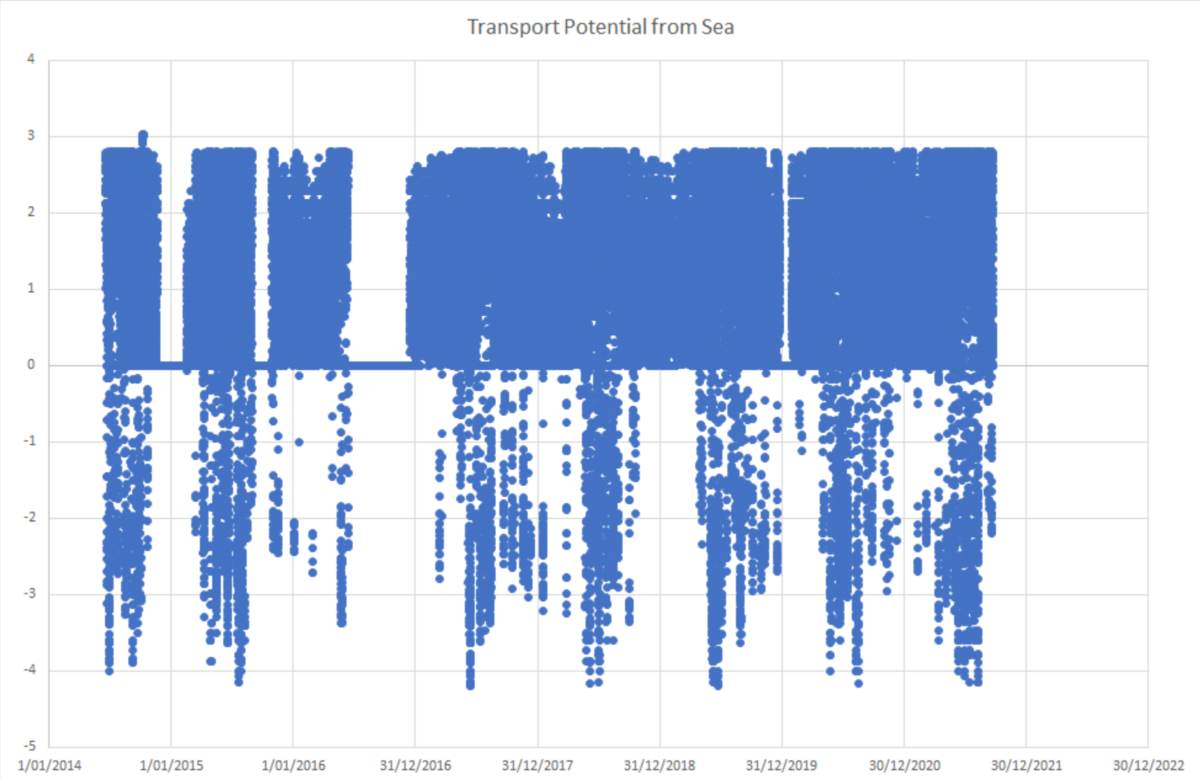



**Figure B-11: Alongshore Sediment Transport Potential from Sea Waves**

Alongshore transport potential from swell (Figure B-12) is also predominantly northward on a west-facing coast. Southward sediment transport potential is infrequent, and there are occasional brief periods of very high northward transport potential, such as the strong southwesterly storm, with long wave periods occurring in August 2018 (Figure B-13).

Cumulative alongshore transport potential over each calendar year (Figure B-14) is shown for three different directions of 262°, 270°, 277° which approximately correspond to Sunset Beach South, an overall ‘average’ alignment near the Chapman River mouth, and along north Bluff Point shore. Characteristics shown include:

- Transport potential due to sea waves is much smaller than for swell waves.
- Sea waves cause prevailing northward transport potential throughout the year, with minor reversals (which appear as ‘kinks’ in the curve).
- Swell waves cause prevailing northward transport potential throughout the year, but there is increased transport potential during winter months.
- Transport potential slightly decreases to the north due to the change in angle. Note that this analysis does not capture the effects of changing shelter from Point Moore or reef systems.

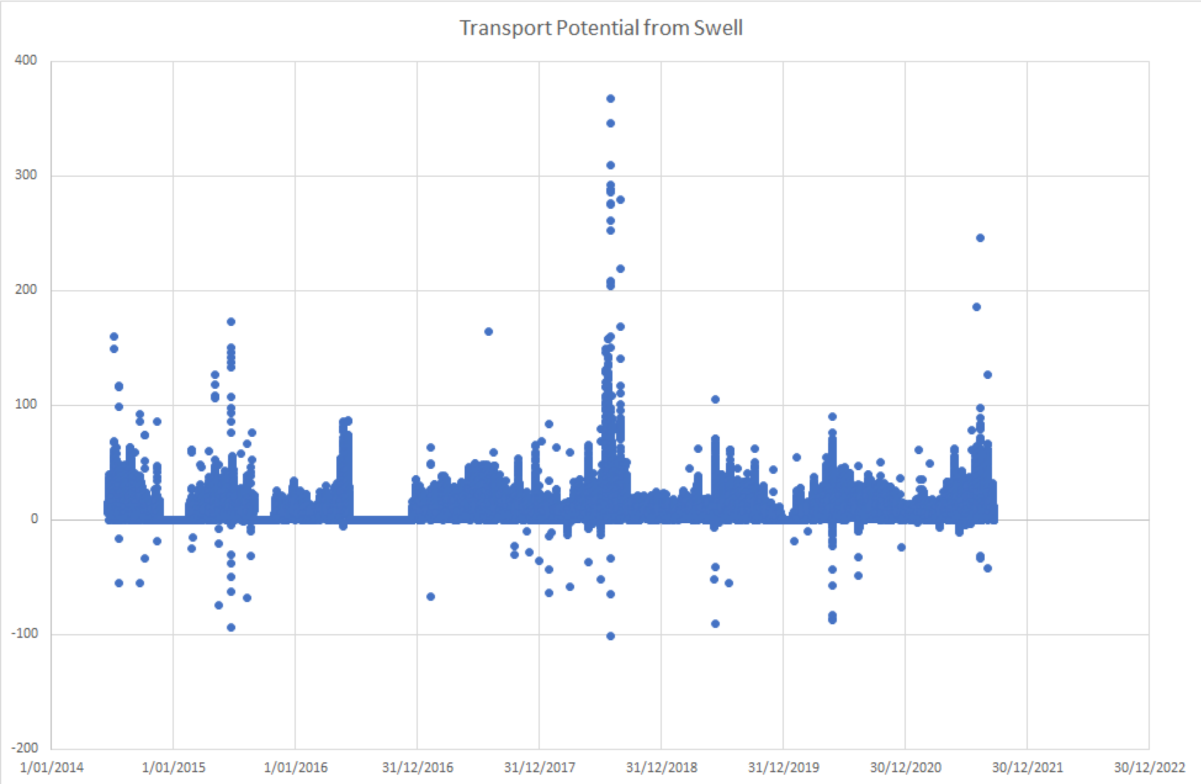



**Figure B-12: Alongshore Sediment Transport Potential from Swell Waves**

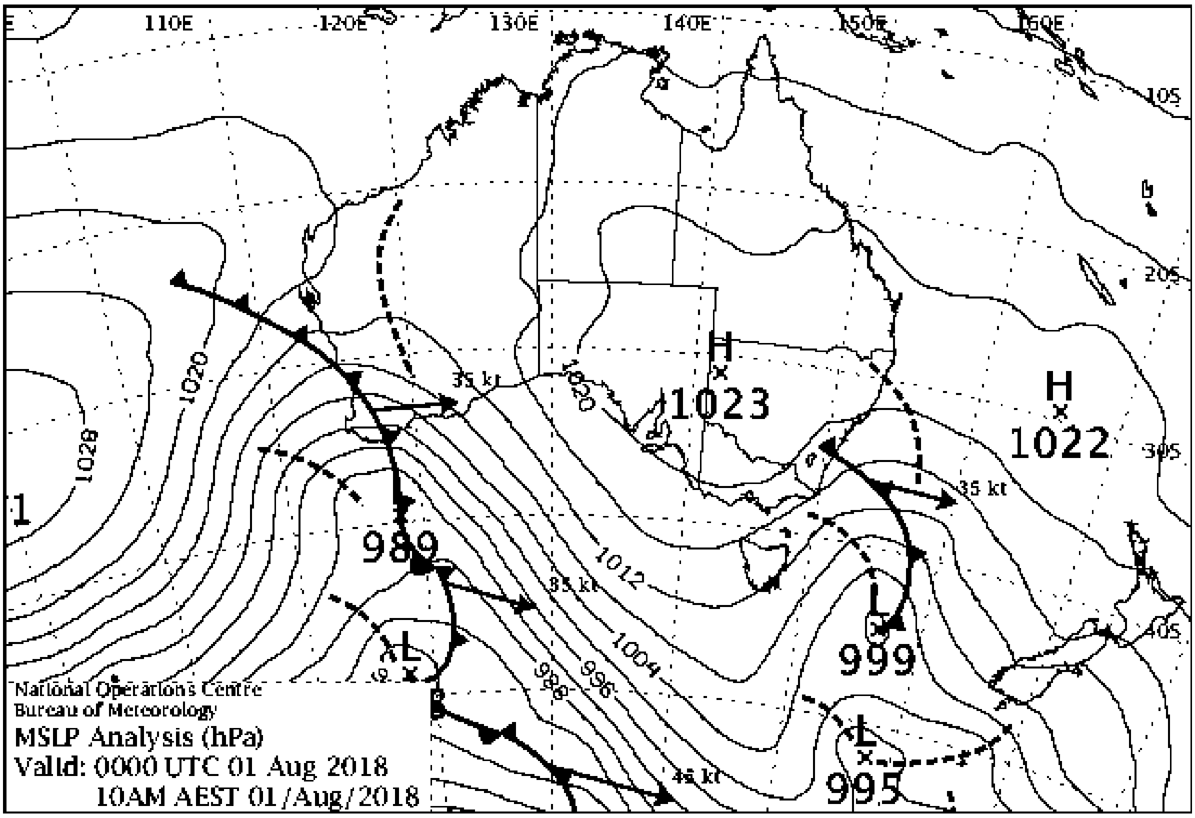



**Figure B-13: Synoptic Chart From Extreme Alongshore Transport Event**

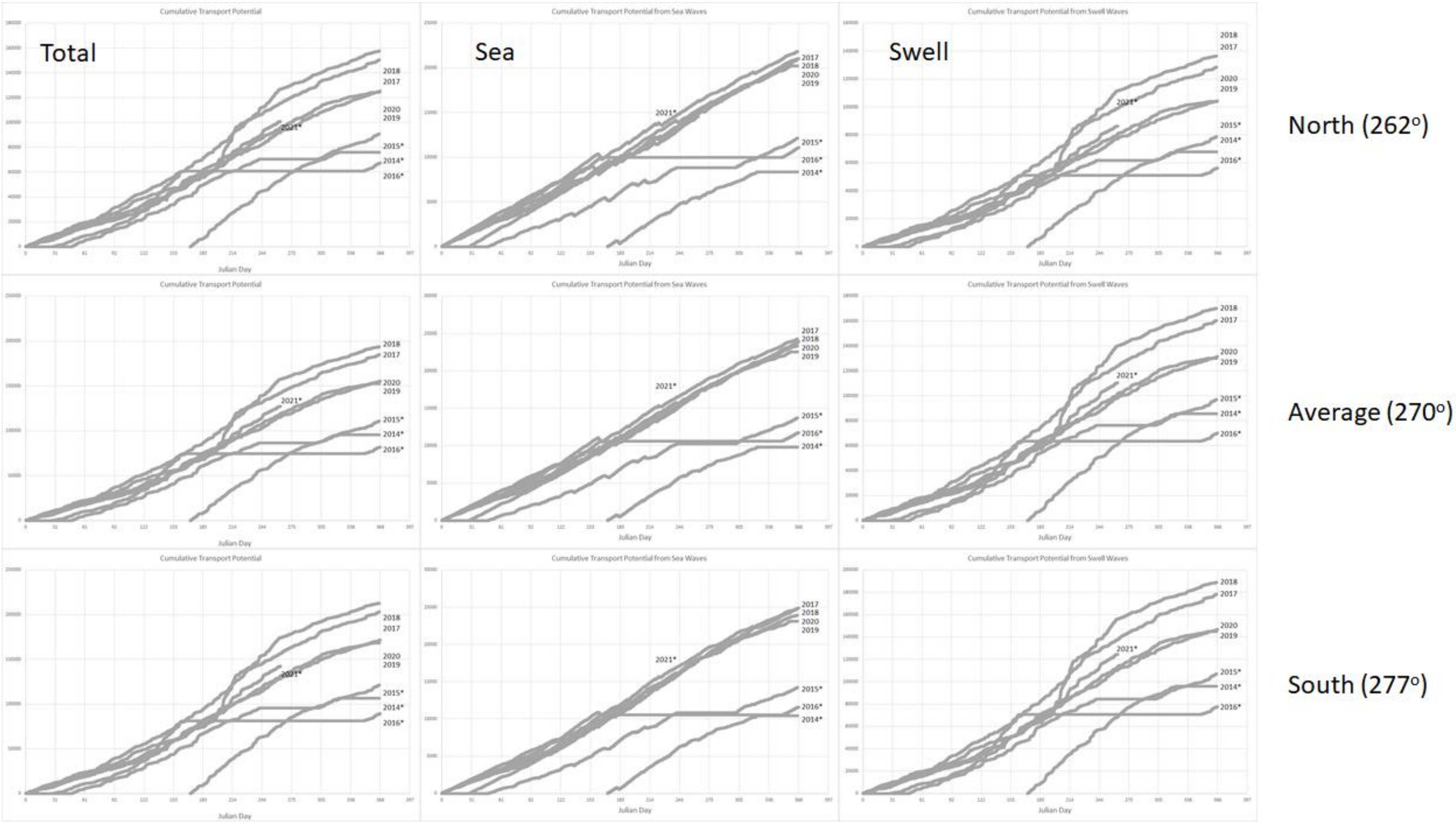



**Figure B-14: Cumulative Alongshore Transport Potential**

The seasonal pattern of alongshore transport potential for a west-facing coast (Figure B-15) indicates greater capacity for northward movement during winter due to both sea and swell. However, there is a greater seasonal increase for swell.

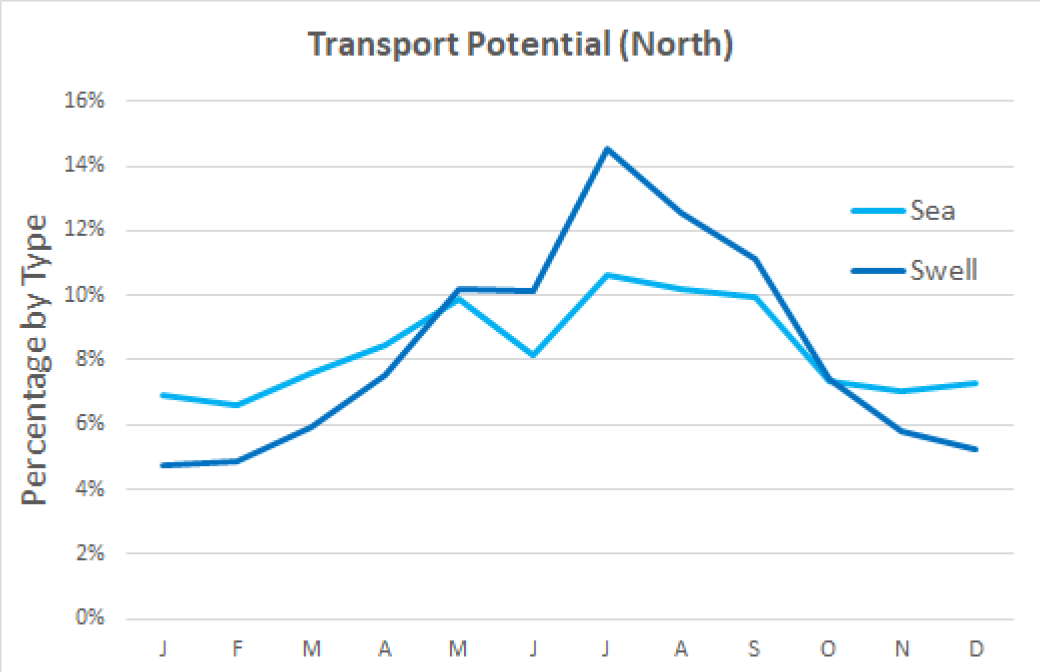



**Figure B-15: Seasonal Variation of Alongshore Sediment Transport Potential (Unscaled)**

Accounting for relative contributions of the two wave types, seasonal variation of alongshore transport potential for a west-facing coast (Figure B-16) is pronounced, with almost three times the capacity for transport during June than in January and February.

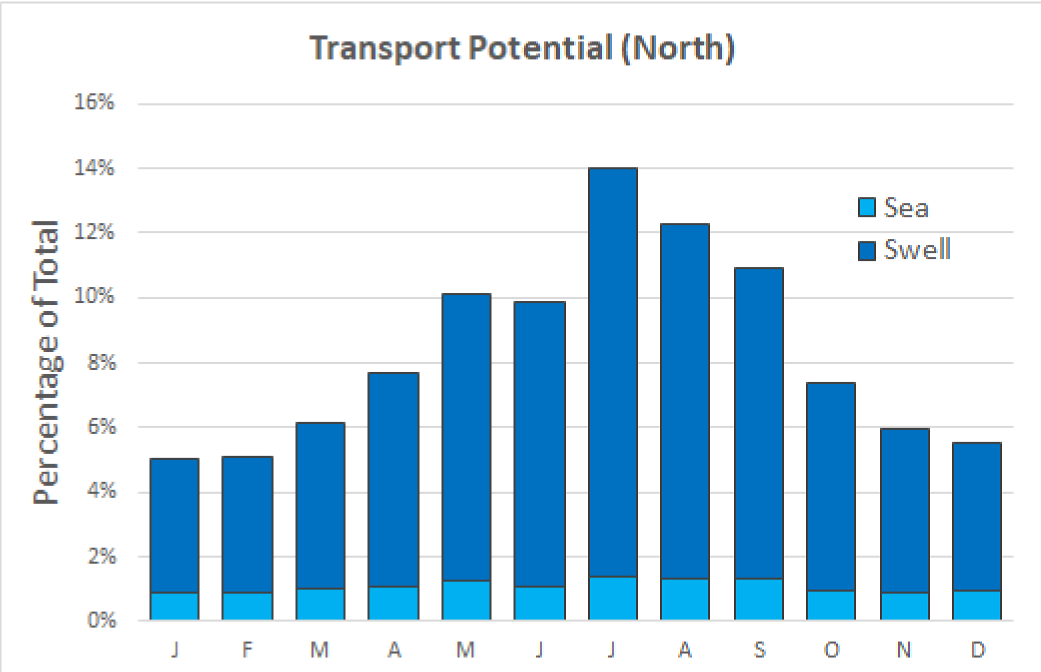



**Figure B-16: Seasonal Variation of Alongshore Sediment Transport Potential (Scaled)**

Variation of alongshore transport potential with shore direction (Figure B-17) suggests there is significant variation along the shore, with North Bluff Point having almost the highest possible alongshore transport potential within this (simulated) nearshore wave climate. A shore facing approximately 240° would experience near zero net alongshore transport potential.

It is reiterated that actual transport rates differ from alongshore transport potential due to multiple factors. Consequently, although North Bluff Point has a higher alongshore transport potential than South Sunset Beach, it is also has a greater presence of rock, which limits the availability of sediment.

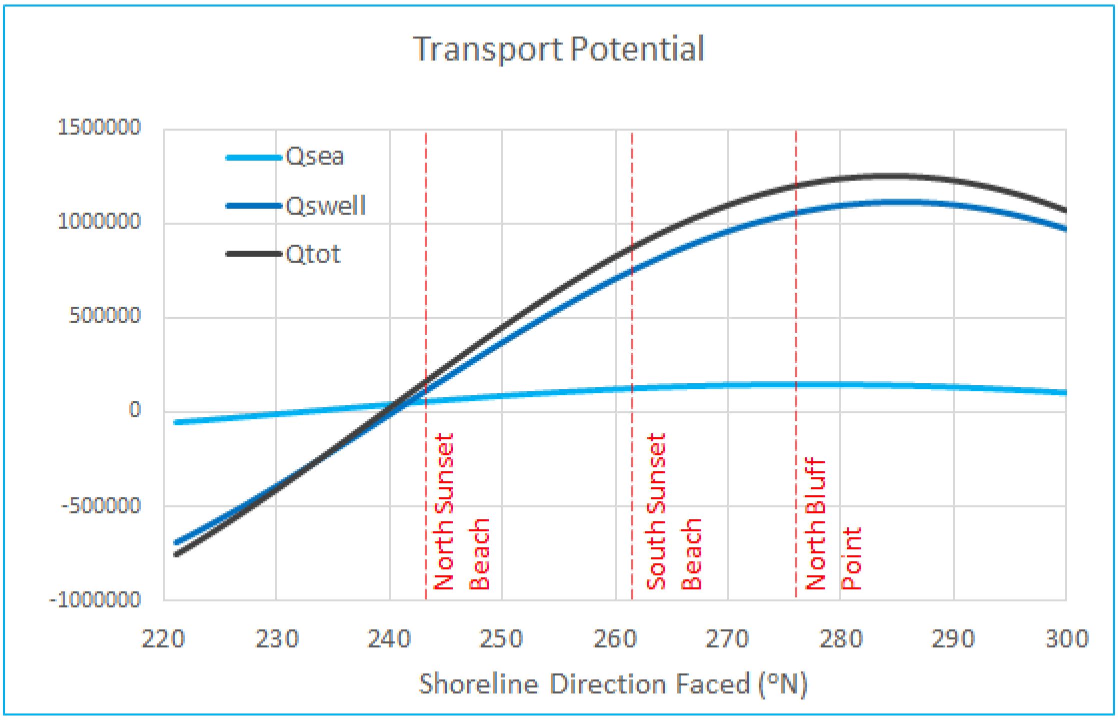



**Figure B-17: Variation of Alongshore Sediment Transport Potential with Shore Direction**

The shore alignment with capacity for net zero alongshore transport potential is important for an engineered coast, as it represents the maximum angle to which a shoreline can adjust by capturing sediment updrift of a groyne. However, this parameter varies seasonally, which results in seasonal capture and release of sediment storage. Evaluation of seasonal variation of the net zero potential shoreline angle (Figure B-18) suggests a range of 8° occurs over a year, with an anti-clockwise rotation during winter (i.e. a groyne will hold less sediment on its south side). Released sediment is typically dispersed along the shore.

Two main consequences of sediment storage by a groyne and its variability (Figure B-19) are:

- The initial storage volume should be matched by capital nourishment, otherwise it will cause downdrift erosion. For the estimated alongshore transport rates of 5,000-10,000 $m^3$/yr, it would take approximately 1 year to fill a groyne projecting 20-30m from the shore. A groyne projecting 40m from shore would take 2-4 years to fill without nourishment.

- Variation of sediment storage causes downdrift erosion. For a groyne projecting 20-30m from the shore, 1,200-2,900 $m^3$/yr of alongshore transport would be trapped in the groyne's storage cycle. A groyne projecting 40-55m from shore may effectively intercept the entire sediment supply, although this will cause net shoreline accretion on the updrift side and its influence would reduce over time.

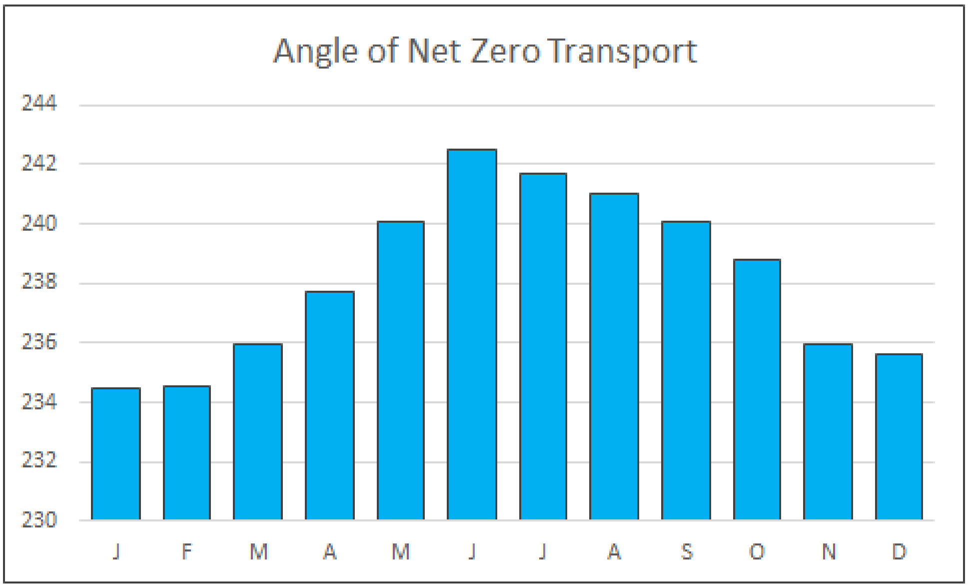



**Figure B-18: Seasonal Variation of Angle of Net Zero Transport**

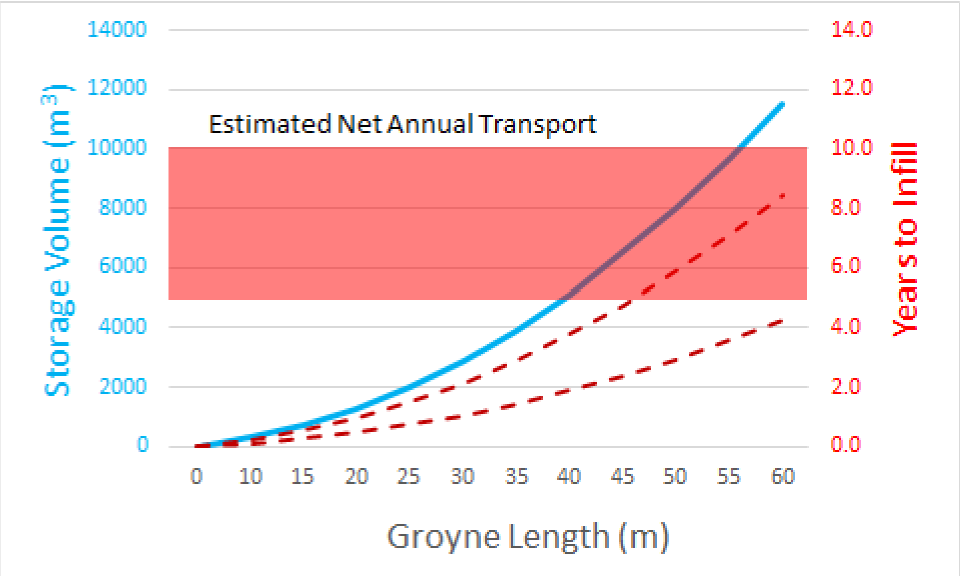



**Figure B-19: Effect of Groyne Length on Seasonal Storage Volume Change**

## APPENDIX B.4 CROSS-SHORE TRANSPORT CONSIDERATIONS

Although seasonal and inter-annual beach dynamics are commonly considered in terms of alongshore sediment transport, higher frequency beach fluctuation associated with cross-shore dynamics involves at least an order of magnitude greater volumes of sediment flux, and consequently this is critical to beach behaviour.

Cross-shore sediment transport occurs with several inter-connected processes through the nearshore, beach and dunes (Figure B-20):

- Over time scales of hours to days, the beach face is responsive to changing wave conditions, modulated by the coincident tidal conditions.
- Over time scales of days to months, beach elevation is affected by peak waves and tides, resulting in a change in beach storage. Under most conditions, high energy conditions raise the beach level, but it may be cut through beach face flattening, or subject to destruction and rebuilding at a lower level through alongshore transport.
- Over time scales of months to years, wind-blown sand transfer to and from the dune system provides a potential change in the volume of sediment available to the beach and nearshore areas. This process typically involves small volumes of volume change (2-10 $m^3/m$ annual flux) compared with potential changes associated with wave-driven alongshore or cross-shore dynamics (10-100 $m^3/m$ annual change).

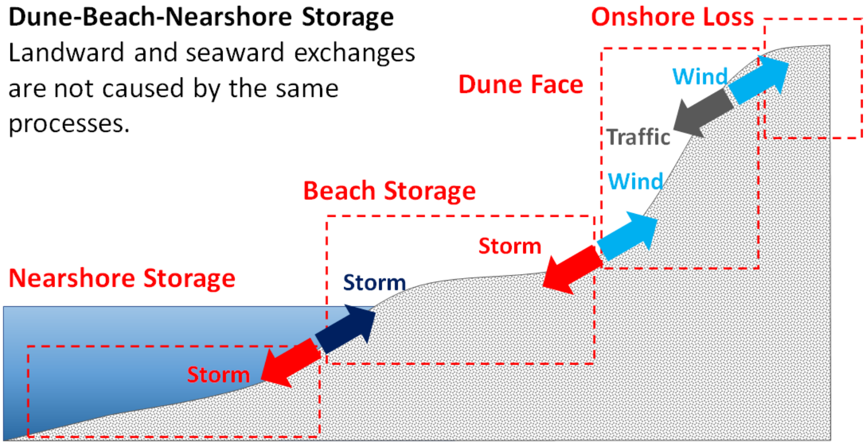



**Figure B-20: Cross-shore Zones and Connections**

Wave-driven cross-shore coastal dynamics are strongly related to the way in which the beach face dissipates wave energy:

- On a steeper face, the effect of plunging waves creates greater sediment mobility and may drag beach material offshore as the wave withdraws. This process is enhanced in situations where wave-induced rip currents form. Offshore movement of sediment creates a flatter beach profile, which allows the beach to better dissipate wave energy.
- Under calmer conditions, spilling waves percolate through the beach sediment; therefore, the offshore flow as the wave withdraws is much reduced compared with a plunging wave. This helps provide a gradual landward movement of sediment, which supports the beach building towards a steeper profile, depending in part on sediment grain size and tidal conditions (Wright & Short 1984, Masselink & Short 1993).

Aerial imagery for Chapman River mouth (see Section 2) shows limited sub-seasonal variation in beach width, suggesting limited 'destructive' phases for the beach flat. i.e. although the beach may accrete or erode over years, it does not experience substantial seasonal variation, such as observed along Perth metropolitan beaches (Masselink & Pattiaratchi 2001). This has been interpreted to mean that the main cross-shore processes are (i) fluctuation of beach face steepness; and (ii) longer-term trends due to coastal evolution.

No suitable information to describe beach face flattening and steepening has been identified. Consequently, *potential* for this behaviour has been evaluated using the long-term offshore wave record, by considering relative wave steepness (wave height to wavelength, the latter which is a function of wave period). This is very much an indicative measure, as these two parameters provide a simplified description of an entire wave spectrum, and are not related to the coincident water level, which strongly modulates beach response to wave conditions. Further:

1. Significant wave transformation occurs from offshore to the beach face.
2. Beach flattening or steepening due to waves is state-dependent, e.g. if a beach flattens at the start of a storm, sustained steep wave conditions will has lesser, or potentially negligible effect.

Wave steepness derived from the offshore wave record from 1998-2021 shows substantial seasonal and inter-annual variability in the occurrence of steep wave conditions.

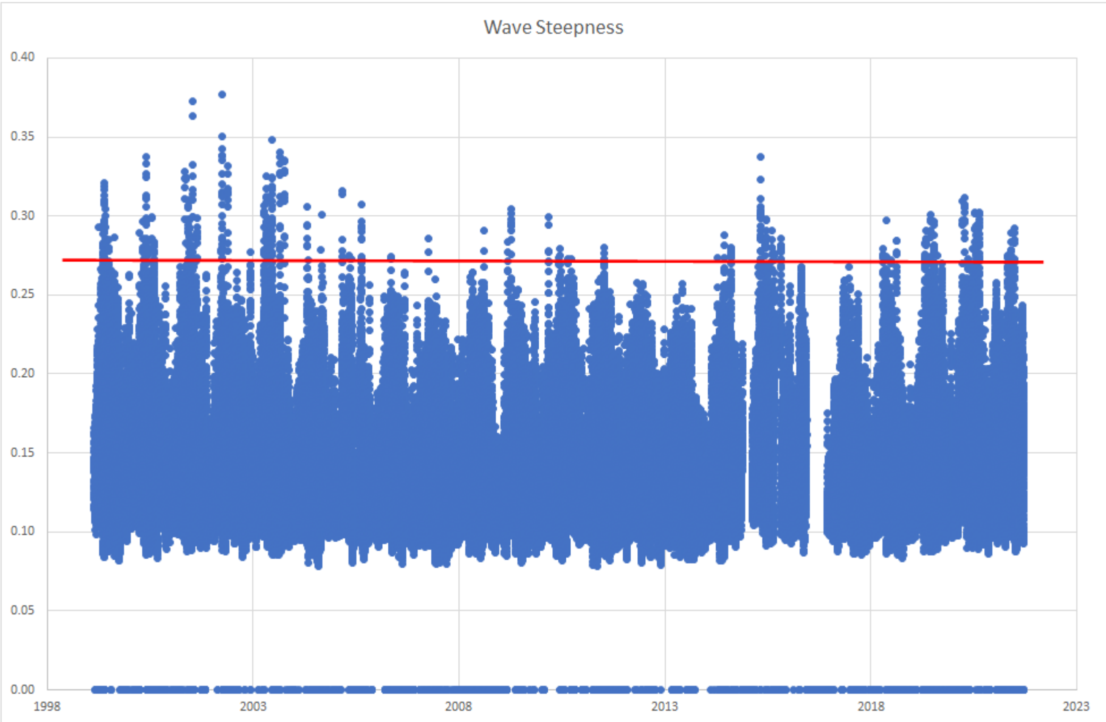



**Figure B-21: Wave Steepness Derived from Offshore Wave Time Series**

Using a relatively arbitrary cut-off (0.27), seasonal and inter-annual distributions of wave steepness have been determined (Figure B-22). These show that steep wave conditions capable of causing beach flattening are predominant between April and August. The long-term wave record indicates tremendous variation between years, with a sustained quiescent period between 2006 and 2014.

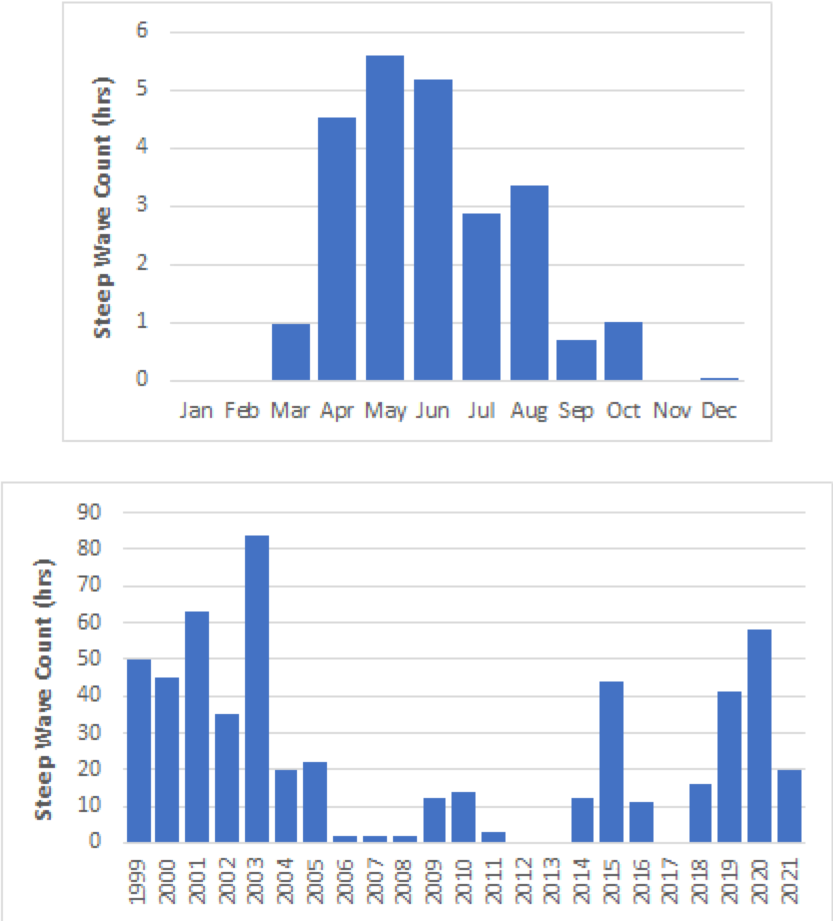



**Figure B-22: Seasonal and Inter-annual Distributions of Wave Steepness Derived from Offshore Wave Time Series**

## APPENDIX B.5 TIDAL PRISM ASSESSMENT AND ENTRANCE STABILITY

Tidal prism is the volume of water that enters an estuarine waterbody during flood flow and exits during ebb. This is an important parameter affecting entrance behaviour, as tidal flow may keep the channel scoured open, or provide a mechanism for transfer of sediment from the coast into an estuary. Tidal prism is not a constant, being affected by variation of tidal drivers, mean sea level and channel structure, with a shallow entrance impeding tidal exchange.

Although somewhat ambiguous in meaning, estuarine influence in the lower Chapman River has previously been reported as 1.5km upstream (WRC 2001). Potential range of tidal prism has been considered by estuary area (cumulative upstream), tidal range and relative tidal exchange (Figure B-23 shows area and tidal range combined). For an assumed tidal exchange efficiency of $C_T$~0.5 (e.g. linear decay over 1.5km) average tidal prism is estimated at 190,000m$^3$, varying by around +/-50,000m$^3$ within monthly variation (spring-neap), and up to 50% greater during annual spring tidal peaks in June and December. Annual mean sea level variation, which peaks in May-June and is lowest in October-November, also modifies tidal prism, but with a small influence due to the estuary having comparatively defined banks.

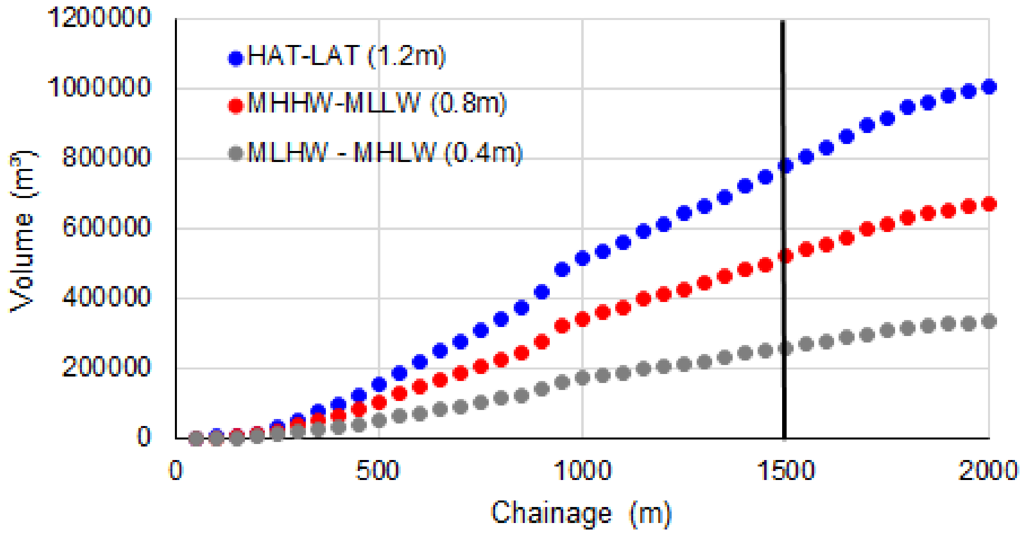



**Figure B-23: Basis for Tidal Exchange (Efficiency $C_T$ = 1.0)**

The capacity for tidal exchange to hold an entrance open has been parameterised relative to the ratio between tidal prism and alongshore sediment transport (Bruun & Gerritsen 1960). This was an empirical assessment, for substantially larger estuaries, in different sedimentary and oceanographic settings. However, derived inlet stability ratings (Table B-1) provide an indication of anticipated behaviour, based on the ratio: $r = P/M$, where:

- P – Tidal prism, typically defined at a spring tide (HLLW to MHHW).
- M – sum of the longshore transport to the inlet from either direction: as inlets are generally a sink for sediment, therefore they are more affected by gross than by net transport rate.

**Table B-1: Inlet Stability Ratings (USACE 2006)**

| Inlet Stability Ratings | |
|---|---|
| $P/M_{tot} > 150$ | Conditions are relatively good, little bar and good flushing |
| $100 \le P/M_{tot} \le 150$ | Conditions become less satisfactory, and offshore bar formation becomes more pronounced |
| $50 \le P/M_{tot} \le 100$ | Entrance bar may be rather large, but there is usually a channel through the bar |
| $20 \le P/M_{tot} < 50$ | All inlets are typical "bar-bypassers" |
| $P/M_{tot} \le 20$ | Descriptive of cases where the entrances become unstable "overflow channels" rather than permanent inlets |

A range of stability ratings are calculated (Table B-2), based on three tidal prism estimates and possible existing rates of gross littoral sediment transport (refer to Appendix B.3). The ratings suggest the channel may tend to remain open if rates of gross sediment transport are lower than 5,000m³/year (i.e. 400m³/month).

**Table B-2: Chapman River Entrance Tidal Stability Ratings (r)**

| | | Est. Average | | | Annual Max |
|---|---|---|---|---|---|
| | | P = 140,00 | P = 190,00 | P = 240,00 | P = 285,000 |
| (Min) Est. Sed. Transport (Max) | M = 2,000 | 93.3 | 126.7 | 160.0 | 190.0 |
| | M = 3,000 | 46.7 | 63.3 | 80.0 | 95.0 |
| | M = 5,000 | 28.0 | 38.0 | 48.0 | 57.0 |
| | M = 8,000 | 17.5 | 23.8 | 30.0 | 35.6 |
| | M = 10,000 | 14.0 | 19.0 | 24.0 | 28.5 |
| | M = 17,000 | 8.2 | 11.2 | 14.1 | 16.8 |
| | M = 20,000 | 7.0 | 9.5 | 12.0 | 14.3 |

Legend (shading): Open; Offshore Bar; Channel Through; Bar Bypass; Closed

Seasonal and sub-seasonal variation of tides and alongshore sediment transport can rapidly vary the relative likelihood for closure of the inlet. Increased likelihood of closure occurs during neap tides, or when there is a high rate of alongshore sediment transport, although the entrance can remain open during a neap tide phase if there is low wave action.