REPORT

Emu Point to Middleton Beach Coastal Adaptation and Protection Strategy

Coastal Vulnerability Study and Hazard Mapping

Part 1 ï Coastal Processes and Hazard Mapping

Client: City of Albany

Reference: M&APA1558R001F004
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Executive Summary

Royal HaskoningDHV (RHDHV) has prepared this report on behalf of The City of Albany (CoA). CoA has commenced the process of completing a Coastal Hazard Risk Management and Adaptation Plan (CHRMAP) for the area of coast from Ellen Cove to the Emu Point Boat Pens. As the first stage of this process, this report presents Tasks 1 and 2 of the *Emu Point to Middleton Beach Coastal Vulnerability and Hazard Mapping Study* (CVHMS). The CVHMS is broken down in to the following tasks:

- Task 1 ï Review of available information and knowledge summary
- Task 2 ï Coastal processes assessment including numerical modelling
- Task 3 ï Coastal vulnerability assessment
- Task 4 ï Adaptation options assessment
- Task 5 ï Temporary coastal monitoring and management plan

The main objective of this phase of the work has been to complete a coastal hazard assessment including hazard mapping to meet the requirements of State Planning Policy 2.6 (SPP2.6).

To ensure the objectives of the study were met, RHDHV undertook the following as part of this phase of the study:

- Literature review to summarise the current state of knowledge on coastal processes in the study area;
- Review and analysis of the various coastal monitoring datasets available for the study area;
- Development and calibration of numerical modelling tools and the application of these tools in understanding the coastal processes and hazards in the study area;
- Development of a working conceptual coastal processes model that identifies sediment sources, sinks, pathways and vulnerable areas for focus in subsequent stages of the study; and
- Definition of appropriate coastal erosion and inundation set-backs (or allowances) based on SPP2.6 and the application of the knowledge gained from the above tasks.

Current State of Knowledge

There have been several key coastal process/erosion related studies over the past 20 years that are relevant to this study. For the most part these studies have focused on Emu Point, and attempted to understand and address the erosion problems that have occurred in this area.

Some of the studies have resulted in the construction of the various coastal protection structures that presently occupy the shoreline along Emu Point. While there are some points of general agreement in the literature, the casual mechanisms for the erosion observed at Emu Point remain to be adequately resolved. This study summarises the available knowledge, including practical information on the study areaôs historical timeline and dredging and nourishment works. It then builds on the knowledge through a review of the extensive coastal monitoring data available for the area and application of numerical modelling tools.

Coastal Monitoring Data

Since late 2013, the City of Albany in collaboration with the Western Australia Department of Transport (DoT) and other state government agencies have been actively monitoring the coastal environment within the study area. The recent intensive coastal monitoring has been informed by a number of peer reviews. Community consultation and involvement has also been an integral part of both the scoping and undertaking of the monitoring program. The recent observational data is supplemented by additional historical and longer term datasets, many of which exist due to the Port of Albany operations in Princess

Royal Harbour. When combined, the observational dataset is extensive and underpins this coastal processes study. It includes: morphological data (e.g. aerial photography, repeat nearshore bathymetric surveys, beach transects), metocean data (e.g. wind, wave, current and water level measurements) and data on seagrasses and sediments.

Numerical Modelling

Numerical modelling undertaken for this study included the following main tasks:

- Spectral Wave (SW) modelling ï a 38-year wave hindcast was undertaken to better understand the nearshore wave climate along Middleton Beach and Emu Point. This resulted in defining the long-term average conditions as well as providing valuable information in important historical storms such as the August 1984 event;
- Hydrodynamic (HD) modelling ï modelling of tidal and wave driven flows including use of the hydrodynamic model to assist in understanding the historical changes that have occurred over the important Lockyer Shoal area;
- Longshore sediment transport ï this modelling looks at identifying the rate and direction of longshore transport and puts this process into context with other coastal processes.

The numerical modelling completed for this study focused on the present day (or existing) conditions within the study area. However, a number of simulations were also completed to look at future climate change conditions and historical conditions (i.e. pre-structure bathymetries). The results of the numerical modelling were used to inform the understanding of coastal processes and hazards within the study area.

Conceptual Coastal Processes Model

Based on review of available data and literature, site observations, numerical modelling and understanding of coastal processes, a conceptual model of sediment transport processes in the study area has been developed. The conceptual model identifies sediment sources, sinks, pathways and vulnerable areas for focus in subsequent stages of the study. To summarise the key points:

- Given the overall accretion observed along the study areaôs shoreline, this coastal barrier/beach system is believed to benefit from a long term supply of sediment. The source of this sediment is believed to be the deeper areas of King George Sound. Given the mechanism of supply, this process is believed to continue into the future
- Although longshore sediment transport differs in both magnitude and direction along the study area, they were seen to be quite small. Gross rate of longshore sediment transport were determined to be as high as approximately 20,000m^3/year with maximum net rates found to be only 10,000m^3/year to the west.
- Shape and morphology, both nearshore bathymetry and coastal morphology, are important to consider in determining the dominant coastal processes operating in each sector of the study area. In general, the shape is explained by the similar alignment of the beach to the incoming wave crests. This means that longshore transport is generally low.
- Historically, Emu Point was susceptible to coastal erosion from storms. Results from the 38-year hindcast show that the period between the mid-1980ôs and mid-1990s was particularly stormy and erosion concerns lead to the introduction of the coastal protection structures along Emu Point. While these structures have protected the residential areas from storm erosion, they have resulted in significant changes to the coastal processes in the local area.

- The changes observed between the pre-structure and post-structures conditions are most evident at Lockyer Shoal and along the Emu Point shoreline. These changes are summarised as:
  - Lockyer Shoal is now significantly smaller than it was prior to the introduction of the coastal structures. That is, the area of shallow water is less expansive.
  - The shoreline, including the salient at Firth Street, has eroded and rotated to be more in-line with the altered wave direction over the now smaller Lockyer Shoal.
- Based on a review of the repeat bathymetric surveys, it is believed that the main cause for the changes has been the changes to the tidal and wave driven sediment transport caused by the structures themselves. Other contributing factors include the long term loss of seagrasses and general storminess over that period including the 1984 storm.
- While it has taken almost 30-years for the area to adjust to the introduction of the coastal structures, evidence from the bathymetric surveys and seagrass re-colonisation indicates that the Emu Point/Lockyer Shoal area is beginning to stabilise again. This ónew normalôincludes a smaller shoal and a shoreline that is no longer as sandy but afforded protection by the rock coastal protection structures. The beach around the detached breakwater still provides beach amenity to the area.

A decision on whether this new normal is acceptable will be an important consideration for future stages of the CHRMAP process.

Coastal Hazard Mapping

The objectives of this investigation are to:

1. Present a knowledge summary and data analysis based on a review of the existing information including identification of any data gaps;
2. Develop calibrated and validated numerical models for the simulation of wave, hydrodynamics and sediment transport over the study area for the present day situation;
3. Simulate present day and predicted future cross shore and longshore sediment transport and shoreline evolution during storm conditions and typical seasonal weather patterns;
4. Identify sediment sources, sinks, pathways and vulnerable areas for focus in subsequent stage of the study;
5. Complete coastal hazard assessment and mapping to meet the requirements of Schedule 1 in SPP 2.6 for the planning periods: 2017 (base year), 2030, 2050, 2070, 2090 and 2120.

It is noted that the outcomes sought through meeting the above objectives will directly inform Tasks 3 to 5.

Through the above tasks an understanding of coastal processes in the study area has been gained. This understanding has been used to define appropriate allowances for coastal hazards and mapped in accordance with SPP2.6. This included:

- Adopting the following planning periods required by CoA: 2017 (base year), 2030, 2050, 2070, 2090 and 2120.
- Suitable erosion hazard allowances (S1, S2 and S3) have been defined and applied to the defined representative sectors of the study area. For the Emu Point sector, erosion hazard lines have been defined for two scenarios: with and without coastal protection structures.
- Suitable coastal inundation levels have been defined and mapped. This includes identification of low-lying areas that may be potentially impacted by wave-run-up.

The resulting hazard maps are provided in the **Maps** section at the end of this report.

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1 Introduction

1.1 General

Middleton Beach has for the most part shown long term stability, with large storms resulting in temporary short-term erosion. Emu Point has a history of coastal erosion and has experienced several storms in the past 40 years which have resulted in erosion of the shoreline. Following these events, numerous studies have been completed in an attempt to understand and address the erosion problems. Following the recommendations of these studies a series of coastal protection structures were implemented along Emu Point as well as the western section of Middleton Beach. These measures have had varying levels of success. In the short term they have provided a last line of defence to at-risk coastal infrastructure. However, in the long term these structures have resulted in displacement of the erosion issue further down the coast. URS (2013) noted; ñThe public perception of the management of the shoreline is that the construction has been reactive and has not solved the problem of erosion of the coastline of this important tourist and residential area.ò

The City of Albany (CoA) has commenced the process to complete a Coastal Hazard Risk Management and Adaptation Plan (CHRMAP) for the area of coast from Ellen Cove to the Emu Point Boat Pens. As the first stage in this process, this report is part of a series of reports that present the Emu Point to Middleton Beach Coastal Vulnerability and Hazard Mapping Study (CVHMS). The CVHMS can be broken down in to the following tasks.

- Task 1 ï Review of available information and knowledge summary
- Task 2 ï Coastal processes assessment including numerical modelling
- Task 3 ï Coastal vulnerability assessment
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- Task 5 ï Temporary coastal monitoring and management plan

CoA has appointed Royal HaskoningDHV (RHDHV) to undertake Tasks 1 and 2. This report presents the finding of these tasks and is entitled: *Emu Point to Middleton Beach Coastal Vulnerability and Hazard Mapping Study - Stage 1: Coastal Processes and Hazard Mapping*. Tasks 3 to 5 have been appointed to EvoCoast and will be reported separately. The processes, workflow and expected outcomes are shown in **Figure 1**.

It is noted that the Coastal Vulnerability and Hazard Mapping Study has been funded by the City of Albany and Department of Transport (DoT) through their Coastal Adaptation and Protection (CAP) grant program.

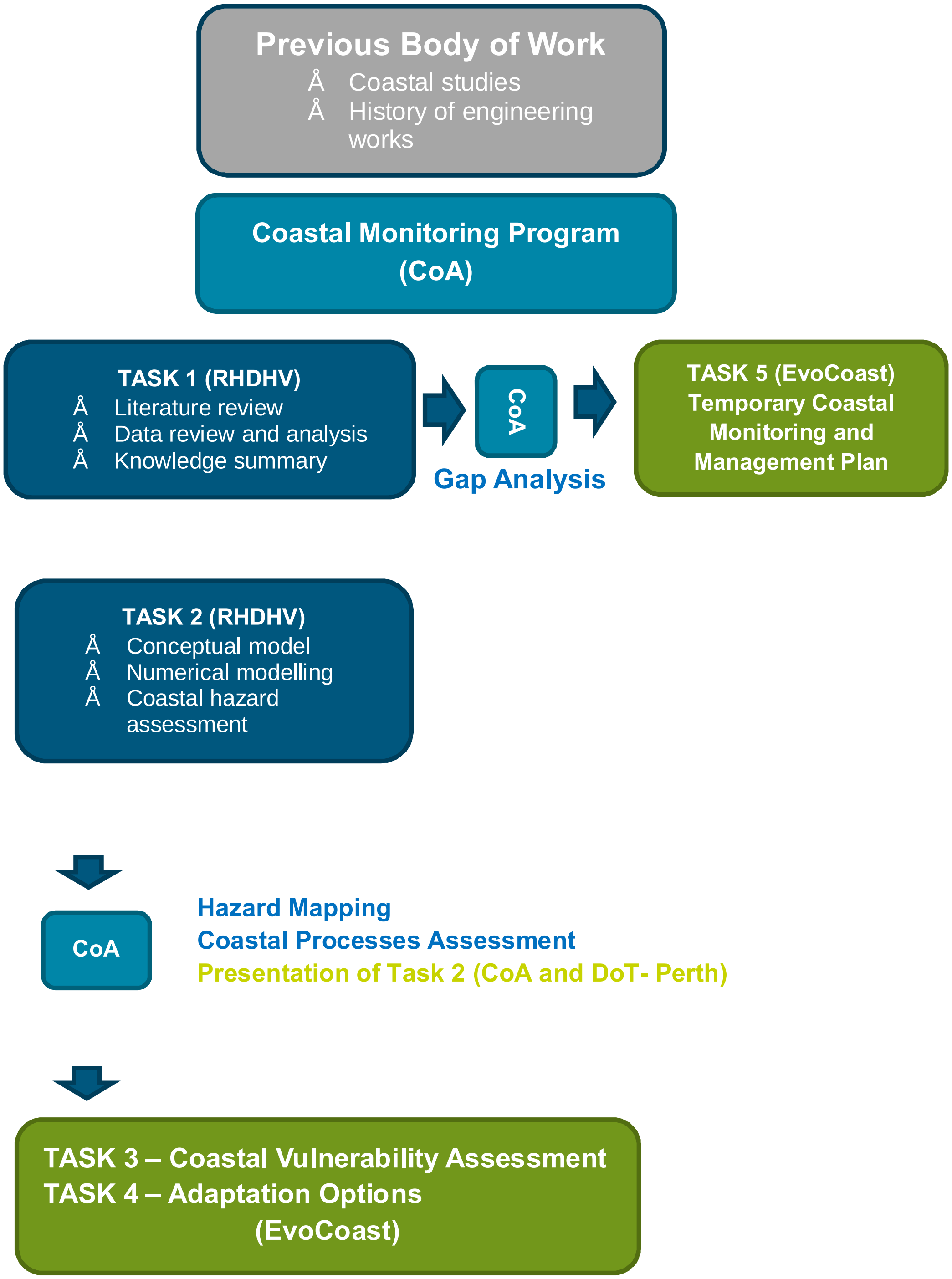


Figure 1 Overview of Emu Point to Middleton Beach Coastal Vulnerability and Hazard Mapping Study

1.2 Study Objectives

The objectives of this investigation are to:

1. Present a knowledge summary and data analysis based on a review of the existing information including identification of any data gaps;
2. Develop calibrated and validated numerical models for the simulation of wave, hydrodynamics and sediment transport over the study area for the present day situation;
3. Simulate present day and predicted future cross shore and longshore sediment transport and shoreline evolution during storm conditions and typical seasonal weather patterns;
4. Identify sediment sources, sinks, pathways and vulnerable areas for focus in subsequent stage of the study;
5. Complete coastal hazard assessment and mapping to meet the requirements of Schedule 1 in SPP 2.6 for the planning periods: 2017 (base year), 2030, 2050, 2070, 2090 and 2120.

It is noted that the outcomes sought through meeting the above objectives will directly inform Tasks 3 to 5.

1.3 Study Area and Report Terminology

The study area extends from the western end of Middleton Beach (Ellen Cove) to the Emu Point Boat Pens and is shown below in Figure 2. Ellen Cove (the main recreation zone at Middleton Beach) is located approximately 3.5kms from the centre of Albany. Emu Point is located approximately 8.5kms from the centre of Albany at the North Eastern tip of Middleton Beach. The entire project falls within the City of Albany municipality.

It is noted that Middleton Beach and Emu Point are integral to the Albany landscape. Given their relatively mild wave climate and proximity to town, Middleton Beach and the Emu Point area are key recreational areas. Studies by the City have shown that the area is highly valued for its naturalness and range of recreational amenity options available for local residence and visitors alike.

The key physical features of the eastern study area adjacent to Emu Point are shown in **Figure 3**. This report adopts the terminology presented in this figure. While every effort is made to use terminology that provides an accurate description, compromise is also required such that the terms are also familiar to key stakeholders and the local community based on the terms adopted in previous coastal management reports and local vernacular.

Figure 2 Map of study area

Figure 3 Aerial image showing key features of the Emu Point study area

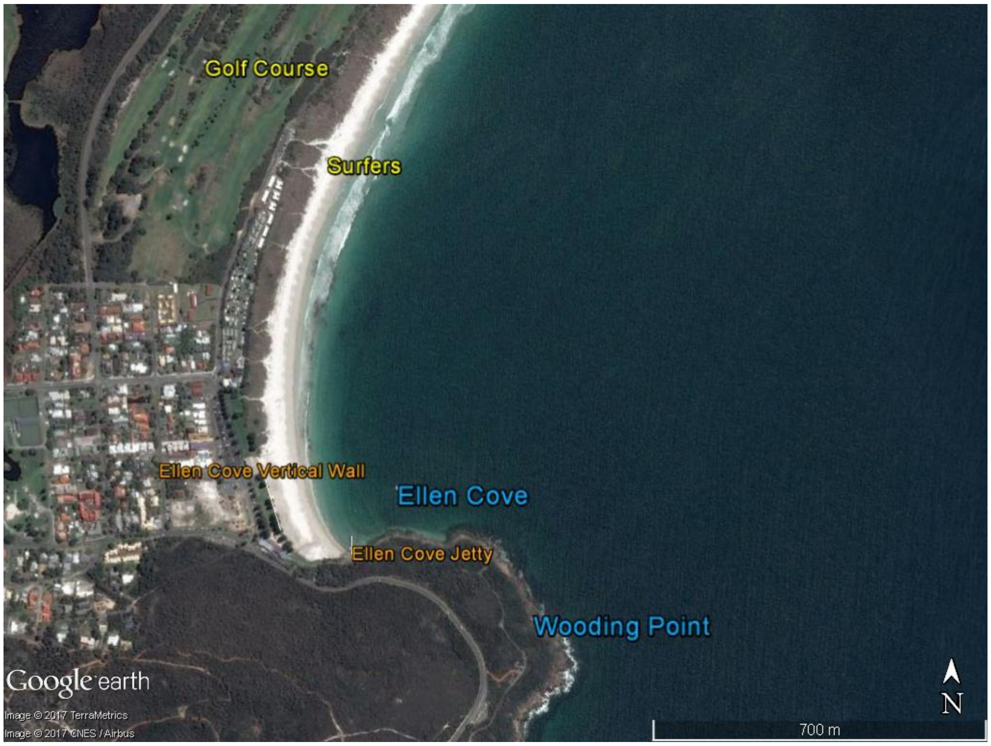


Figure 4 Aerial image showing key features of the Ellen Cove study area

1.4 Report Structure

The structure of this report can be summarised as follows:

- Based on a review of literature, background information summarising the key issues that relate to the coastal processes study for this project is presented in **Section 2**;
- **Section 3** outlines the review of the available coastal monitoring data at Middleton Beach and Emu Point, including presentation of a gap analysis (see *objective 1*);
- The development of the numerical modelling systems including model setup, boundary conditions and model calibration and validation is covered in **Section 4** (see *objective 2*). This section also provides a summary of the result of the model simulations including the present day and future prediction of crossï shore and longshore sediment transport (see *objective 3*);
- **Section 5** provides a knowledge summary in the form of a conceptual coastal processes model. This working conceptual model identifies sediment sources, sinks, pathways and vulnerable areas for focus in subsequent stages of the study (see *objective 4*);
- The hazard mapping is presented in **Section 6** (see *objective 5*);
- **Section 7** outlines the references and sources of information.

2 Literature Review

2.1 Preamble

There have been several key coastal process/erosion related studies over the past 20 years that are relevant to this study. For the most part these studies have focused on Emu Point, and attempted to understand and address the erosion problems that have occurred in this area. Some of the studies have resulted in the construction of coastal protection structures. There are also a number of other relevant studies that are relevant to Middleton Beach, Oyster Harbour and King George Sound. These references are listed in **Section 7**.

The aim of the review of existing literature was to refine our current understanding of issues that were specific to this coastal vulnerability study. The following sections provide a brief summary of the relevant information from these publications. Other sections of this report include references to these publications where relevant.

2.2 Historical Timeline in the Study Area

Given the history of changes in the study area it is important to summarise a timeline which will be referred to throughout this report. A timeline of the key natural events, studies and construction of coastal structures is provided in **Table 1**. **Figure 5** provides an overview of the construction of coastal protection structures at Emu Point.

A full storm history based on the 38-year wave hindcast model is provided in **Section 4.3.4**.

Figure 5 History of construction of coastal structures at Emu Point (source: PRDW, 2013a)

Table 1 Study area timeline

Year	Event
1921	**Storm** - A south-easterly gale lasting several days eroded Emu Point back to the present day Emu Beach Café. *"The big south easterly gale of 1921 lasted for many days….Emu Point disappeared. The end of Johnson's Guest House [now Emu Beach Café site] stood precariously over the channel which dropped sheer into deep water. Several rooms had to be dismantled." (Maritime Albany Remembered, Douglas et al, 2001 in PRDW, 2013a).*
1960ôs	**Structure** ï Emu Point Boat Pens were constructed.
1972	**Structure** ï Emu Point Baths constructed (fixed jetty)
August 1984	**Storm** ï Sever south-easterly storm (approximately 100-year ARI event) at Emu Beach caused considerable erosion, including the loss of beach and foreshore. Several houses were also threatened. Loss of a significant area of seagrass meadow. See **Appendix A** for historical photos.
1985	**Structure** ï The ñBrick wallò (i.e. the rock wall at Oyster Harbour Beach) was built (URS, 2012b).
Mid-1980ôs	**Structure** ï Training wall was built along western bank of the Emu Point Channel, groyne extension was added soon after.
May 1987	**Storm** ï Significant erosion at Emu Point. South/south-westerly storm persisted with winds at 15-25m/s (30 ï 50 knots) for over 4 days. The eroded beach was then re-nourished with sand after this event. See **Appendix A** for historical photos.
1987 - 1988	**Investigations** - Following severe erosion during a storm in May 1987, the Department of Marine and Harbours, WA (DMH) carried out investigations into the problem and subsequently nourished the beach and built two groynes.
1989	**Structure** ï Construction of an 80m southern groyne as an extension to the training wall at Emu Point was completed in October 1989. These works also included 10,000m^3 of nourishment. The purpose of the groyne was to arrest the erosion of the beach to the south and west of Emu Point and stabilise the point (URS, 2012b).
1991	**Structure** - A second northern groyne was built in August 1991 to stop the erosion of the recreational beach to the north of Emu Point in Oyster Harbour (SKM, 1993).
August 1992	**Storm** - 1992 the southern beach to the west of Emu Point (known as Emu Beach) again suffered erosion. As property was again threatened, there was considerable local concern about the effectiveness of the DMH works. High tide and heavy seas generated by southerly winds caused severe erosion, taking about 4m of the southern beach sand bank.
1992	**Investigation** ï Following the construction of the two groynes DHM produced a report that reviewed the effectiveness of these coastal protection structures (DHM, 1992). The considered options were: (i) retain the groyne and monitor (ii) removal of the groyne or (iii) further works such as nourishment, realignment or extension. This report concluded that the groynes should be retained as the southern groyne is serving its purpose by stabilising the western beach with downdrift (northern side) ñdiminishing as time progressesò.
1993	**Investigation** - Following winter storms in 1992 the shoreline to the southwest of Emu Point was eroded, presenting a risk to residential property. Sinclair Knight was engaged by the Town of Albany to complete a coastal protection study that formulated a conceptual model of the dominant coastal processes contributing to the physical changes of Emu Beach. An estimation of the net longshore transport is provided as of the order 10,000m^3/year from west to east. The cross-shore transport is also estimated as a loss of approximately 2,000m^3/year from the area protected by seagrass and as much 4,000m^3/year where there is no protection offered by the seagrass.
1995	**Structure** - Detached breakwater was constructed with 36,000m^3 of sand used to nourish the area in the vicinity of the detached breakwater (URS, 2012b).
1999	**Erosion -** Severe erosion event occurred without storm catalyst. Emu Beach experienced high mean sea levels during the La Nina Event occurring between mid-1998 to early-2001. Erosion of 600m long beach from Boongarrie St to south-west.
1999	**Structure** - Emergency rock revetment constructed in response to erosion event in 1999 (DoT, 2000).

Year	Event
2000	**Investigation** ï DoT (2000) conducted a study that examined aerial photography from 1957 to 2000 and reviewed hydrographic survey data taken in 1994 and 1999. The cause of erosion in 1999 was attributed to unusually high mean sea levels. Six management options were investigated: managed recession, sand re-nourishment, headlands, groynes, a seawall and sand-filled geofabric tubes for protection. The study recommended that unless severe recession of the foreshore was seen to continue, the long term management of the beach should be delayed and re-evaluated in 2003.
2001	**Structure** ï Rock revetment was extended further to the west.
2003	**Erosion** - Extreme storm event and unusually high sea levels were experienced at Emu Beach during La Nina Event occurring between early-mid 2003 (URS, 2012b).
2003	**Investigation** ï MP Rogers undertook a study that analysed: 1. Changes in the coast based on survey/aerial photos of Emu point taken between 1957-2001; 2. Correlations between seagrass loss and coastal erosion; 3. The metocean conditions driving the coastal processes at Emu Point. Report includes a wealth of statistics including hindcast wave data, wave modelling data, water levels in Albany from 1994-2002, tides, current and wind regime etc.
2005	**Structure** ï Final extension of the rock revetment, extended further to the west.
2007	**Structure** ï Emu Point Baths converted from fixed jetty to floating pontoon
2011	**Structure** ï To avoid the relocation of a dual use path at the end of the Emu Pont rock revetment a geotextile sand container seawall (sandbag revetment in **Figure 5**) was constructed in August 2011. This caused immediate downdrift erosion. The dual use path was fenced off in January 2012 due to public safety risks from erosion occurring at end of geotextile seawall. See **Appendix A** for historical photos.
2012	**Investigation** ï URS completed studies to determine a long-term preferred coastal management option/strategy for the coastline between Middleton Beach and Emu Point. The findings were documented in a series of reports (URS 2012a, 2012b, 2012c and 2012d), including reports on structural condition assessment, coastal processes, data and option development and scheme development. In regard to protection strategies, URS recommended the immediate implementation of: (i) construction of new block wall and beach nourishment at Oyster Harbour Beach, and (ii) remedial work to the training wall at Emu Point. Further investigations were recommended into the feasibility of a preferred coastal protection scheme along Emu Point Beach. The preferred schemes included: detached breakwaters, artificial reefs and beach nourishment options. Further studies were also recommended for the enhancement of Oyster Harbour Beach, with concepts including the extension of the norther groyne and significant beach nourishment.
2012	**Investigation** - DoT produced drawings showing the variation in the vegetation line along Middleton Beach and around Emu Point (DoT, 2012).
2013	**Investigation** - On behalf of the City of Albany, PRDW completed a series of reports in 2013 including the main report titled *"Emu Point to Middleton Beach Coastal Adaptation and Protection Strategy"*. The PDRW reports reviewed the 2012 URS studies including: a review of coastal processes, coastal structures, coastal monitoring data and management scheme (or options). PRDW also reviewed a number of schemes suggested by the local community. Recommendations from PRDW (2013b) included: (i) the on-going collection of key coastal monitoring data, (ii) implementation of beach nourishment at Oyster Harbour Beach, remediation of the training wall at Emu Point and sand nourishment in front of the Emu Point seawall (or rock revetment), (iii) a trial groyne be constructed west of the Emu Point seawall to trial a community suggested scheme, and (iv) further investigations (detailed modelling and design) of two permanent coastal protection schemes at Emu Point.
2012 - 13	**Structure** - The dual use path at Emu Point was also relocated landwards.
2014	**Structure** ï A new block wall was constructed at Oyster Harbour Beach to replace the old ñBrick wallò
2014	**Structure** ï In April 2014, CoA installed temporary geotextile groynes to the west of the rock seawall at Emu Point. When the groynes were constructed, approximately 10,000m^3 of sand nourishment was placed in the area. The nourishment was sourced from Ellen Cove (PRDW, 2015). The groynes were installed as a trial to assess what the effect would be of a shore perpendicular structure on the beach.

2.3 Dredging and Nourishment Works

Dredging, disposal of dredged material in the nearshore (not specifically for beach nourishment) and beach nourishment has historically occurred in the study area. This has generally been undertaken by the Department of Transport, the City of Albany or ôSouthern Portsô (Albany) (PoA, 2012).

In order to better understand the sediment budget to the study area it is necessary to have an understanding of the timing, placement areas and quantities of sand sized sediment placed in the vicinity of Middleton Beach and Emu Point. Table 2 provides a summary of dredging and placement/nourishment volumes, while Figure 6 provides approximate placement locations.

Table 2 Summary of dredging and placement volumes

Year	Dredging Volumes (m^3)	Placement Volumes (m^3)	Description
1964 to 1965	54,000m^3	54,000m^3	Between November 1964 and June 1965, capital dredging was used to create the Emu Point Boat Pens and approach channel. It is believed that the dredge material was used to reclaim the area that is currently occupied by the marinaôs car park at the northern end of Oyster Harbour Beach.
1966 to 1967	2,050m^3	Unknown	Additional dredging of Emu Point Boat Harbour between November 1966 and February 1967.
1971	9,000m^3	9,000m^3 assumed to be side-cast	Sand dredged for construction of Emu Point Baths (fixed enclosure). While the placement volumes/locations are unknown, based on a review of aerial photography (see **Section 3.3.1**) it has been assumed that this material was side-cast to the area immediately to the north of the dredged area.
1977 (June to August)	811,000 m^3 of sand	Unknown	Sand was dredged to create new approach channel at 12.2m depth. No information is available on the placement volumes other than the dredge material was either placed in the spoil grounds at Middleton Bay (see **Figure 6**) or was used for reclamation within ôSouthern Portsô (Albany).. In **Figure 6** there is a clear deposition feature in the area marked as Spoil Ground on the Chart (AHS, 2010). A second and larger deposition area shown further out in King George Sound has been identified in the comparison of surveys. This location was also noted in a historic plan from PoA.
May 1978 to June 1979	1,250,000m^3 of sand 21,200m^3 of rocks and boulders.	Unknown	These were used for reclamation to construct an area for future berth extensions. It is unclear whether or not all materials ended up being used for reclamation. It is unclear as to where this material was sourced however it is assumed it was dredge material from the PRH channel and the redesign of the wharf facility.
1985	Unknown	Unknown	Dredging undertaken as part of a maintenance programme to clear silt from a large storm event in 1984. Volume and locations unknown. It is believed the dredging focussed on the approach channel but the exact details are not known.
1987	Unknown	Unknown	Sand was placed along Emu Point and adjacent areas after severe south/south-westerly storms eroded Emu Point and adjacent beaches. The source of the sand in unknown.
1989	Unknown	10,000m^3	Sand was placed on the beach at Emu Point as part of construction of the southern groyne.
1995	Unknown	30,000m^3	As part of the construction of the detached breakwater, the Emu Point Boat Harbour and approach channel was dredged. The dredged material was used to form the beach behind the breakwater (DoT, 1995).
Unknown	Unknown	Unknown	Maintenance dredging of the Emu Point Boat Harbour.

2013	2,250m^3	2,250m^3	Sand removed from Middleton Beach. 750m^3 was placed at the east end of Oyster Harbour Beach in front of the rock wall; 1500m^3 was placed west of the Emu Point Sand Bags.
2014		10,000	Sand was place on the beach to the west of the rock revetment as part of the construction of the trial groynes. This sand was sourced from Ellen Cove (PRDW, 2013a).

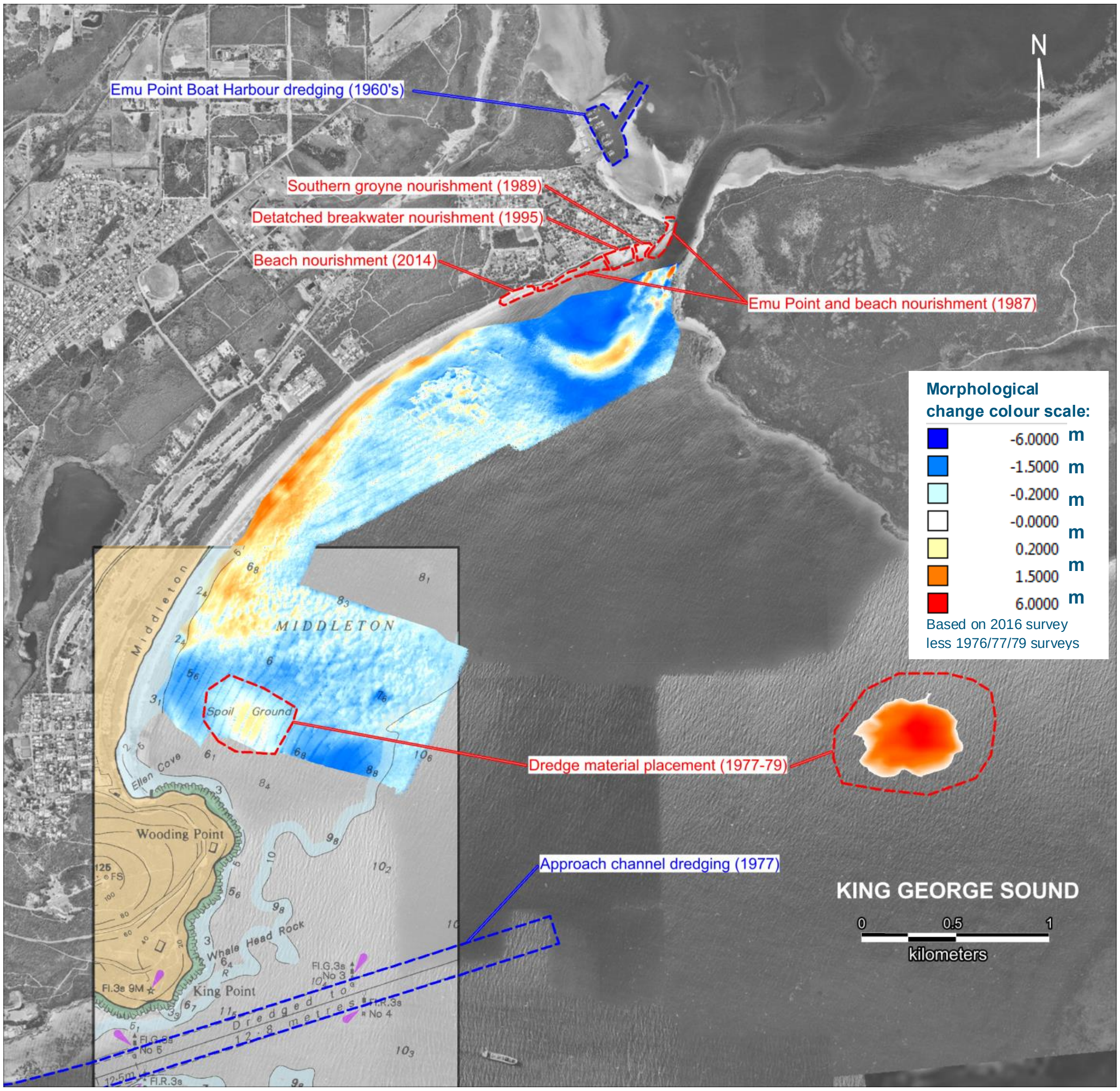


Figure 6 Location of placement areas in the vicinity of Middleton Beach and Emu Point

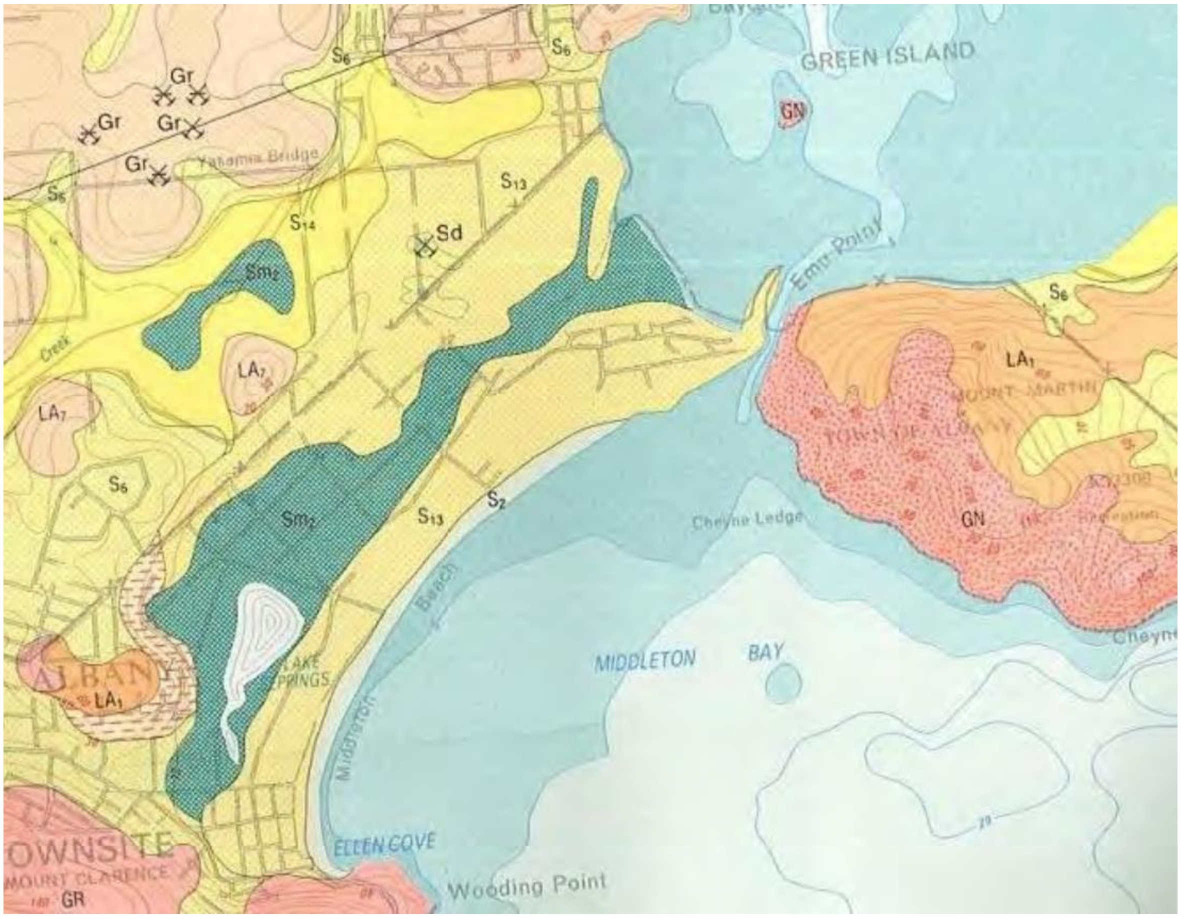
2.4 Geology and Geotechnical Conditions

Based on geology maps of the area, the sediment around Middleton Beach and Emu Point is principally made up of medium grained quartz sands of Holocene age (see **Figure 7**, Maps Unit S_2 and S_{13}). At the start of the Holocene (11,000 years ago) sea levels rose to reach a maximum of about 10m above present day levels, before lowering to stabilise at todayôs levels around 6,500 years ago.

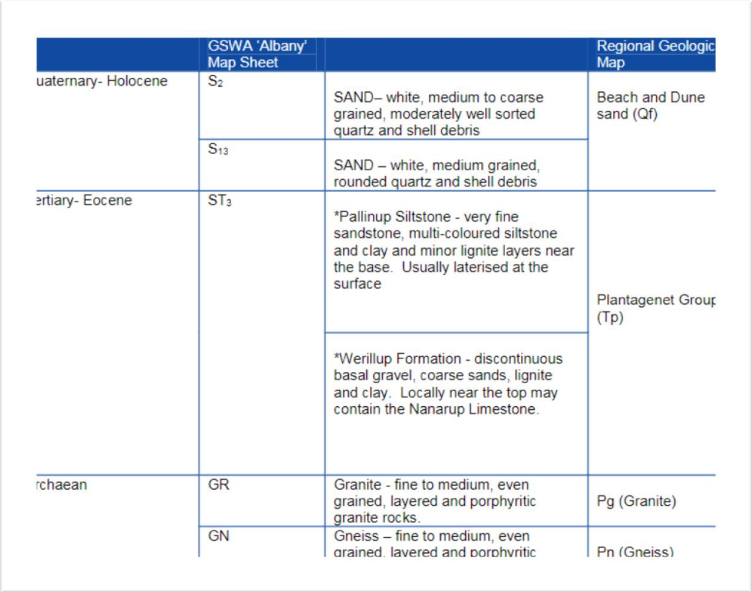
Middleton Beach then formed as a sandy coastal barrier (i.e. beach and dune systems) extending from the granite headland at Wooding Point to terminate at Emu Point. At Emu Point the barrier system terminates with a sand spit that has caused a reduction in the width of the Oyster Harbour entrance to its present dimensions. Siltation behind the coastal barrier formed the low lying swamp area of Lake Seppings (URS, 2012).

A geotechnical investigation carried out at LandCorpôs proposed residential development site (former lot 1512 and lot 1523 Emu Point Drive) indicates that the marine sand ground layer extends below the 10m borehole depth (Douglas Partners, 2007).

Based on the areas geology and limited geotechnical information available (see Section 2.5) it has been assumed that the unprotected sections of beach are composed of unconsolidated marine sands and are subject to wave erosion. Additional geotechnical investigations may expose rock or other hard substrate that are less prone to erosion.



Legend of relevant map units (source: URS, 2012)



	GSWA 'Albany' Map Sheet		Regional Geologic Map
uaternary- Holocene	S_2	SAND– white, medium to coarse grained, moderately well sorted quartz and shell debris	Beach and Dune sand (Qf)
	S_{13}	SAND – white, medium grained, rounded quartz and shell debris	
ertiary- Eocene	ST_3	*Pallinup Siltstone - very fine sandstone, multi-coloured siltstone and clay and minor lignite layers near the base. Usually laterised at the surface	Plantagenet Grou (Tp)
		*Werillup Formation - discontinuous basal gravel, coarse sands, lignite and clay. Locally near the top may contain the Nanarup Limestone.	
rchaean	GR	Granite - fine to medium, even grained, layered and porphyritic granite rocks.	Pg (Granite)
	GN	Gneiss – fine to medium, even grained, layered and porphyritic	Pn (Gneiss)

Figure 7 Geology of Middleton Beach, Emu Point and surrounds (source: GSWA 1:50,000 Albany Map Sheet)

2.5 Geomorphology

The study area consists of the sandy coastal barrier extending between Wooding Point and Lake Seppings, which is made up of three zones: Middleton Beach, Emu Point and Oyster Harbour. The study area lies within King George Sound.

King George Sound is a large embayment on the south coast with wide open bays to the east and west. The Sound is the remains of the river system that drained the land under lower sea levels and it has been shaped by sea levels higher than the present day level. Sediment movement within the sound is limited to large storm events and minor movements under tidal and wind induced currents (URS, 2012a). According to GEMS (2007) the main source of water movement is the wind driven circulation.

The study area experiences micro-tidal fluctuations with a spring tidal range of approximately 0.4m.

The overall morphology across the land sections (i.e. sub-aqueous) of the study area are well represented in the topographic LiDAR map given in **Figure 8**.

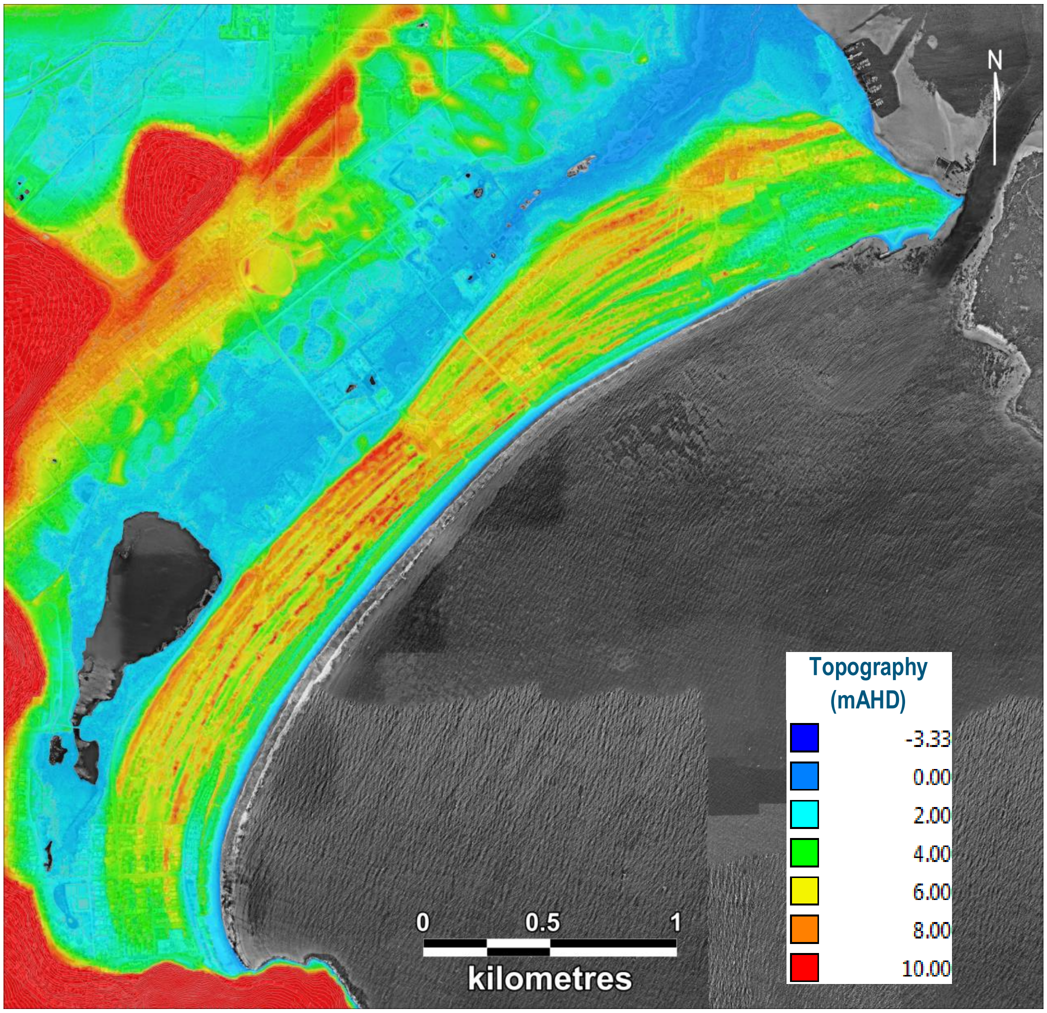


Figure 8 Topographic features within the study area as shown in the LiDAR data, (20/12/2012, FUGRO SPATIAL SOLUTIONS PTY LTD)

2.5.1 Sediment Cells

Historically, Middleton Beach, Emu Point and Oyster Harbour Beach has functioned as one large sediment cell, comprised of three distinct sediment transport sub-cells. For the purposes of this study, and following what was adopted in the (PRDW, 2013a) study the sediment transport model is considered in terms of its constituent sub-cells (or compartments). The three compartments, shown in Figure 11, are as follows:

- Middleton Beach: wave dominated;
- Emu Point: wave and tide dominated; and
- Oyster Harbour Beach: tide dominated / estuarine.

Review of the local geomorphology shows that the section of shoreline extending from Middleton Beach to Emu Point is essentially closed to alongshore losses. That is, sediment is not expected to be lost past the rocky shorelines to the east and west.

Figure 9 Sediment transport sub-cells (source: PRDW, 2013a).

Middleton Beach

Middleton Beach is around 3.5km in length with headland protection at its southern end and Emu Point Beach at its northern end. Deep within King George Sound, the shoreline of Middleton Beach is generally well aligned to incoming refracted swell and the longshore transport gradients are relatively low.

The wave climate affecting Middleton Beach is unidirectional long period swell with a low average wave height (average significant wave height (H_s) of approximately 0.6m). Despite its proximity to the Southern Ocean and its large westerly to south-westerly swells, Middleton Beach has a low average wave height due to the protection afforded from Flinders Peninsula and Bald Head. South west ocean swells wrap into the South Channel and are aligned to the bottom contours of King George Sound prior to their arrival at Middleton Beach (see **Figure 10**).

The western end of the beach is a classic log-spiral (or conical bay) with the beach at Ellen Cove being in the lee of Wooding Point. The Middleton Beach sediment compartment is connected to the sediment transport processes occurring along the shoreline around Emu Point and in the tidal Emu Point Channel.

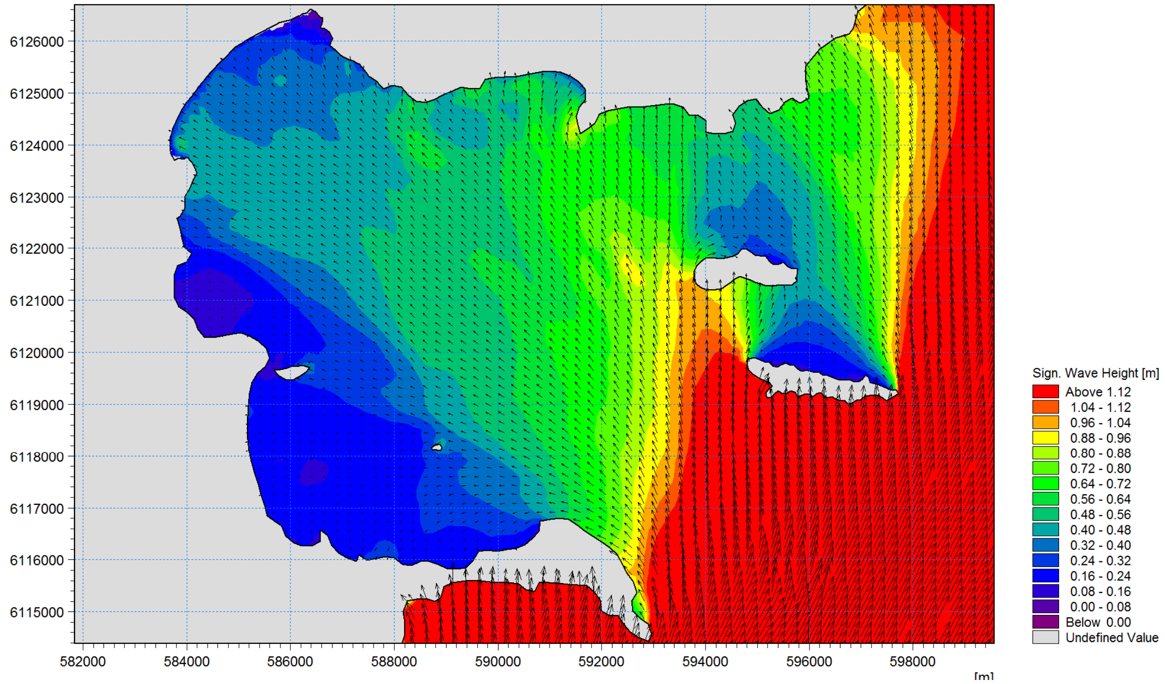


Figure 10 Example of south west swell (offshore) entering and refracting within King George Sound (note pattern of refraction including wave focusing 'streak' centred on 'Surfers' area)

Emu Point and Lockyer Shoal

This area is a complex mix of tidal and wave driven sediment transport processes interacting with the sandy/revetment-protected shoreline extending around Emu Point. In its former natural state Emu Point was a sand spit.

Lockyer Shoal is an ebb tide delta that forms part of the beach morphology along Emu Point. It is practically covered by seagrass *P. coriacea*. The seagrass beds over Lockyer Shoal and along Middleton Beach act to entrap and retain sand under benign conditions. The extent of seagrass coverage is expected to be an important consideration for the coastal processes. Seagrass coverage has varied in the past. For example, prior to a large south-easterly storm that occurred in 1984, the Lockyer Shoal was extensive, shallow and well covered in seagrass. Its shape and shallow depth caused waves to focus and break, creating a salient shoreline feature in its lee, óknown as the Firth St Salient.ô

Oyster Harbour Beach

Oyster Harbour Beach is the sand beach along the south-western corner of Oyster Harbour. In a natural state this beach is connected to Emu Point and Middleton Beach via the sand spit at Emu Point and tidal circulation within the Emu Point Channel.

Well sheltered from swell waves within King George Sounds, Oyster Harbour is characterised as being an estuarine environment. In this low wave energy environment, tidal water level fluctuation and tidal currents predominately control the morphology. Like much of Oyster Harbour, Oyster Harbour Beach has gently sloping shores.

Oyster Harbour has a catchment of approximately 378,000 hectares and drains through Kalgan River, King River and Napier Creek. These rivers have supplied sediment in the past however it is now considered that there is very little sediment within the catchment to be mobilised and therefore these rivers are not considered a source of sediment (DAF, 2007).

2.6 Coastal Processes

Each of the historical reports has completed a range of studies into the sites coastal processes, including assessments of the shoreline movement and changes to features such as Lockyer Shoal, assessment of the water levels and offshore wave conditions and consideration of the role of seagrass in the protection of the shoreline. The following summarises some of the key points taken from these reports.

In regard to the erosion observed at Emu Point and over the Lockyer Shoal the various reports:

- All reports agree that this is a complex area with fine balance between tidal, wave driven and fluvial forces determining the morphological response of the beach and ebb tide delta (Lockyer Shoal).
- While the reports do not entirely agree on the cause of the observed erosion, there is general agreement that the loss of seagrass meadows and the storm in 1984 were key factors in the subsequent erosion. Other factors proposed in the literature include:
    - The various coastal structures introduced at Emu Point have modified the natural sediment transport pathways. Specific mechanisms offered include:
        - Construction of the training wall and groynes at Emu Point has resulted in a disconnection of the Emu Point and Oyster Harbour sediment cells. That is, the net addition of sediment to the Emu Point cell has ceased (PRDW, 2013a).
        - Disruption of a clockwise sediment circulation that operated between Emu Point, Emu Point Channel and Lockyer Shoal due to training and coastal structures that changed the flow regime of Emu Point Channel (PRDW, 2013a).
        - Wave energy reflected from the rock revetment has resulted in scour and a general lowering of the seabed in front of the revetment (URS, 2012 and (PRDW, 2013a).
    - Erosion of Lockyer Shoal has resulted in reduced nearshore wave refraction and a subsequent straitening of the shoreline around the Firth Street salient (MP Rogers, 2003);

  - Increased wave energy reaching the shoreline due to elevated water levels (possibly associated with oceanographic events such as La Nina) and significant storms (DoT, 2000).

  - Both URS (2012) and PRDW (2013a) provide conceptual coastal processes models and shoreline recession lines for Emu Point, in both the undeveloped and developed scenarios. One of the major differences is that URS (2012) argue that without the structural intervention that followed the 1984 storm, erosion at Emu Point would have continued as a natural development of the bay. However, PRDW (2013a) argue that without human intervention (and in the absence of major coastal storm), Emu Point would have recovered and re-established at an equilibrium beach plan shape similar to the average shoreline prior to the storm.

In regard to the direction and rate of net longshore drift in the Emu Point area:

- Using approximate calculation methods SKM (1993) believed that the net transport along Emu Beach was from the west toward the east (i.e. towards Oyster Harbour). The transport rate was estimated to be roughly 8,000m^3/yr. along the western portion of Emu Beach and roughly 10,000m^3/yr. along the portion east of Boongarrie Street (SKM, 1993). This method suggested that swell waves did not contribute to longshore transport whereas other methods indicate that swell waves are the most important driver of longshore transport.
- MP Rogers calculated the rates of longshore transport along Emu Point Beach using the equations presented by Kamphuis (2000) and 6.5 years of hindcast wave modelling results. The calculated sediment transport rates were calibrated to volumetric changes observed in surveys over the Lockyer Shoal area. The average net longshore transport rate was 11,000m^3/yr. from east to west (i.e. towards Ellen Cove).
- Based on a review of aerial photography and beach surveys taken after the installation of the trial groynes. PRDW (2013c) concluded that the net longshore transport is directly to the west.

The proposed management schemes suggested in each report are similar with a common recommendation that detached breakwaters are used to stabilise the shoreline, such as the DoT (2000) proposal.

It is suffice to say that while there are some points of general agreement in the literature, the casual mechanisms for the erosion observed at Emu Point remain to be adequately resolved. It is noted that the previous reports:

- A lack of coastal monitoring data and detailed numerical modelling to underpin conceptual coastal processes models presented in the reports;
- While some of the reports provide indicative possible future shoreline positions (or erosion set-backs), none of the reports provide coastal hazard mapping in accordance with State Planning Policy 2.6 ï State Coastal Planning (SPP2.6);
- None address the coastal inundation risk due to elevated ocean water levels (tide and storm surge) and wave set-up and run-up.

3 Coastal Monitoring Data

3.1 Preamble

Since late 2013, the City of Albany in collaboration with DoT and other state government agencies have been actively monitoring the coastal environment within the study area. In 2015, the City engaged PRWD to undertake a review of the coastal data collected during this time (i.e. 2013 to 2015), identify gaps and make recommendations for on-going coastal monitoring (PRWD, 2015c). Community consultation and involvement has also been an integral part of both the scoping and undertaking of the monitoring program. The observational data collected by the most recent strategic coastal monitoring program underpins this coastal processes study.

The observational data is supplemented by additional historical and longer term datasets, many of which exist due to óSouthern Portsô (Albany) operations in Princess Royal Harbour. This observational data will be used in various capacities throughout the study, including:

- Analysis and interpretation to provide a conceptual understanding of the important process affecting erosion and sediment transport along Middleton Beach and Emu Point.
- Long data sets are particularly valuable to establish the natural variability in metocean conditions, particularly in the magnitude and frequency of extreme events.
- Input data to establish the various numerical model systems. Quality input is a pre-requisite for quality model output.
- Calibration and validation of the numerical models. This process ensures that the model is able to provide an accurate representation of this coastal system.

This section presents a summary of the available data, a targeted analysis of the data most relevant and important to this study, identifies any remaining gaps and makes recommendations on future coastal monitoring.

3.2 Summary of Coastal Monitoring Data

Table 3 presents a summary of the coastal monitoring data available for use in this study.

Table 3 Summary of coastal monitoring data

Data Type	Date(s)/Length of Record	Source	Location	Description
Morphological Data (Bathymetric and Topographic Surveys, Beach Transects and Aerial Photography)				
DoTõs Bathymetric Surveys	1. April 1976 2. June 1987 3. July 1991 4. May 1994 5. July 1999 6. August 2002 7. November 2006 8. December 2011 9. June 2013 10. February 2014 11. December 2016	1. DoT 2. PoA 3. PoA 4. DoT 5. DoT 6. PoA 7. DoT 8. DoT 9. DoT 10. DoT 11. DoT	1. King George Sound, Oyster and Princess Royal Harbours 2. King George Sound (.pdf only) 3. Cheyneõs Ledge (.pdf only) 4. Middleton Beach 5. King George Sound, Middleton Beach 6. Western King George Sound (.pdf only) 7. Emu Point 8. Emu Point 9. Princess Royal Harbour channel 10. Middleton Beach and Emu Point 11. Middleton Beach, Emu Point, Princess Royal Harbour channel	These repeated nearshore bathymetric surveys allow for identification and quantification of the morphological changes that have occurred in the study area over the period of record. They are important for an accurate description of the sediment budget. They are also used for model setup.
CoAõs Beach Surveys	Quarterly transects covering a 3-year period; 2013 - 2015	CoA	The CoA beach transects cover the entire length of the study area from Ellen Cove to the õEmu PointöBoat Pens. In the cross-shore direction, they extend from the secondary dune to 250m offshore.	Beach surveys are direct measurements of the behaviour of the coastal profiles along the study area. Quarterly surveys can be used to determine seasonal and annual beach volume change.
Topographic LiDAR and Aero Metrix Survey	LiDAR ï 2012	CoA	The topographic LiDAR covers the whole Albany LGA.	The topographic LiDAR will be used for the description of coastal topography for the assessment of coastal inundation.

Data Type	Date(s)/Length of Record	Source	Location	Description
Aerial Photos	1943, 1954, 1957, 1961, 1976, 1986, 1991, 1992, 1994, 2000 - present	CoA	Various extents but most cover the study area.	Interpretation of aerial photography can be very useful in understanding coastal processes. Older photographic records vary in resolution and extent. It is sometimes difficult to determine land/water/vegetation/seagrass boundaries, especially with black and white photography.
Photo Monitoring	Late 2013 to current. (3-year period)	CoA	Fixed locations along Middleton Beach and Emu Point.	Photos were taken fortnightly in winter and monthly in summer by volunteers and CoA staff from fixed locations using an iPhone App that ensure the photos are comparable.
Fixed Camera	2.5-year record: Oct-14 ï current	COA / BMT Oceanica	The fixed camera is located at the south-west end of the rock revetment, looking south-west towards the trial óGSCô groynes.	Time lapse images are taken every half an hour. These images can be complied into a time series óvideoô of changes at the temporary groynes.
Metocean Data				
Nearshore AWACôs (wave, current and water level)	1. 2.8-year record: 12/12/2013 - 18/10/2016 2. 1.2-year record from 04/09/2015 to 28/11/2016	1. DoT 2. CoA / RHDHV	1. Emu Point in approximately 8m water depth 2. Middleton Beach (óSurfersô) in approximately 8m water depth Refer to **Figure 23** for a map of locations.	Two AWAC instruments have been deployed on the seabed in the nearshore area off Middleton Beach. AWACôs instruments measure waves, currents velocities through the water column and water level. Both instruments are currently on-going with data available after field servicing and download. Both AWACs have been removed.
Offshore Waves (permanent)	12-year record: from 29/06/2005 to current.	DoT	Approximately 11.5km offshore of West Cape Howe in approximately 40m water depth. Refer to **Figure 23** for a map showing the location of transects.	This long term wave monitoring site consists of a Directional Wave Rider Buoy that transmits wave parameters in near real-time. It provides a reference for the wave climate offshore of King George Sound.
Historical wave/current observations	1. 3.3-year record: 24/06/1981 - 24/06/1983; then a 7-month record:	1. DoT 2. PoA	1. King George Sound 2. Princess Royal Harbour Entrance Refer to **Figure 23** for a map of locations.	While it is useful to understand that this data exists, in this study emphasis will be on the most recent and high-resolution, concurrent data from the nearshore AWACôs.

Data Type	Date(s)/Length of Record	Source	Location	Description
	25/07/2015 - 27/02/2002. 2. NA			
Tide Gauges	1. 30-year record from 01/01/1987 to current. 2. 2.5-year record from Sept-14 to current.	1. DoT 2. CoA/DoT	1. Princess Royal Harbour 2. Oyster Harbour Boat Pens Refer to **Figure 23** for a map of locations.	This water level data will be used to calibrate/validate the hydrodynamic models. The long-term record at Princess Royal Harbour will be used to examine the natural variability in non-tidal water levels including the magnitude and return period of extreme events such as storm surges. The Oyster Harbour tide gauge is useful to examine the dynamics of the Emu Point Channel and Oyster Harbour during normal tidal conditions and during storm/river flood conditions.
Wind	1. 3-year record: Jan-2014 - current. 2. 23-year record: Jan-1994 to current	1. CoA 2. BoM	1. Emu Point (on top of PoA navigation beacon) 2. Albany Airport	Due to the local topography, the wind record at Albany Airport (BoM) is not representative of the wind over King George Sound. The Emu Point station is well situated to record representative wind. Initially the Emu Point anemometer had several large gaps but data coverage has improved.
UWA Current and Sediment Monitoring	Fieldwork was conducted in 2014 (spring and neap tides)	UWA	Oyster Harbour, Emu Point Channel and Lockyer Shoal.	Field studies of the water velocity and particular load in the water column were carried out. These included GPS drogue tracking designed for surface layers of the water column. Sediments were measured by taking water samples. While the study is useful the methods adopted where not particularly relevant to this study as they did not measure the key influences on sediment transport in this area (i.e. no measurements of bottom currents or bed load sediment transport).

Sediments and Seagrass Characterisation				
Sediment	Samples collected in	CoA/Geoff	Beach and inner nearshore areas from Ellen	74 samples were taken from the beach and shallow water of

Sampling	2014.	Bastyan	Cove to the Oyster Harbour Boat Pens, Also taken over Lockyer Shoal. Refer to **Figure 35** for a map of locations.	Middleton Beach and Oyster Harbour Beach. 9 samples were taken from Lockyer Shoal. All samples were analysed for Particle Size Distribution.
Seagrass monitoring	Mapped by Geoff Bastyan Associates (GBA) in April 2014	CoA/GBA	Middleton Beach nearshore area including Lockyer Shoal. Refer to **Figure 32** for a map of locations.	Using a combination of high quality aerial photography and field investigations (towed video and scuba diving) the seagrass distribution was mapped. Previous to the mapping by GBA, seagrass distribution has been inferred from aerial photography.
Structures				
Trial ‘GSC’ Groynes	Installed in April 2014	CoA	Immediately west of the rock revetment and geotextile seawall at Emu Point.	These short groynes were installed as a trial to assess what the effect would be of a shore perpendicular structure. When installed 10,000m^3 of beach nourishment was placed in the area.
Structures Conditions Assessments	Annual between 2012 and 2015	CoA, URS and PRDW	Coastal structures at Emu Point.	Regular monitoring of the rock and geotextile structures at Emu Point including photos and engineering condition assessment. Assessments were carried out every 12-18 months

3.3 Analysis of Morphological Data

3.3.1 Interpretation of Aerial Photography

As noted in **Table 3** a range of aerial photography spanning a 73-year period was available for this study. **Figure 13** presents the selected aerial photography for the study area. Close inspection and comparison of these images reveals the long term changes to beach plan and form within the study area. This section discusses the observed changes to the sub-aerial beach. Changes to the seagrass distribution observed in historical aerial photography are discussed in **Section 3.5**.

Middleton Beach

Using vegetation line position information digitised by DoT, the relative changes of the Middleton Beach shoreline has been determined at 100 intervals from Ellen Cove (0m chainage) to Emu Point (3,700m chainage) for dates between 1943 and 2014 (DoT, 2012; MP Rogers, 2015). **Appendix B-1** presents further details of the analysis method. The results are discussed below.

The study area has been divided into 6 sectors for the purposes of this analysis; 4 sectors along Middleton Beach and the sediment sub-cell or compartments of Emu Point and Oyster Harbour. These are demarcated in Figure 11. The sectors were defined based on review of the historical shoreline data as well as a review of the shape and morphology of the study area. Visual and numerical analysis was first completed to ensure observed historical trends were representative within each sector as well as being aligned to key morphological features.

The long term rates of shoreline change along Middleton Beach as presented in **Figure 12**. The shoreline data was used to undertake the regression analysis shown in **Figure 14**. The regression analysis has been used to identify trends in historical ôvegetation line positionôover the selected beach sectors shown in **Figure 12**. Negative values indicate a recessive / erosion trend while positive values indicate an accreting trend.

The results of this analysis show that Middleton Beach has accreted significantly between 1943 and 2014, however the accretion has not been uniform. The following summarises the observed shoreline change:

- The average long-term accretion rate across the main sector of Middleton Beach (Sector 2 - Surfer and the Golf Course) has been 0.6m/yr. over the period. The Surfers area has the highest rates of accretion in this sector with rates as high as 1.1m/yr. It is noted that the Surfers area is in a location of the highest average wave heights (i.e. a wave focusing area). The minimum rate of long-term accretion is observed in the eastern most portion of the sector has been 0.3m/yr.
- Sectors 3 and 4, to the east of Sector 2 have had lower rates of accretion as the beach transitions to Emu Point.

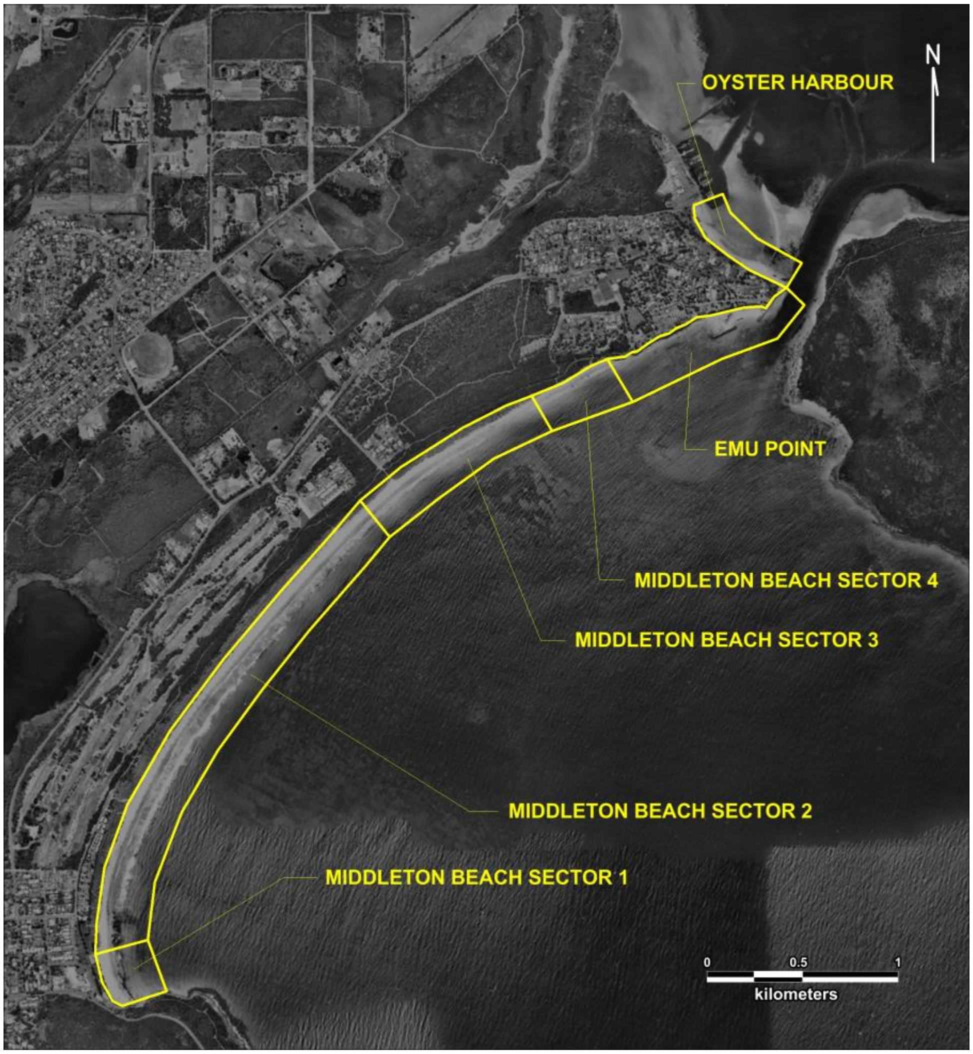


Figure 11 Sediment cells within the study area

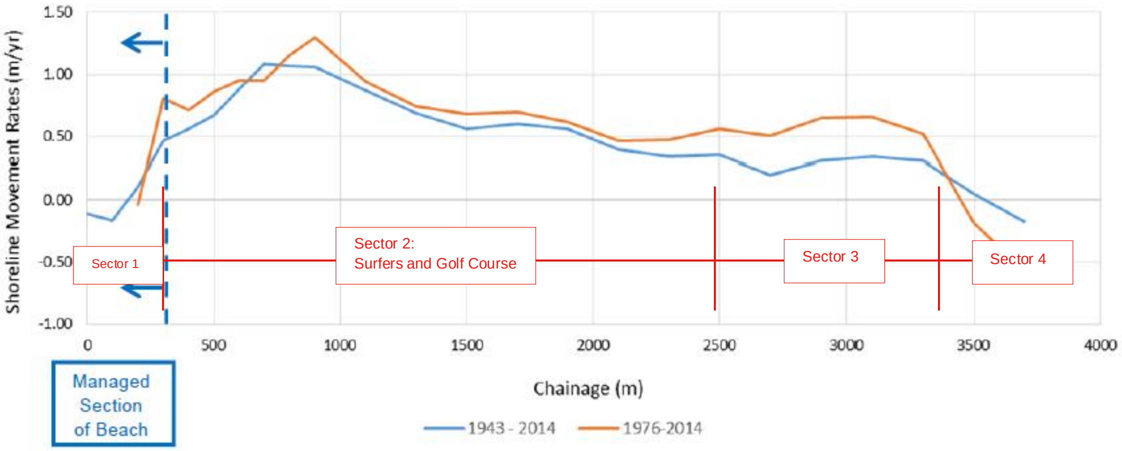


Figure 12 Rates of shoreline movement based on historical aerial photography (source: MP Rogers, 2015)

Figure 13 Comparison of aerial photography – Middleton Beach (source: Geoff Bastyan).

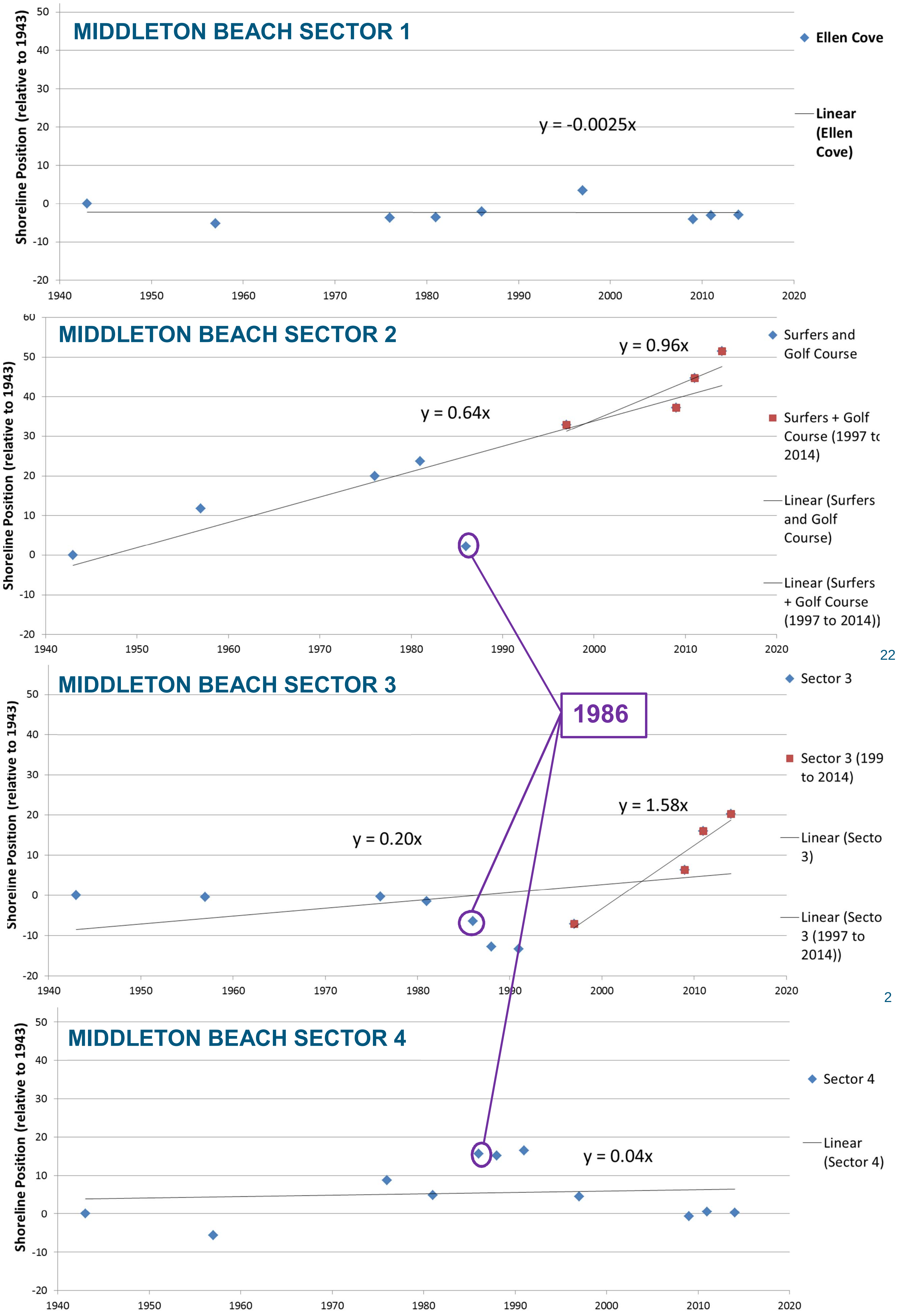


Figure 14 Time series of the vegetation line position and regression analysis by sector along Middleton Beach

- Ellen Cove (Sector 1) has been stable, neither accreting nor eroding. While this area has been managed by the CoA, it is also noted that the stable shoreline is likely a product of the control provided by the rocky headland at Wooding Point.
- Between 1943 and the early 1980ôs, Sector 3 had been stable (i.e. a minimum accretion rate of approximately 0 m/yr). Following the introduction of the coastal structures at Emu Point and the stormy period in the 1980ôs, this previously trend of a stable shoreline changed to a trend of accretion. Over the period from 1997 to 2014, rates of accretion accelerated in Sectors 2 and 3.. This is predominantly the case in Sector 3 where recent rates have recently increased to around 1.5m/yr. This is compare to Sector 2 where rates increased by around 60% to approximately 1.0m/yr.
- In Sector 4 it is noted that the sector averaged trend is essentially zero (i.e. no net accretion or recession). However, the eastern edge of this sector is adjacent to coastal structures at Emu Point (i.e. a localised area of shoreline less than 200m in length around profiles at chainage 3,600m and 3,700m). Following the extension of the seawall in 2005 there was about 25m of erosion observed between 1997 and 2009 in this localised area. Prior to the seawall extension the area had shown a trend of accretion (see **Figure 15**). The recent localised erosion is a result of the seawall/revetment structures (i.e. downdrift end effect erosion). The erosion was most noted in 2012-13 when the dual use pathway had to be relocated landward.

  Figure 15 provides the sector averaged trends separated into pre-construction of Emu Point coastal structures and recent. It is noted that pre-structures, this area had been accreting, however, in recent years this trend has changed to erosion (rate of ~0.3m/yr.). This recent erosion is related to the localised óend effectôerosion describe above.

  The latest available data (i.e. 2014), shows that this localised erosion appears to be stabilising. The stabilisation may have been related to the construction of the trial geotextile groyne and associated 10,000m^3 of sand nourishment and the on-going trends are subject to uncertainty.

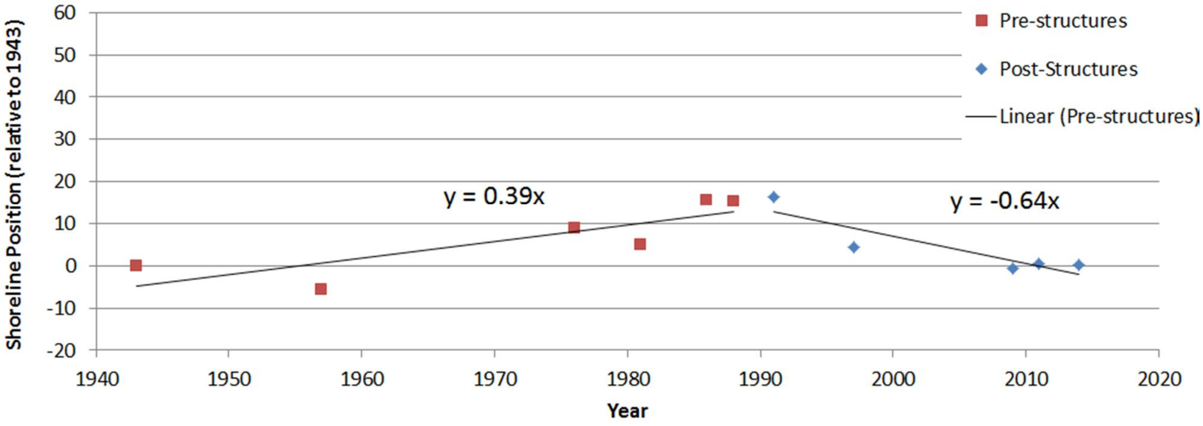


Figure 15 Pre-Emu Point structures and recent (1997 to 2014) erosion/accretion trends averaged over Sector 4.

- The late 1980s and early 1990s shoreline showed signs of significant plan form change relative to the overriding trend of accretion. In Sector 2 and 3, the late 1980s shoreline had eroded back to being comparable on average to the 1943 shoreline. The analysis shows this period was a particularly stormy period, which is further explained in Section 4.3.4. The shoreline appears to have largely recovered by the time of the next aerial image. The plotted location of the 1980s and 1990s vegetation lines in Figure 14 is an important reminder that while the long term trend is accretion, storminess (series of storms occurring over a given period) or large single event storm can still result in erosion of the shoreline over a short term period.

Emu Point

At Emu Point the introduction of a series of coastal protection structures from the mid-1980ôs onwards has had a significant effect on the behaviour of the shoreline. It is important that these coastal management practices are incorporated into the interpretation of changes in the long-term position of the shoreline. While the DoT shoreline data has still been used the analysis at Emu Point focused on changes to key shoreline features as discussed below.

The salient at Firth Street was a persistent shoreline feature in aerials from the 1970ôs up until 1980ôs but had reduced by 1994 and had all but disappeared by 2005. Using the DoT vegetation line as a proxy for shoreline position, an analysis was completed on the change in the area of this feature over the 71-year period of the shoreline record.

The resulting time series is provided in **Figure 16**. It is interesting to note that the salient was not prominent in 1943. The reason for this is unknown but may have been because the area was still recovering from a major storm erosion event in 1921. Between 1943 and the mid-1980ôs, the salient was accreting, and by the mid-1980ôs the area was at its greatest before declining. The reversal in the trend happened following the introduction of the Emu Point coastal structures. The present day shoreline in the area of the former Firth Street salient is now occupied by the seawall (both rock and geotextile revetment) with little remaining beach.

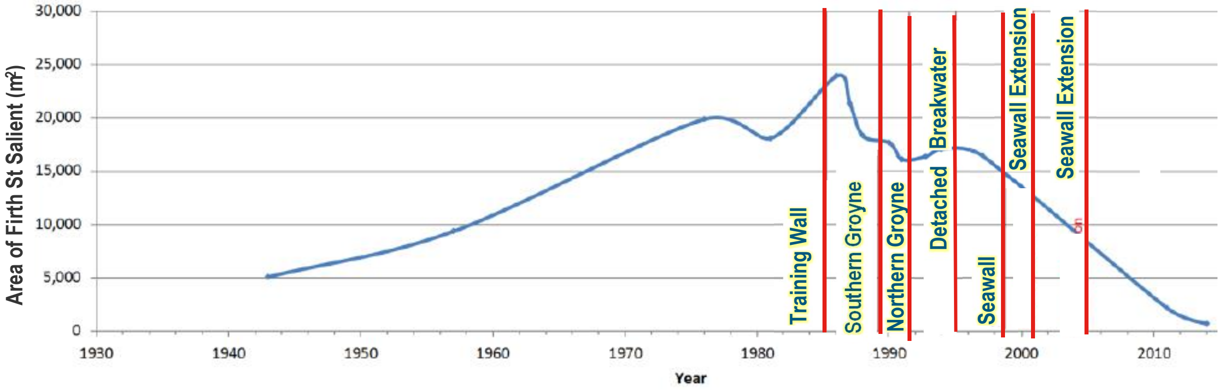


Figure 16 Trend in the changes in area of the Firth Street salient

Oyster Harbour Beach

Like Emu Point, Oyster Harbour Beach has undergone significant anthropogenic changes in the period since the 1940ôs. DoT has provided information on the capital works that have been undertaken in the Oyster Harbour Beach area (see **Section 2.2** and **Section 2.3**). This information has been combined with the comparison of the historical aerials shown in Figure 18 to examine the most significant changes to occur along Oyster Harbour Beach. These are described as:

- Capital dredging of the Emu Point Boat Pens harbour, took place from 1962 to 1971 and was associated with reclamation of land adjacent to the boat harbour (i.e. the land occupied by the present day marina car park)
- The Emu Point Baths; a recreational swimming area was constructed in 1972 and involved dredging of a pool in the nearshore area and construction of a fixed jetty enclosure. While it is difficult to determine the approached used, from a close review of the aerials it appears that a small area was deepened and that the dredge spoil was side-cast as a small mound appears

directly adjacent to the deepened areas. In 2007 the fixed jetty was converted to floating pontoons.

- From the mid-1980ǒs to mid-1990ǒs, various coastal protection structures at Emu Point were introduced including the training wall and northern groyne that works to retain littoral movement within the Oyster Harbour Beach compartment.

The Oyster Harbour Beach shoreline has responded to these changes as follows:

- The northern end of Oyster Harbour Beach now curves out to meet the reclamation area at the car park to the Emu Point Boat Pens.
- A small salient has developed on the beach in the lee of the Emu Point Baths (the swimming enclosure). It took some time for this salient to develop (see 1976 and 2003 aerials) and this slow response is evidence of the low energy estuarine environment. Since 2003, the salient has been a fairly stable feature, maintaining its location and approximate size/volume. The salient may have started to change in recent times in response to alterations to the structure that encloses the swimming area.
- The mound side-cast from the swimming enclosure has progressively elongated, spreading offshore in the direction of the flood currents. This material now seems to form a small bar running northwest along the tidal shallows in the nearshore area of Oyster Harbour Beach.
- Between 1976 and 2003, a smaller salient on the beach approximately 100m to the west of the swimming enclosure had developed. From 2003 to 2016, this smaller salient was seen to have migrated approximately 100m along the beach towards the boat harbour, leaving an apparently stable beach in its previous location
- A reduction in the extent of the seagrass meadow; meadows closer to shore becoming sparser by 1976. By 1981 the sand flats appear more extensive with seagrass meadows retreating before stabilising. In more recent aerials, the size and extent of the seagrass meadow appears to have stabilized by 2005-2012, with little change since then.

Again, the DoT vegetation lines have been used as a proxy for shoreline position at Oyster Harbour Beach. For Oyster Harbour, the analysis has taken into account the significant anthropogenic changes that have occurred as well as the limitation of the data. By using beach transects at less than 5m intervals the analysis also accounts for the along shore variability in the shoreline along Oyster Harbour Beach. The resulting time series is provided in Figure 17. It can be seen that Oyster Harbour Beach has generally been stable over the long-term, however, in recent years a small erosion trend has been observed. It is noted that while the raw analysis was undertaken at a fine spacing, it is suitable to interpret shoreline trends generally for the whole shoreline as Oyster Harbour Beach is effectively a closed sediment cell.

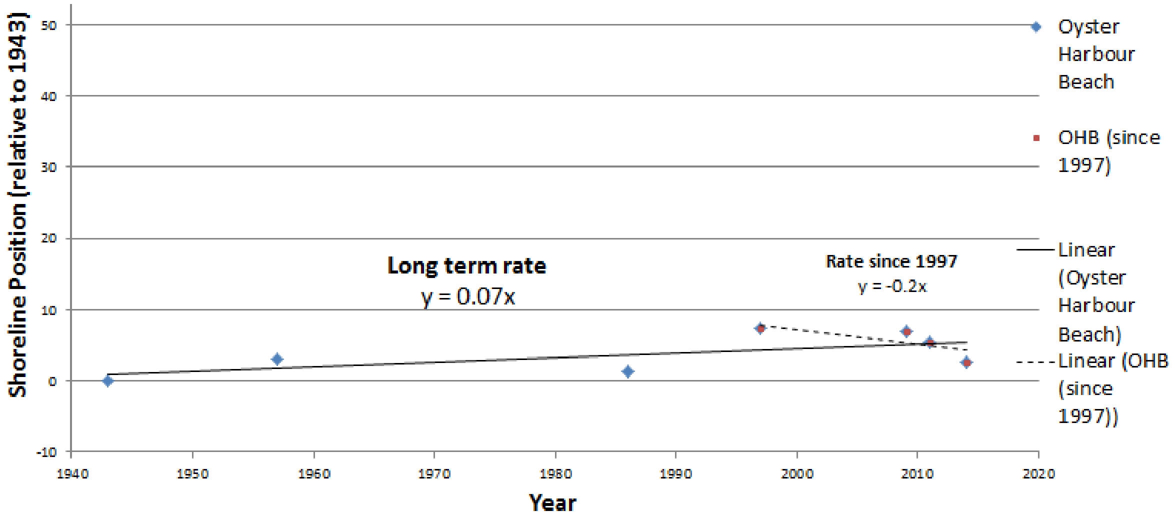


Figure 17 Rates of changes observed in the DoT shoreline data for Oyster Harbour

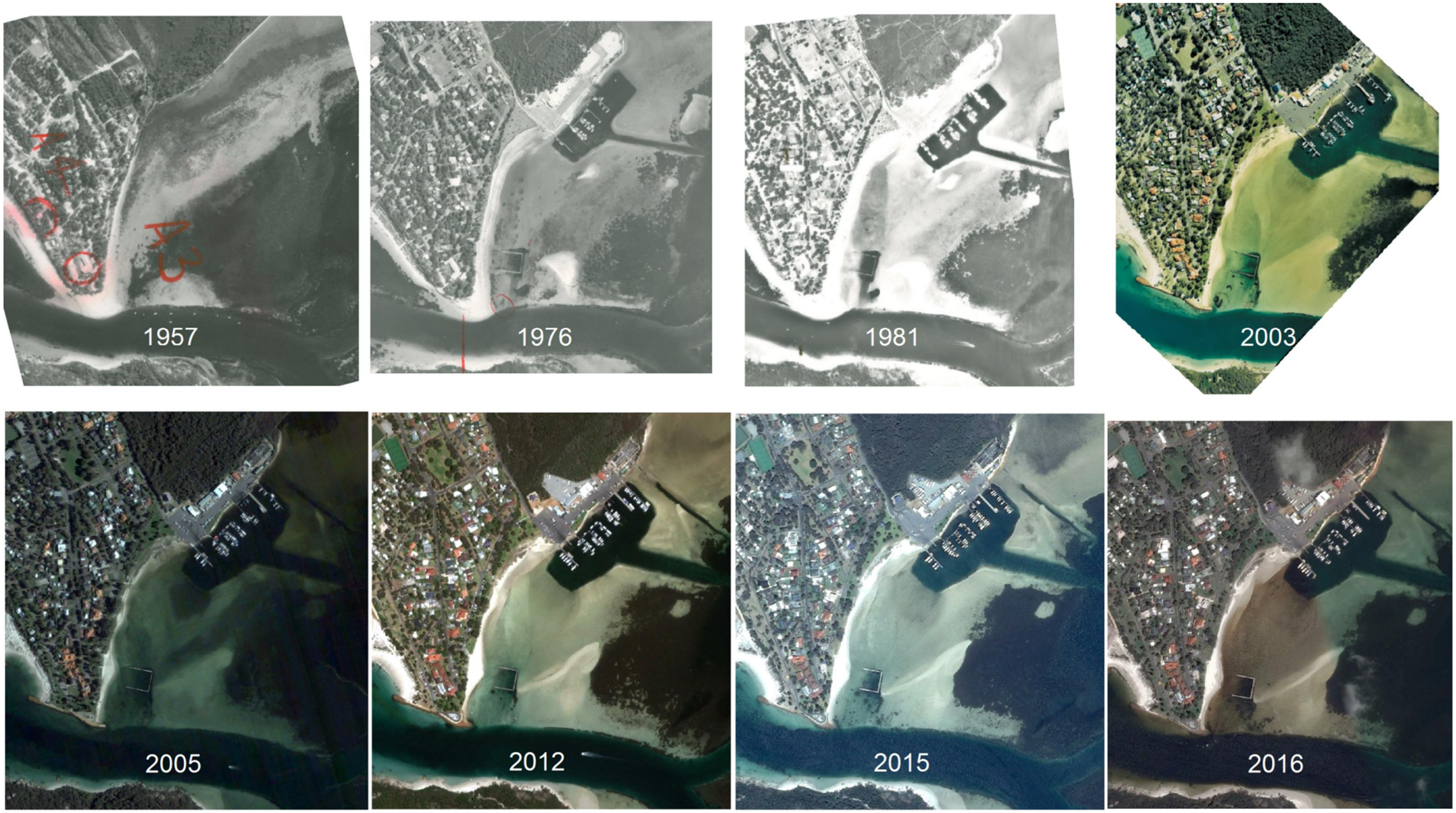


Figure 18 Comparison of aerial photography ï Oyster Harbour Beach

Shoreline Change Summary

Table 4 provides a summary of the adopted rates of shoreline change.

Between 1943 and 2014, a 2.25km section of shoreline along Middleton Beach had accreted by an average of 43m. This represents a significant volume of sediment that must have been derived from a source of sediment. The source of the sediment is discussed in **Section 5**.

Historical shoreline trends at Emu Point have been influenced by the introduction of coastal structures. The present day shoreline is controlled by these structures and future shoreline changes are not expected unless there is a significant change to the controlling structures.

Oyster Harbour Beach has generally been stable but since the construction of the structures at Emu Point, a minor shoreline recession trend has been observed.

Table 4 Representative rates of shoreline change in the study area

Sediment Sub-cell		Beach Chainage (m)	Average rate of long term shoreline movement ï 1943 to 2014 (m/yr.)	Average rate of recent shoreline movement ï 1997 to 2014 (m/yr.)	Comment
Middleton Beach	**Sector 1**	0 - 250m	0.0	0.0	
	Sector 2	250 - 2,500	+0.6	+1.0	Long-term rates of accretion range from _+1.1m/yr. at óSurferôto +0.3m/yr. in the eastern portion of this beach sector.
	Sector 3	2,500 ï 3,400	+0.2	+1.5	
	Sector 4	3,400 ï 3,700	0.0	-0.3	Localised and recent erosion is noted along eastern edge of this sector due to coastal structures at Emu Point.
Emu Point		3,700 ï 4,500	na	0.0	The Emu Point shoreline was accreting prior to the introduction of coastal structures. Future shoreline changes are only expected if there is a change in the coastal structures.
Oyster Harbour		na	+0.1	-0.2	Oyster Harbour Beach

Note: in this table positive (+ive) values indicate accretion while negative (-ive) values indicate erosion.

3.3.2 Beach Transects

The CoA has undertaken regular beach transect surveys along the extent of the study site (as a recommendation of the previous PRDW (2013a) report) between October 2013 to December 2016. For this study beach transects were available up until December 2016. The extent and nomenclature for each transect can be seen in Figure 19**.**

Due to the relatively short duration (or record) of these transects, long-term trends will be difficult to determine from the data set. An analysis of longer term nearshore morphologic change has been undertaken in **Section 3.3.3**.

However, combining the recent quarterly beach transect data and the shoreline change analysis (see **Section 3.3.1**) it is possible to derive an estimate of the volume of sand that has been accreted on Middleton Beach (**Table 5**). This has been performed by shifting the beach profiles using the long-term changes in the position of the shoreline and re-profiling the lower sections of the profile (see **Figure 20**). The re-profiling of the lower section was guided by and checked against the comparisons of historical hydrographic surveys (i.e. surveys from 1976 and 2016). The area between the two profiles was then calculated as the beach volumes per unit metre of beach run values (units of m^3/m). This was done for a range of measured beach profiles between transects MB-02 to MB-04. These beach transects correspond to the area of most accretion.

The volume sand volume changes (**Table 5)** have been completed for two periods: 1943 to 2014 and 1976 to 2014. The period from 1943 to 2014 was selected as this is the longest period for which aerial photography (and associated vegetation lines) was available. The period from 1976 to 2014 was selected as this is the longest period for which both aerial photography (and associated vegetation lines) and nearshore hydrographic survey was available. By using the two data sources in the period from 1976 to 2014, an increase in the accuracy of the volume estimates is possible, this is reflected in the range of the estimates which is also provide in the **Table 5**.

CO-ORDINATE LISTING

NAME	EASTING	NORTHING	ELEV
ALB-15	583111.33	6124053.53	1.84
MB-01	583578.98	6123888.70	2.33
MB-02	583715.43	6124582.15	4.48
MB-03	584196.40	6125278.10	4.23
MB-04	584559.34	6125668.99	4.25
ALB-10	584803.57	6126002.91	5.11
MB-05	585042.89	6126053.95	2.91
MB-06	585263.26	6126184.26	2.87
MB-07	585515.39	6126304.69	4.13
MB-08	585720.55	6126435.83	3.63
MB-09	585636.48	6126410.54	4.17
EP-01	586172.30	6126623.93	3.78
EP-03	586338.69	6126635.83	2.09
OH-01	586536.06	6126723.48	1.35
OH-02	586396.94	6126808.69	1.54
OH-04	586161.75	6127020.15	1.61
OH-06	586075.51	6127328.29	1.16

NOTES:
- CO-ORDINATES SHOWN ARE MGA94
- LEVELS SHOWN ARE AHD, RTK-GPS DERIVED.
- LEVELS ON PVC/CONCRETE PILLARS ARE TO TOP OF BOLT, BENEATH CAP.
- LOCATION OF OH-2, OH-4 & OH-6 PER ATTACHED SKETCHES.

Figure 19 Location of CoA beach survey transects (JKA, 2014)

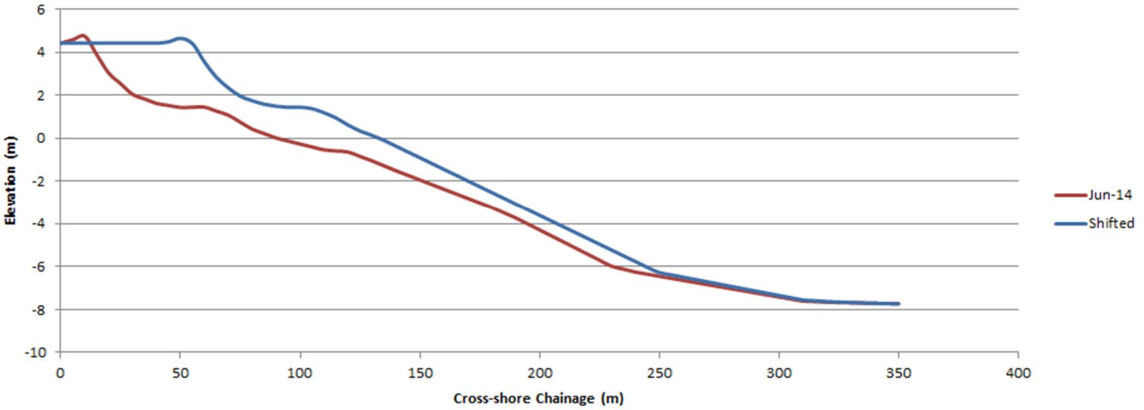


Figure 20 Example beach transect (MB01- June-2014) showing original and shifted profile used to estimate beach volume change

Table 5 Representative rates of beach volume change in the study area

Sector	Beach Chainage (m)	Beach volume change along Middleton Beach ï 1943 to 2014 (m^3) [Best Estimate (estimated min ï estimated max)]	Beach volume change along Middleton Beach ï 1976 to 2014 (m^3) [Best Estimate (estimated min ï estimated max)]
Sector 1 Ellen Cove	0 - 250m	0	0
Sector 2 Middleton Beach	250 - 2,500	+925,000 (810,000 ï 1,160,000)	+500,000 (430,000 ï 620,000)
Sector 3	2,500 ï 3,400	+120,000 (110,000 ï 150,000)	+65,000 (58,000 ï 83,000)
Sector 4	3,400 ï 3,700	0.0	0.0
Total	**3,700**	**+1,045,000** **(920,000 – 1,310,000)**	**+565,000** **(490,000 – 700,000)**

3.3.3 Observed Nearshore Morphological Change

Based on the available repeat bathymetric surveys an analysis of the observed nearshore morphological changed has been completed. A summary of the key results are presented here, while the completed analysis is described in **Appendix B-2 and Appendix B-3**.

Figure 21 provides an example of the observed morphological change over the complete 40-year period of observations. Based on the volumetric analysis from this period, between 1976 and 2016 (40-years) there was:

- 1.17Mm3 of net erosion in the nearshore areas of Middleton Beach (i.e. area defined by the extent of the 2016 bathymetric survey);
- 550,000m3 of net erosion over Lockyer Shoal;
- 176,000m3 of accretion in the areas adjacent to the Golf Course.

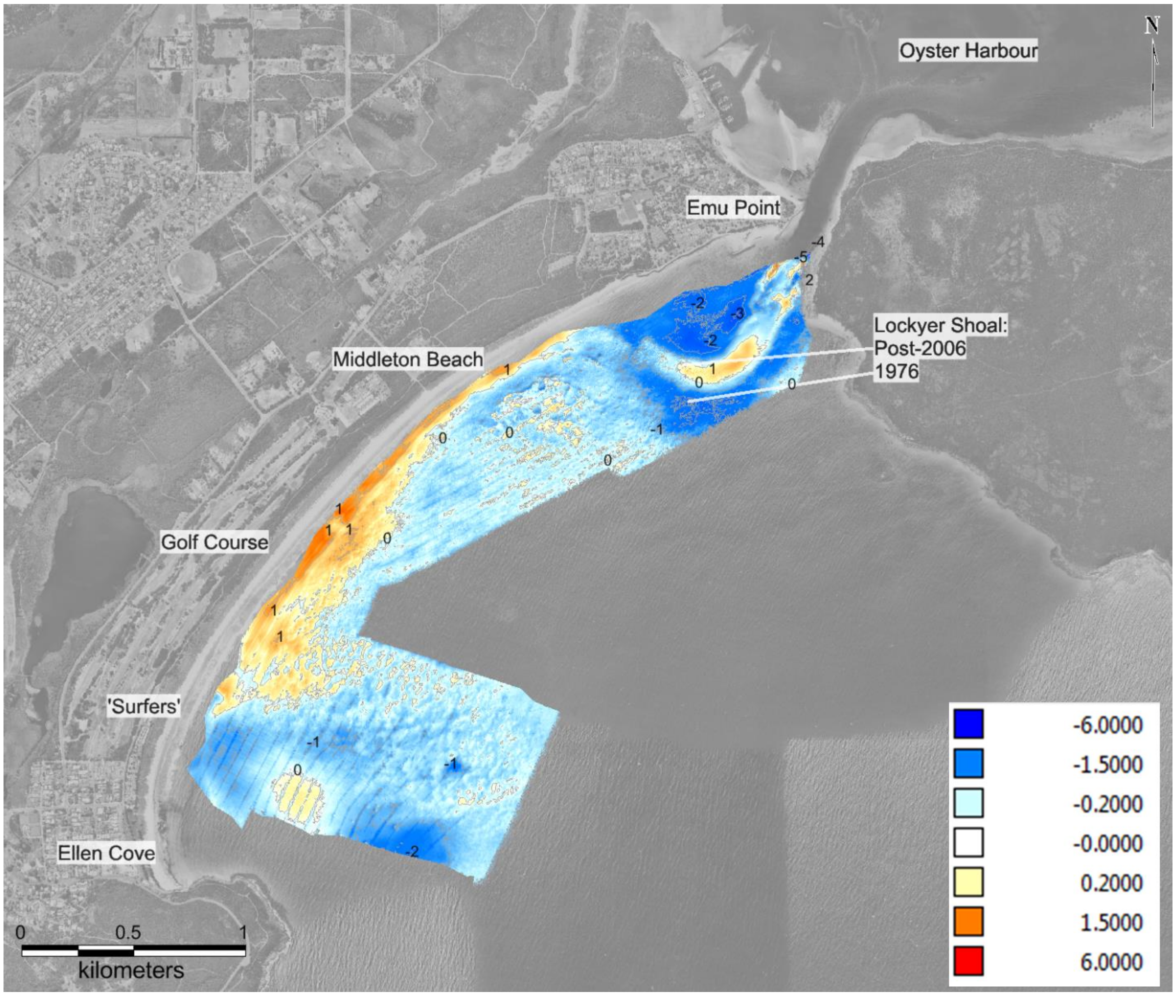


Figure 21 Survey difference map (Isopach) comparing the changes observed between 1976 and 2016 (2016 less 1976)

3.3.4 Review of Trial Groynes

In April 2014, CoA installed two temporary groynes to the west of the rock seawall at Emu Point. During construction the area around the groynes was nourished with approximately 10,000m^3 of sand. The temporary groynes are only short and do not extend far seaward of the sub-aerial beach.

The groynes were installed as a trial to assess what the effect would be of a shore perpendicular structure on the beach. Groynes are shore perpendicular structures that work by capturing longshore drift and widening the beach on their updrift side.

This can have adverse effects for beaches downdrift of the dominant sand movement direction, with erosion often occurring on the downdrift side of groynes.

PRWD (2015c) undertook a review of the groynes by comparing aerial photographs taken before and after the temporary groynes were installed (see **Figure 22**). The review did not indicate a major build-up of sand by the two groynes, although the evidence from the 2015 aerial image does show that the groynes have influenced the shape of the coastline. This is described as:

- A measured 2.1 degree difference in coastline orientation around the groynes along with minor erosion to the west of the two groynes indicates that net sand transport is directed to the west. However, the rate of net transport is small.
- It is clear that the sand is bypassing the end of the short temporary groynes.
- Indications are that the ongoing erosion, evident in the area before the groynes were installed, has stabilised.

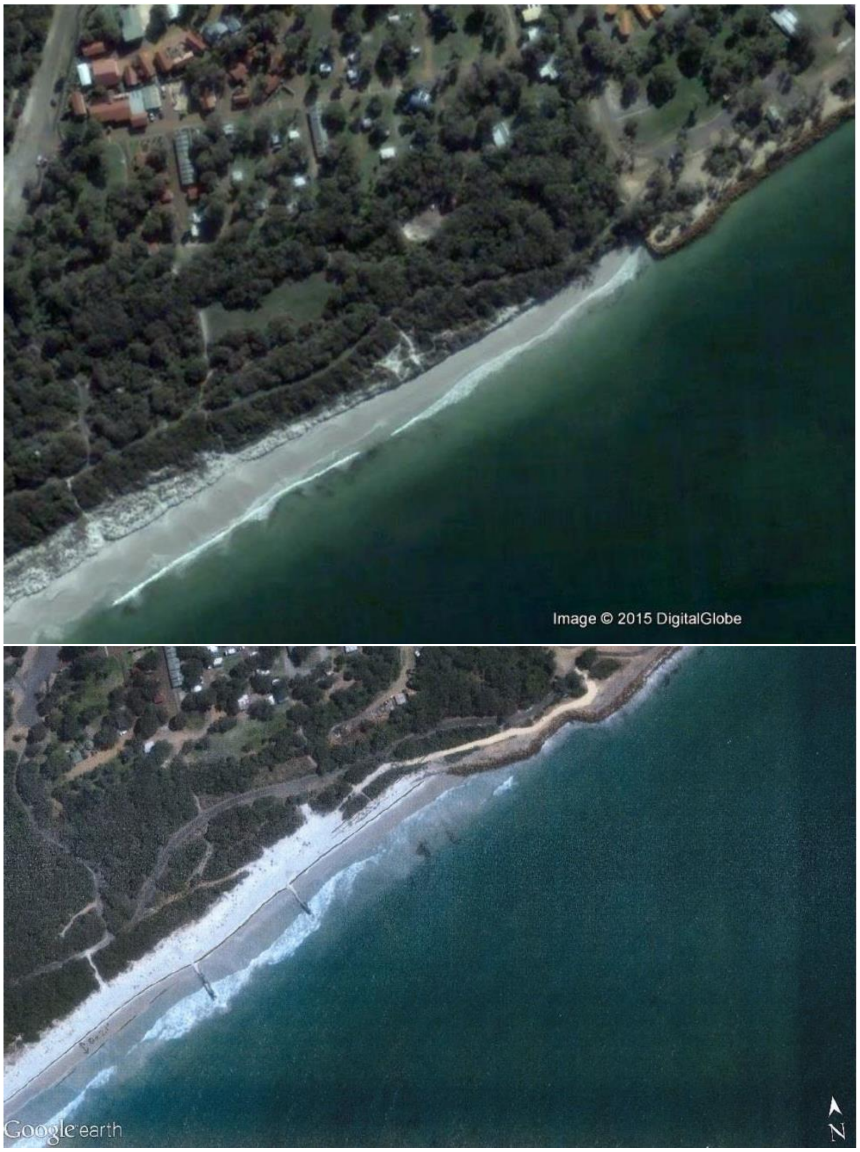


Figure 22 Aerial images from before (top -2005) and after (bottom – 2015) groyne construction (source: Google Earth)

3.4 Analysis of Metocean Data

The following section details the available metocean data (summarised in **Table 3**) and provides a preliminary data analysis as it relates to the project objectives.

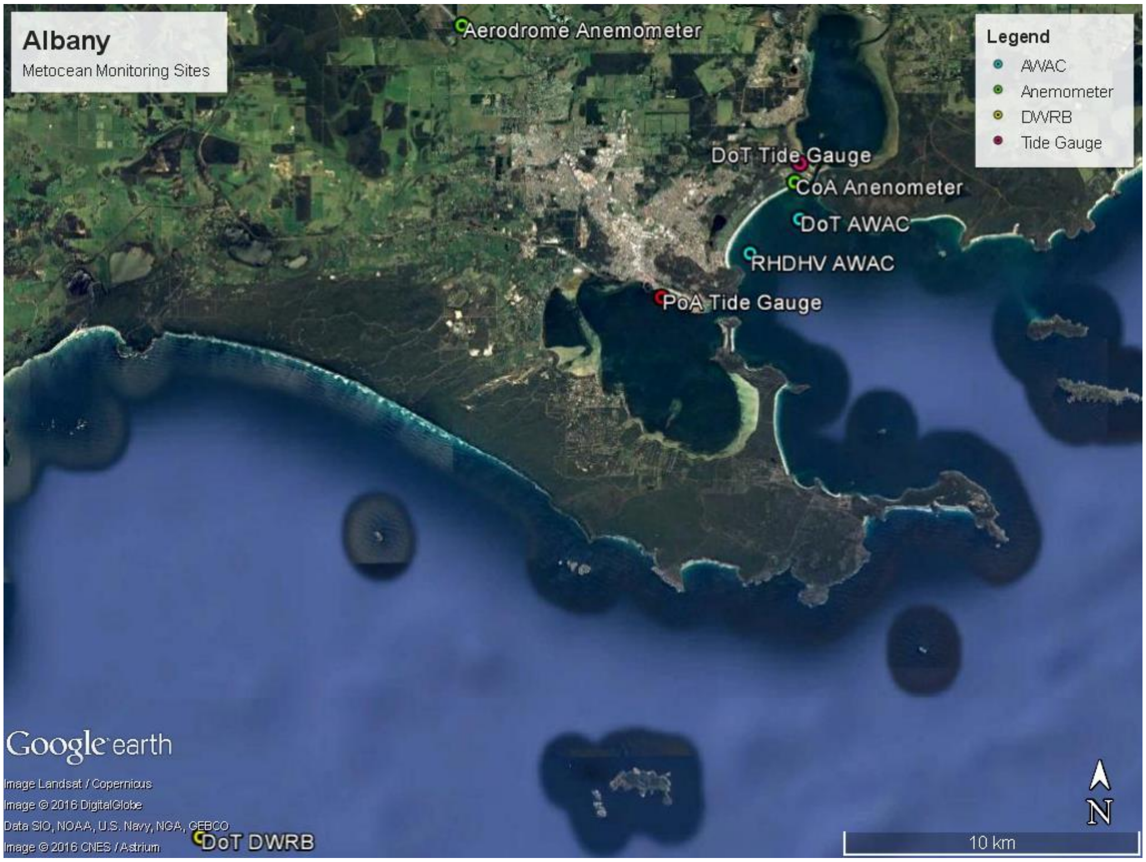


Figure 23 Map of locations with observed metocean data

3.4.1 Water Level (Tidal and Non-tidal) Data

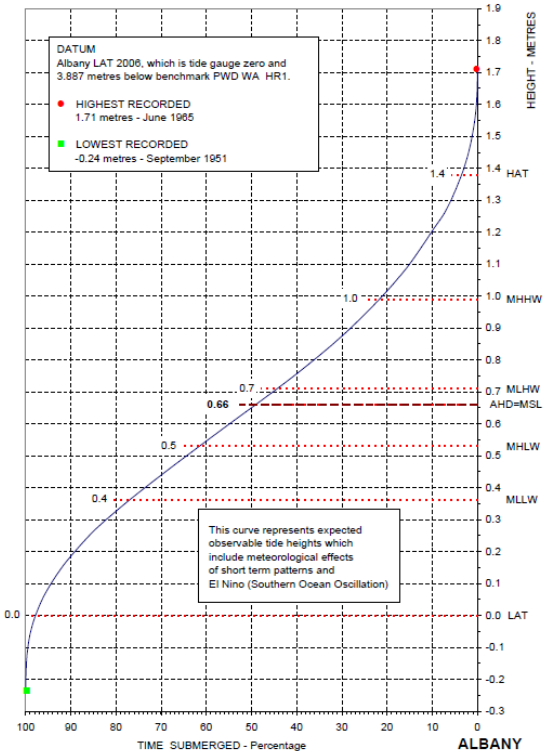
Recorded water level data was analysed from the tide gauge operated by the Western Australian Department of Transport (DoT) which is located in Princess Royal Harbour, as seen in **Figure 23** over the period 01/01/1987 to 31/12/2015.

A harmonic analysis was undertaken on the recorded signal to determine 68 tidal constituents from the 30-year data set. A predicted tidal signal was then recreated for the period of the recorded data set and compared to the predicted level to determine the residual component of the recorded signal for surge analysis. The tidal planes for the recording site were also calculated following the harmonic analysis and can be seen in **Table 6**.

King George Sound and the study site experience a semidiurnal, micro-tidal regime with a tidal range of less than 0.5m The proximity of the King George Sound entrance to the Southern Ocean and the ôRoaring 40sômeans that intense west-east travelling low pressure systems can affect the water level regime at the study site due to the inverse barometric effect.

Table 6 (left) Calculated tidal planes (relative to MSL) based on a harmonic analysis of a 28 year recorded water level signal within Princess Royal Harbour, Albany (right), DoT Submergence Curve for Albany, relative to Albany LAT (DoT, 2006).

Tidal Plane Parameter	mMSL
HAT	0.73
MHWS	0.18
MHWN	0.03
MSL	0.00
MLWN	-0.03
MLWS	-0.18
LAT	-0.75
Spring range	0.36
Neap range	0.06
Mean range	0.20
Total range	1.15



An Extreme Value Analysis (EVA) was undertaken on recorded water level signal to determine the Annual Return Interval (ARI) for Princess Royal Harbour. It is expected that there will be very minimal amplification of the tidal signal within the harbour itself, in comparison to the greater King George Sound (and subsequently Middleton Beach and Emu Point). As such, it was evaluated that elevated water levels recorded within the harbour can be used as a proxy for the study site. These values, as seen in **Figure 24**, will be used to determine extreme water level events along the study site.

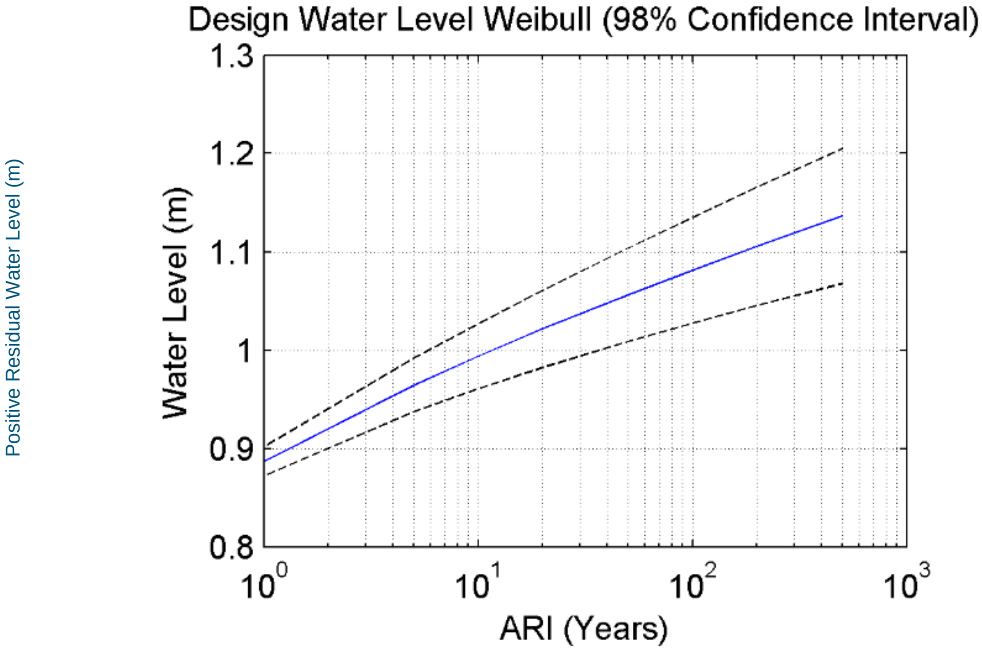


Figure 24 Annual Return Interval (ARI) for recorded water level (m) based on a 30-year tidal dataset recorded at Princess Royal Harbour, Albany

The top ten individual highest water level events recorded at the gauge can be seen in the harmonic analysis reconstruction plot seen in **Figure 26.** Time and height of each of the events can be seen in

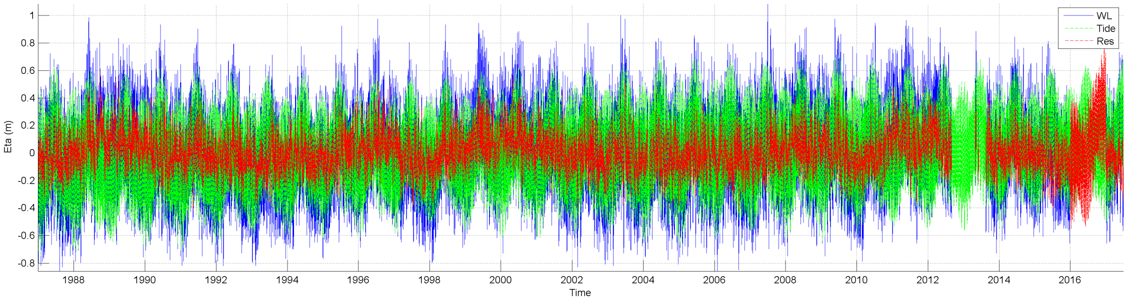


Figure 25 Harmonic analysis of the 30 year water level dataset recorded at the DoT tide gauge within Princess Royal Harbour. The blue line is recorded water level, green is the predicted water level based on the harmonic analysis. The red line denoted the residual component of the recorded water level.

Table 7 Top ten highest water level events recorded at the DoT Princess Royal Harbour tide gauge 1987-2015.

Date/time	Water Level (m MSL)
2/07/2007 11:35	1.09
16/05/2003 10:50	1.00
2/06/1988 10:20	0.98
16/07/1996 11:35	0.97
22/05/2009 9:20	0.97
20/05/2011 11:15	0.97
26/06/2003 8:35	0.97
30/06/2007 10:10	0.96
31/05/1988 9:50	0.95
16/05/1999 11:20	0.94

3.4.2 Wind

Two wind speed and direction datasets have been made available as part of this study; Albany Aerodrome and Emu Point Anemometer sites, co-located as seen in **Figure 26**.

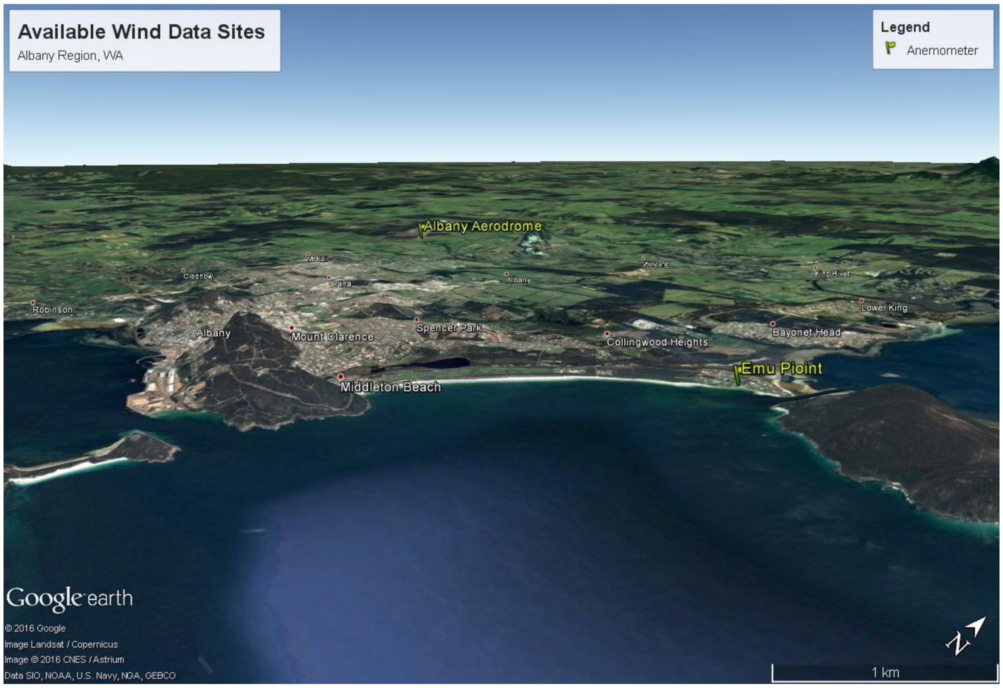


Figure 26 Location map of available wind data relevant to the Emu Point-Middleton Beach study site

The Albany Aerodrome site, managed by the Bureau of Meteorology (BoM), was found from experience to have a large discrepancy at the study site in both wind speed magnitude as well as resultant direction due to its geographical location, as seen in **Figure 26**. The average wind conditions experienced at Albany Airport for the period from 1994 to 2012 are provided in **Figure 27.**

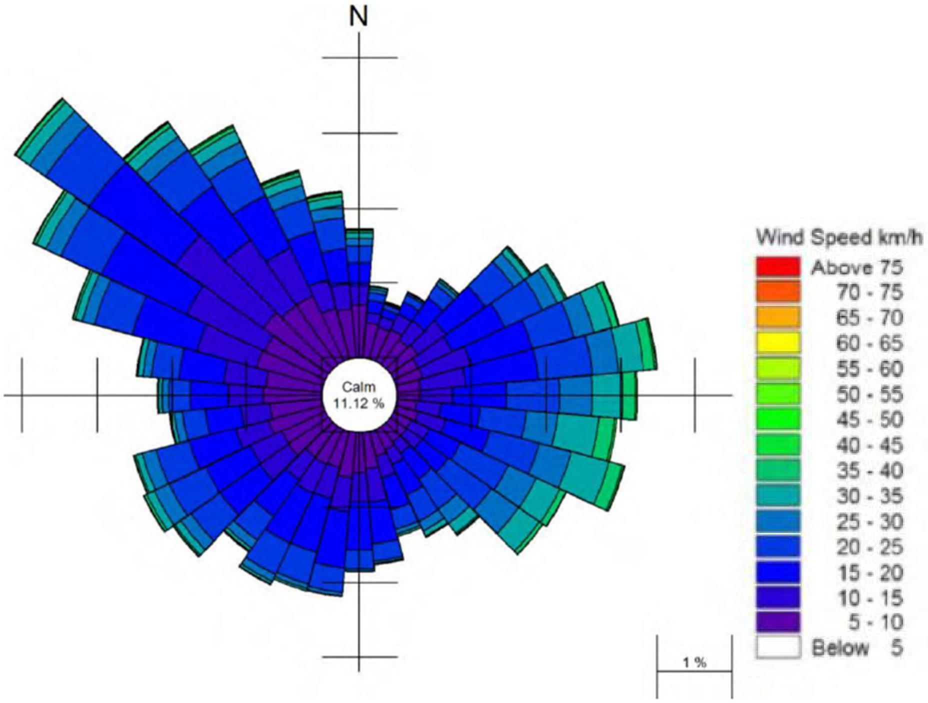


Figure 27 Wind rose showing wind speed and direction at Albany airport over the period from 1994 to 2012. Note limitations in text (Source: URS, 2012)

Emu Point Anemometer was installed along the foreshore of Emu Point as a result of recommendations made in a previous coastal processes study of the project site. The anemometer has been recording data since October 2014. Although the site has experienced intermittent failure (predominantly in the initial stages following installation), changes to servicing and maintenance procedures have resulted in a more reliable dataset.

As such, for analysis within this study as well as model calibration, the Emu Point data was determined as being the most suitable. A total-record as well as seasonal wind roses for the 2.5 year dataset were produced based on the available data and can be seen in **Appendix C-1.** In general, there is a clear trend of southerly winds experienced at the recording site. This tendency is mainly due to the locationôs proximity to the Southern Ocean and the meteorological trends that this produces, discussed in the previous section.

Two predominant synoptic periods were identified in the King George Sound region (GEMS, 2007), the first spanning from March to June and the second spanning from July to February. In the first synoptic period of summer, winds predominantly have an easterly persuasion i.e., arriving from the north-east to the south-east. During the latter synoptic period of winter, winds are predominantly experienced from a westerly direction.

This seasonal variation was found to be related to the position of a subtropical ridge, which is at its most southern position during March and then returns north due to the cooling continent around April (GEMS, 2007). Hence in winter, the south-west corner of Australia and the Albany region is subject to the passing of frequent cold fronts and low pressure systems.

Due to the limited record of winds recorded at Emu Point, another wind data source was deemed necessary in order to sufficiently provide boundary conditions for wind generated wave models. Wind and wave data was extracted from NOAAs 38 year global hindcast model (described further in **Section 4.3.3)** at location offshore of Albany. As the data was used to generate wave models it was deemed that this source would be more suitable being in the open ocean free from the influence from landforms and local topographic events on both speed and direction.

A comparison of the Emu Point and the NOAA extracted wind speed and direction can be seen in **Figure 28**. Although trends in the rise and fall and change in direction can be seen between each data source, it can be seen that in general the NOAA data source tends to have speeds than that of Emu Point. This will be an important factor in the generation of waves in the numerical modelling phase as well as calibration of these models to other offshore sites.

A filtered version of the plot in Figure 28 which only shows winds from the southerly sector (90°-200°) can be seen in Figure 29. This plot not only furthers the sentiment that the greatest wind speeds come from the southerly sector but shows the correlation in the data trends at each site.

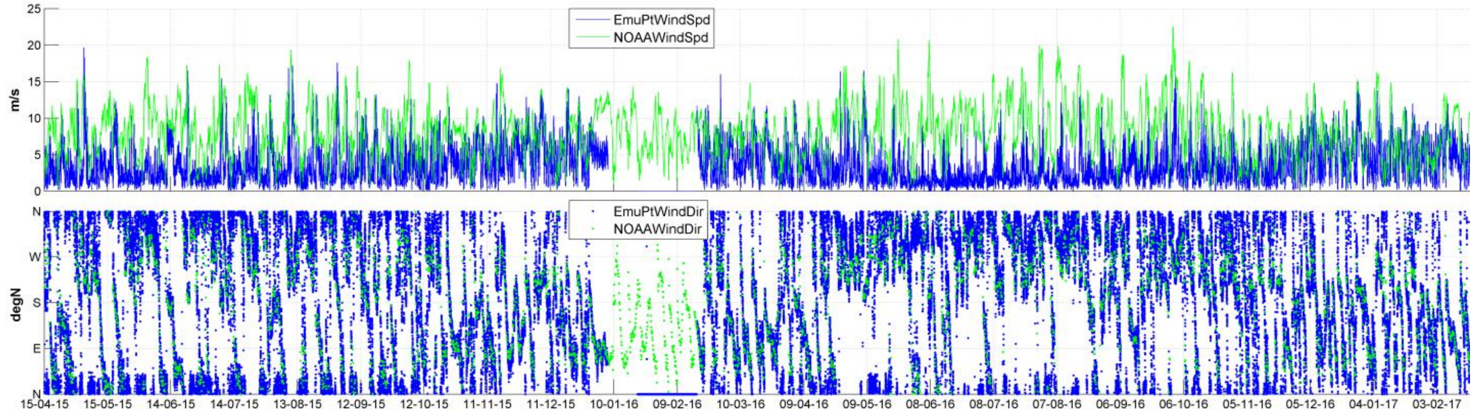


Figure 28 Emu Point wind speed and direction (blue) against NOAA hindcast model offshore (KGS) extraction point (green)

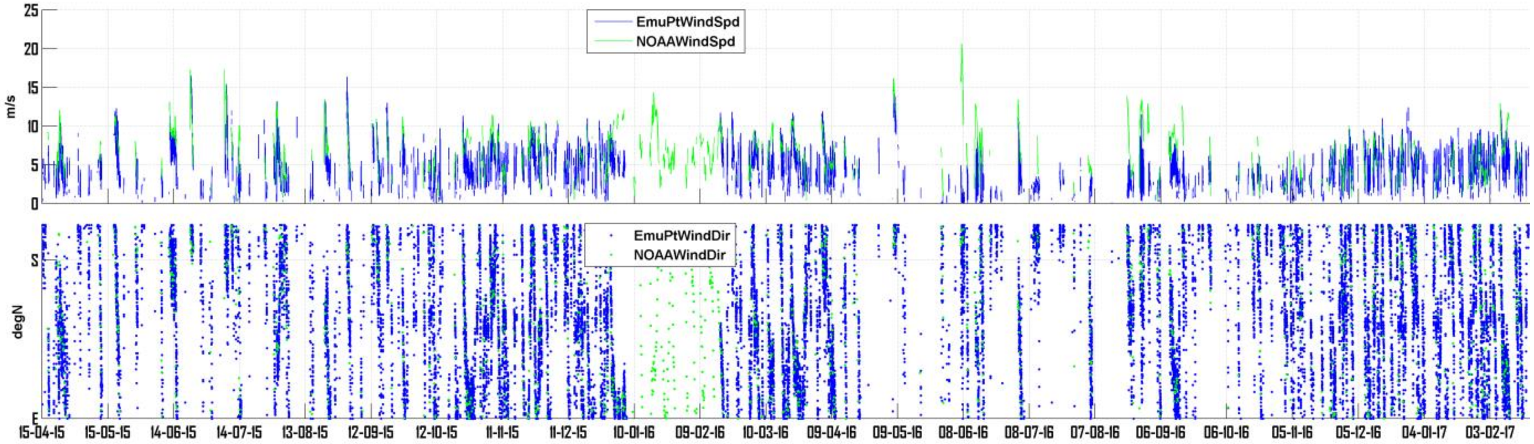


Figure 29 Emu Point wind speed and direction (blue) against NOAA hindcast model offshore (KGS) extraction point (green) filtered to southerly wind directions only (90°-200°).

3.4.3 Wave

Several sources of wave data were available within and adjacent to King George Sound as well as regional hindcast model sources. The two regional model sources used within the study; AUSWAVE 30year hindcast and the NOAA WWIII 1979-2017 reanalysis data grids, can be seen in

Figure 30.

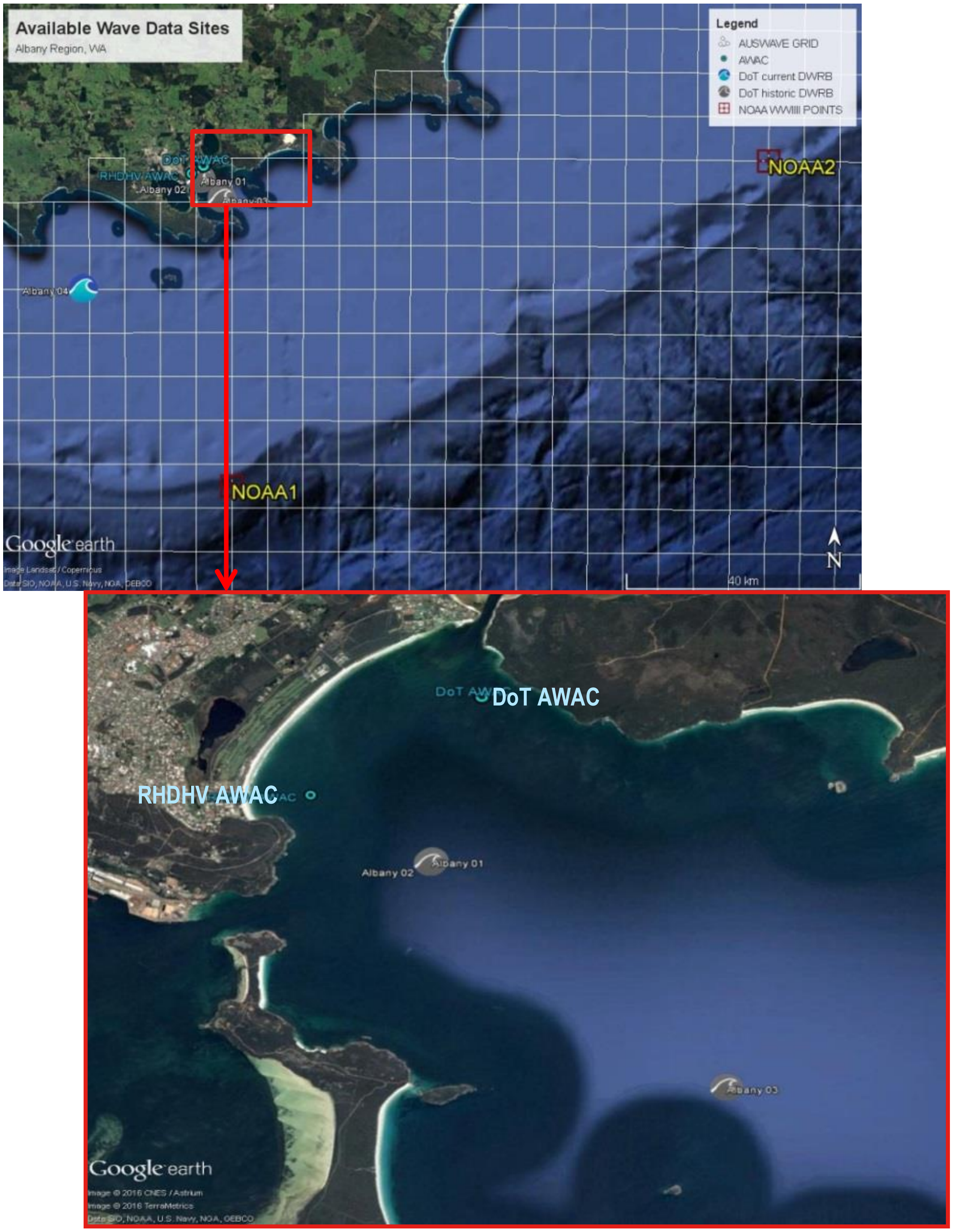


Figure 30 Local and regional wave data sources used in the metocean data analysis

Two site specific Acoustic Wave and Current (AWAC) deployments have been undertaken in the nearshore region between Middleton Beach and Emu Point, statistics on each of these deployments and their relation to the study objectives are elaborated below.

RHDHV AWAC:

Royal HaskoningDHV (RHDHV) was engaged to monitor waves, currents and water levels through the deployment of an AWAC device offshore of a proposed artificial reef location at Middleton Beach. The AWAC was initially installed 4th September 2015 in approximately 7m of water offshore of the site colloquially known as óSurfersô at the Southern end of Middleton Beach, as seen in

Figure 30. A subsequent 5 deployments and recovery exercises as well as an annual maintenance and servicing regime were undertaken on the instrument. The average as well as seasonal statistics can be seen in **Table 8**. It can be seen that the deployment site is dominated by low energy, long period swell waves with a small seasonal increase in the percentage of sea state in the summer to the winter months (from 2%ï 41% Tp >8sec).

The weighted average wave directions were calculated based upon the wave energy of each reading, as follows:

$Dp_{weighted} = (Hs^2 \text{ x } Tp \text{ x } Dp) / sum(Hs^2 \text{ x } Tp)$

Table 8 Average as well as seasonal wave statistics calculated for the approximate 1.5 year deployment of the RHDHV AWAC deployment in 7m of water offshore of Middleton Beach

Parameter	Statistic	Average	Winter	Autumn	Summer	Spring
Hs(m)	Average	0.63	0.73	0.63	0.57	0.60
	20%ile	0.37	0.38	0.36	0.35	0.37
	90%ile	1.04	1.47	1.03	0.96	0.92
	Max	2.38	2.38	2.35	1.84	1.80
Tp(s)	Average	12.54	13.73	12.82	10.02	12.79
	20%ile	10.03	12.53	11.28	6.42	10.79
	90%ile	15.42	15.43	15.79	14.68	15.45
	% of Time Sea (Tp<8s)	16	2	13	41	16
	% of Time Swell (Tp>8s)	84	98	87	59	84
Peak Wave Direction (˚N)	Weighted Average	121	122	119	117	123
	Average	120	121	118	117	122
	STD	6	4	5	7	5

The waves can be seen to be generally unidirectional (~120°) with a very small standard deviation in the peak wave direction of between 4° in the winter and 7° in the summer. This is due to the direction of the locally generated sea state in the summer (S-SE) coming from a different direction to the dominant swell direction (SW). Long Term Average (LTA) as well as seasonal wave roses can be seen in **Appendix C-1** Spectral analysis of the datasets is also made available in the appendix, these illustrate the unidirectional nature of the wave climate as well as the sea/swell breakdown.

DoT AWAC:

The DoT has managed the deployment and maintenance of an AWAC device installed in approximately 7m of water offshore of Emu Point since December 2013. The device has undergone 11 separate deployments over that time, the LTA and seasonal statistics from the monitoring campaign can be seen in **Table 9.**

Table 9 Long Term Average (LTA) as well as seasonal wave statistics calculated for the approximate 4year deployment of the DoT AWAC deployment in 7m of water offshore of Emu Point

Parameter	Statistic	LTA (4 years)	Winter	Autumn	Summer	Spring
Hs(m)	Average	0.38	0.36	0.37	0.43	0.36
	20%ile	0.24	0.22	0.25	0.29	0.23
	90%ile	0.60	0.58	0.56	0.64	0.57
	Max	1.59	1.53	1.05	1.16	1.59
Tp(s)	Average	10.9	12.7	11.5	8.3	11.0
	20%ile	7.1	11.3	7.7	4.8	7.2
	90%ile	15.4	16.2	15.6	13.1	15.5
	% of Time Sea (Tp<8s)	29	11	21	55	28
	% of Time Swell (Tp>8s)	71	89	79	45	72
Peak Wave Direction (˚N)	Weighted Average	137	139	132	134	141
	Average	136	138	132	135	142
	STD	14	10	10	14	17

Similarly to the RHDHV AWAC the DoT site experiences a unidirectional swell regime with peak wave directions centred around 135° however with a larger standard deviation range between the winter and summer months of 10-17° respectively. This small difference may be attributed to the longer data set, with greater variability experienced through the years when the RHDHV AWAC was not deployed. The slight secondary peak in wave energy can be seen in the summer and autumn wave roses (**Appendix C-1**) as well as in the 1 dimensional (1d) and 2 dimensional (2d) spectral analysis plots.

There is also a reduction in the average wave height for Middleton to Emu Point (Hs, LTA = 0.63m to 0.38m). This phenomena was highlighted in the preliminary spectral wave modelling undertaken as part of the Albany Artificial Surfing Reef (AASR) Feasibility Study (RHDHV, 2014) which indentified wave focussing hotspots along the Middleton to Emu Point coastline. The results of this analysis informed the subsequent RHDHV AWAC deployment.

Generally offshore (seaward of King George Sound) wave direction has very little influence on the directionality that was recorded at either of the AWAC sites. This is due to the ófunellingô effects of the Sound and the long distance the incoming waves have to travel across a relatively uniform bathymetry. Following this passage, incoming swells are basically aligned to the orientation of the bathymetry/shoreline once they have arrived at either of the shallow AWAC sites.

3.4.4 Currents

Each of the AWAC devices is also capable of measuring directional currents through the water column (in addition to relative pressure, temperature and Acoustic Backscatter intensity). The following section describes the processing and analyses of the recorded current data from each of the devices.

RHDHV AWAC:

LTA depth-averaged current statistics calculated for the approximate 1.5 year deployment of the RHDHV AWAC in 7m of water offshore of Middleton Beach from September 2015 to October 2016 can be seen in **Table 10.** The summation shows a generally benign current environment with extremely low current flow, and a depth-averaged current magnitude over the deployment period of 4cm/s.

Table 10 Long Term Average (LTA) as well as seasonal current statistics calculated for the approximate 1.5 year deployment of the RHDHV AWAC deployment in 7m of water offshore of Middleton Beach

Parameter	Statistic	LTA
Current Magnitude (m/s)	Average	0.04
	20%ile	0.02
	90%ile	0.07
	Max	0.26
Net Direction (˚N)	Average	129

Due to the location of the site at a distance to both entrances to Princess Royal and Oyster Harbours, current flow at this location is expected to be due to wave driven currents or due to wind-driven surface flow. The micro-tidal environment is also expected to produce very low circulation patterns within the Sound and subsequent currents at the site. This assumption will be verified through the hydrodynamic (HD) modelling phase of the study.

The distribution of current speed and directions through the water column can be seen in the current vector spiral displayed in **Appendix C-1**. As with the depth-averaged currents represented in the previous plot, it can be seen that for most bins there is a predominant net offshore current flow. The highest current speeds (albeit still very small) are seen to occur at the surface. This is most probably attributed to wind interaction and the high proportion of N-NW winds (of low magnitude) experienced at the site, as can be seen in the LTA wind rose for the Emu Point Anemometer (**Figure C1-1 in Appendix C-1**).

DoT AWAC:

In contrast to the current field in the vicinity of the RHDHV AWAC, the DoT device has a greater propensity to be influenced by tidal flow due to its proximity to the entrance to Oyster Harbour. It can be seen however, from the long term depth-averaged statistics in **Table 11** that the site also experiences very low current speeds, with a depth-averaged LTA of 5cm/s.

Parameter	Statistic	LTA (35.9 months)
Current Magnitude (m/s)	Average	0.05
	20%ile	0.03
	90%ile	0.09
	Max	0.42
Net Direction (˚N)	Average	177

Table 11 Long Term Average (LTA) as well as seasonal current statistics calculated for the approximate 4 year deployment of the DoT AWAC deployment in 7m of water offshore of Emu Point

The net direction of the depth averaged currents is 177°, almost 45° further south than that experienced at the RHDHV site. This leads us to believe that wind may not be the dominant force affecting the net currents at this location as it would be expected that both the RHDHV and DoT sites would have similar wind driven flow directions. However, looking at the comparison of the current spirals in **Appendix C-3**, it can be seen that the surface bin current directions are both of a similar southerly inclination.

The net depth-averaged currents are also seen to be influenced by the vertical distribution of the current directions through the water column. The distribution of the RHDHV site tends to be more centred around the south-east directional quadrant, whereas the DoT site has a more south-west inclination, with only the very top and bottom bins following the south-east trend.

3.5 Review of Seagrass and Sediment Data

3.5.1 Seagrass

Geoff Bastyan & Associates (GBA) has had a long history studying the growth, colonisation and life cycles of various seagrass species within King George Sound, Princess and Oyster Harbours and the study site. GBA have been engaged by RHDHV to provide a background on their extensive data set attained through their field studies and historic investigations. This information is summarised below.

The dominant seagrass in Middleton Bay is Posidonia coriacea, a species that is high-energy tolerant and has a rhizome (underground stem) that grows vertically rather than horizontally. This species traps sand and thus causes a gradual reduction in water depth. P. coriacea grows in water depths between 1 and 30 metres. Seeds tend to settle in sand wave depressions, thus forming rows of plants (**Figure 31)**.

It can be seen that prior to the 1984 storm event and construction of the coastal structures at Emu Point dense beds of this species were present in the inner and outer shoal areas of Lockyer Shoal. Historical observations showed that the outer Lockyer Shoal was formed over considerable time with the concurrent seagrass growth resulting in an accumulation of more than 4m of sediment. In the months following the 1984 storm, GBA dived on Lockyer Shoals and recorded rhizome descending for some 4 metres in remnant seagrass ócolumnsô

Recent observations indicate that extensive seagrass recolonization is occurring over the Lockyer Shoal and is associated with accumulation of sediments on the shoal.

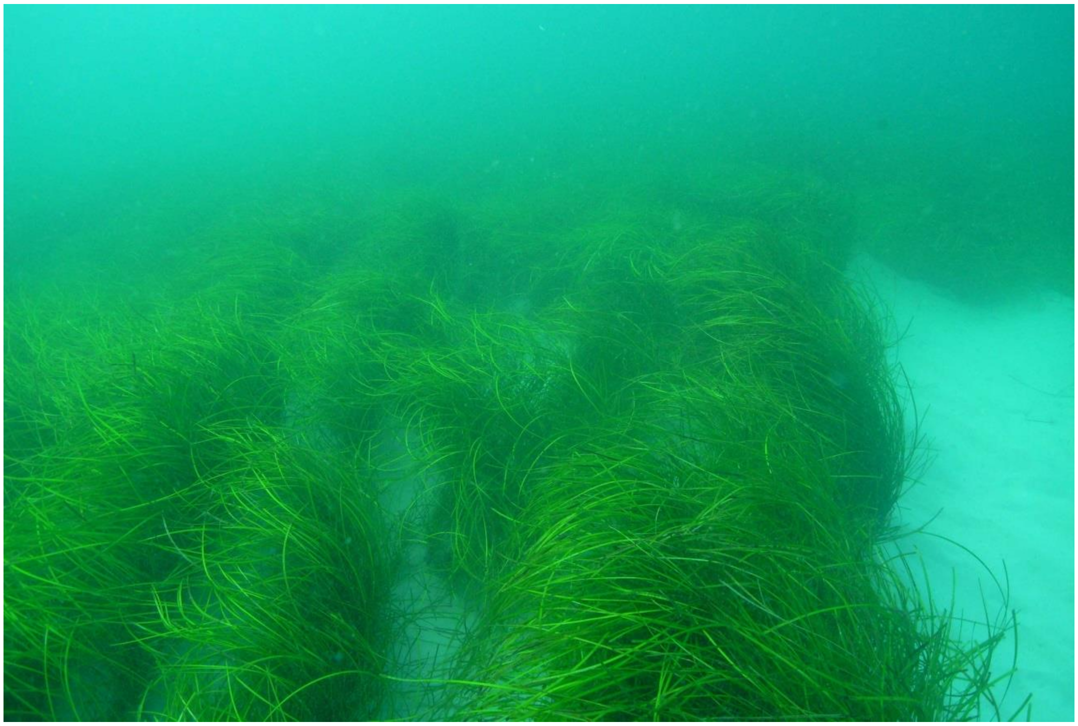


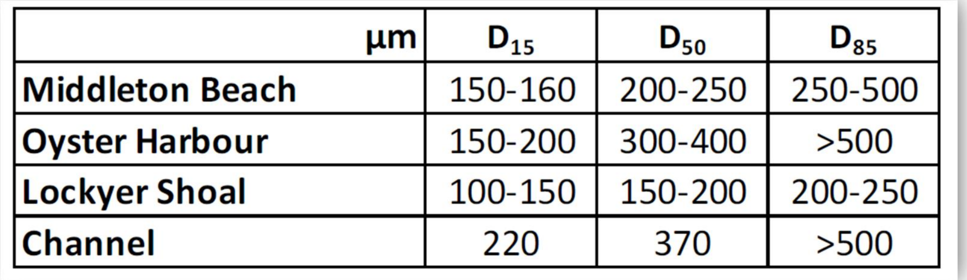
Figure 31 Mature P. coriacea meadow typically forms distinct rows, (GBA, 2017)

3.5.2 Sediments

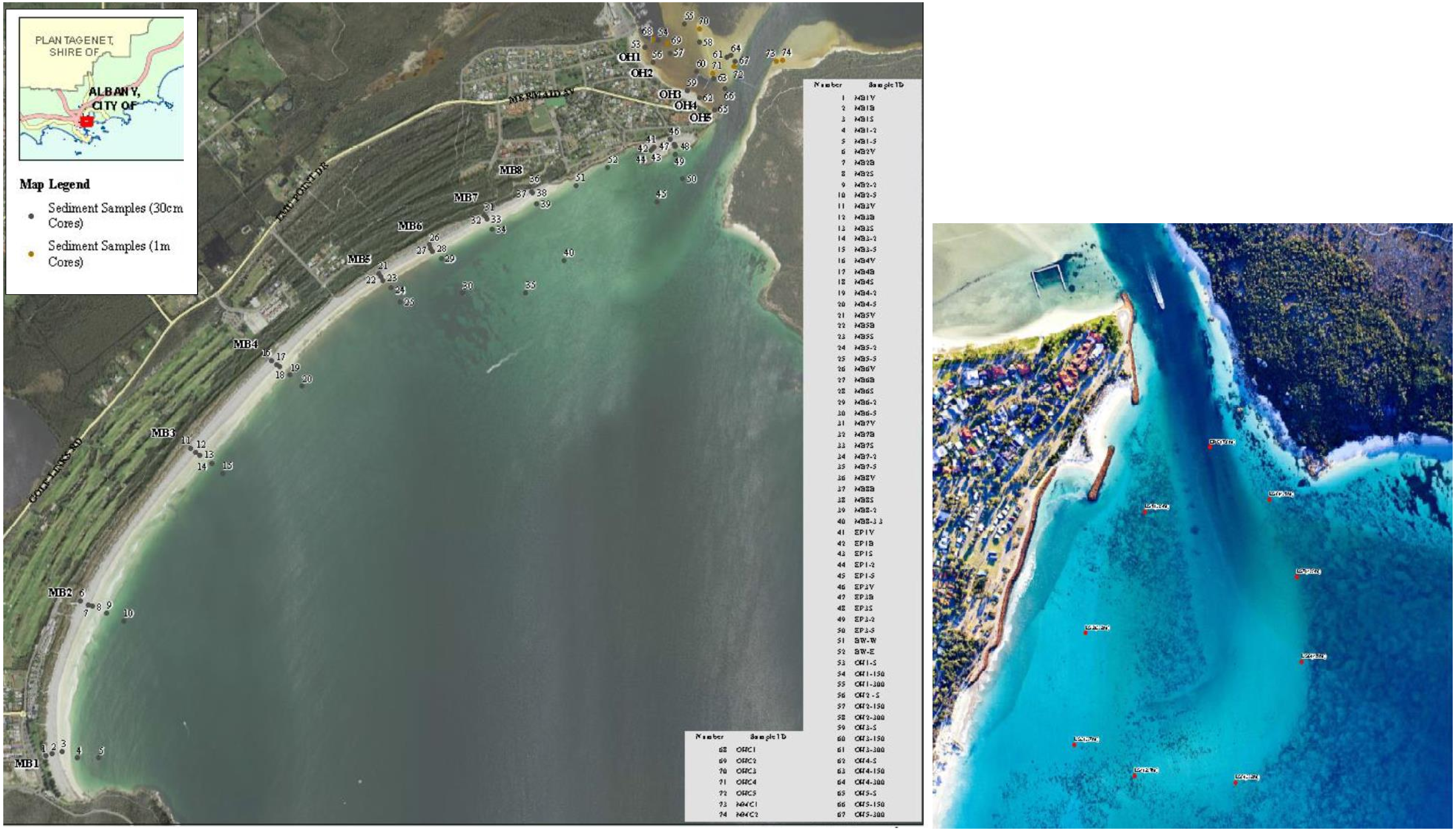
An extensive set of sediment samples were collected on the sub-aerial beach, shallow sub-aqueous beach and shallow nearshore areas along Middleton Beach, Emu Point and Lockyer Shoal in 2014 as indicated by the locations in **Figure *32***.

Particle Size Analysis using sieves was carried on the sediment samples. Most of the sand samples are classified as fine to medium sand. The D_{15}, D_{50} and D_{85} grain sizes for each of the samples was calculated. The range of grain sizes in the various locations is shown in **Table 12**.

Table 12 Grain size distribution in study area



µm	D_{15}	D_{50}	D_{85}
Middleton Beach	150-160	200-250	250-500
Oyster Harbour	150-200	300-400	>500
Lockyer Shoal	100-150	150-200	200-250
Channel	220	370	>500



Number	Sample ID
1	MB1V
2	MB1B
3	MB1S
4	MB1-2
5	MB1-5
6	MB2V
7	MB2B
8	MB2S
9	MB2-2
10	MB2-5
11	MB3V
12	MB3B
13	MB3S
14	MB3-2
15	MB3-5
16	MB4V
17	MB4B
18	MB4S
19	MB4-2
20	MB4-5
21	MB5V
22	MB5B
23	MB5S
24	MB5-2
25	MB5-5
26	MB6V
27	MB6B
28	MB6S
29	MB6-2
30	MB6-5
31	MB7V
32	MB7B
33	MB7S
34	MB7-2
35	MB7-5
36	MB8V
37	MB8B
38	MB8S
39	MB8-2
40	MB8-3 3
41	EP1V
42	EP1B
43	EP1S
44	EP1-2
45	EP1-5
46	EP2V
47	EP2B
48	EP2S
49	EP2-2
50	EP2-5
51	BW-W
52	BW-E
53	OH1-S
54	OH1-150
55	OH1-300
56	OH2 - S
57	OH2-150
58	OH2-300
59	OH3-S
60	OH3-150
61	OH3-300
62	OH4-S
63	OH4-150
64	OH4-300
65	OH5-S
66	OH5-150
67	OH5-300
68	OHC1
69	OHC2
70	OHC3
71	OHC4
72	OHC5
73	MMC1
74	MMC2

Figure 32 Map of Middleton Beach and inner nearshore sediment sample locations (top) and Lockyer Shoal location (bottom).

3.6 Gap Analysis and Monitoring Recommendations

Based on the collation of coastal monitoring data available in the study area and a preliminary and targeted analysis of the data most relevant and important to this study, **Table 13** presents a gap analysis and recommendations for future coastal monitoring data collection in the study area.

Table 13 Coastal monitoring gap analysis and recommendations.

Data Type	Comment	Priority
DoT's **Bathymetric Survey**	The regular bathymetric surveys completed by DoT provide a direct and quantitative measurement of morphological change in the study area. Combined with beach surveys they provide the most beneficial data to understand the coastal processes and sediment transport regimes. The most recent surveys (e.g. 2016), while covering the full longshore direction of the study area only extend offshore to a depth of between -5m (Lockyer Shoal) and <-15m (offshore of ôSurfersö). The 1976 survey however, included deeper areas. Volumetric analysis demonstrates that the area surveyed in 2016 showed a net erosion of approximately 1.2Mm^3 when compared to 1976. This is a significant volume of sand, which must have been transported and deposited somewhere. Possible deposition locations include deeper areas further offshore of the recent survey extents, and the sub-aerial beach adjacent to the Golf Course or within Oyster Harbour. The data gap is then recent bathymetric survey coverage of the areas offshore to 20m depth contour and potentially within Oyster Harbour. Should funding be available it is highly recommended that these surveys be continued and at least one survey be undertaken that extends to incorporate depths offshore to the 20m depth contour all the way along Middleton Beach. Consideration should also be given to widening the extents within Oyster Harbour so that meaningful volumetric analysis can be completed. It is hoped this would enable the volume of missing sand to be located.	High
CoA Beach Profiles	The quarterly beach surveys provide quantitative data on changes to the beach system and should be continued for as long as possible. At present no direct measurements of storm erosion exist within the study area. The volume of storm erosion (or storm bite) along a coastal profile can be measured using a set of beach transects taken prior to and immediately following a storm event. As the amount of storm erosion is a key element in the definition of coastal hazard it is recommended that consideration be given to obtaining measured storm bite. Given sufficient funding is available to continue beach surveys the following is recommended for consideration: • To provide better value for money, the City should investigate a reduction in the frequency of seasonal transects (i.e. from quarterly to a single set of summer and winter transects taken annually (2 per year)); • Ability to mobilise beach survey team prior to and immediately after large storms to measure storm response; • Alternative technologies could be considered such as survey drones or RTK quad bikes.	Medium
AWACs **(waves and currents)**	The two AWACôs within the study area now have a combined record length of around 4 years, with just over 1 year of concurrent wave, current and water level measurements. These are important for direct measurements of the key physical drivers for sediment transport and coastal erosion and also for calibration and validation of numerical models. The location of the two AWAC deployments has been very useful for recording nearshore waves. In regard to the Emu Point AWAC, this has also been useful in measuring tidal currents. Sufficient data now exists for nearshore waves for model calibration.	High

Data Type	Comment	Priority
	Our review of the AWAC data indicates that the only remaining gap is in the measurement of wave-driven currents in the vicinity of the Lockyer Shoal. These wave-driven currents are likely to be critical to understanding the erosion at Emu Point. Accurate representation of wave-driven currents will provide verification of wave and flow modelling and also inform the understanding of sediment transport processes in its lee. It is understood that DoTôs AWAC currently located at Emu Point will be recovered and relocated away from the Albany region. It is therefore recommended that the remaining AWAC be located in an area with the primary purpose of recording wave-driven currents in the Lockyer Shoal area. A secondary objective would be to record additional tidal currents. A suitable location can be determined by the wave and flow modelling completed as part of this study. Any funding saved through the completion of DoT AWAC monitoring activities is recommended to be allocated to the activities described above.	
Photo Monitoring	The photo monitoring carried out by CoA and volunteers is relatively inexpensive to collect but does not provide quantitative data. The fixed time lapse and video camera, whilst inexpensive it is time consuming to and expensive to process and the low and remote position of the camera reduces the suitability for interpretation. Moreover it is very time consuming to analyse following post-processing. It is recommended that the ongoing video monitoring being undertaken at Emu Point be rolled back with the focus on documenting pre- and post-storm conditions at key locations. To make better value of the data collected thus far, post-processed by a consultant familiar with similar monitoring techniques, incorporating (at a minimum) the following: • Several Timex (merged) images taken at 5-10minutes around the same tidal position each day (e.g. 0m MSL). • Identification of structures, shoreline and vegetation lines are made throughout each image. • Video and graphical representation of each of these daily images is made for comparison as well as to identify erosion/accretion trends and structural failure.	Low
Photogrammetry	It is recommended that regular high-resolution geo-rectified aerial images be produced (similar to that produced by GBA (2014) to identify accretion/erosion trends as well as seagrass growth rates and extent). These images can be taken through several methods such as light aeroplane, UAV or drone. They can also be undertaken by a third party subscription to an imaging website such as Nearmap, Landgate, etc.	Medium

4 Numerical Modelling

4.1 Preamble

This section describes the numerical modelling undertaken for this study including the methodology and results for each of the various modelling packages. The numerical modelling completed includes:

- Spectral Wave (SW) modelling ï 38-year wave hindcast;
- Hydrodynamic (HD) modelling ï modelling of tidal and wave driven flows including scenario testing;
- Longshore sediment transport ï long term trends.

The numerical modelling completed for this study focuses on the present day (or existing) conditions within the study area. However, a number of simulations are also completed to look at future climate change conditions and historical conditions (i.e. pre-structures bathymetries).

The results of the numerical modelling are used to inform the understanding of coastal processes (see **Section 5**) and hazards (**see Section 6**) within the study area.

4.2 Model Description

The MIKE 21 software package has been adopted for use in the hydrodynamic and spectral wave components of this study. MIKE 21 is a computer program that simulates flows, waves, sediment transport and ecology in rivers, lakes, estuaries, bays, coastal areas and seas in two dimensions. MIKE is developed by the Danish Hydraulic Institute (DHI).

The Flexible Mesh (FM) version of MIKE 21 (MIKE 21 FM) has been adopted as it allows the spatial resolution of the computational grid to be locally increased in areas of interest, i.e., at the project site, whilst the resolution in other areas can be coarser to help maintain acceptable model run times. The spatial discretisation of the equations in MIKE 21 FM is performed using a cell-centred finite volume method.

Two MIKE 21 models are used in the present study:

- MIKE 21 FM Hydrodynamic (HD); and
- MIKE 21 FM Spectral Wave (SW) Module.

Both models are described in MIKE by DHI (2011) a very brief description is given here as:

- Hydrodynamic (HD) module which calculates the depth integrated phase averaged mean currents and surface elevation by solving the non-linear shallow water equations; and
- Spectral Wave (SW) module which calculates the integrated wave parameters, significant wave height (H_s), peak wave period (T_p), peak and mean wave direction (Dp/Dz), directional spreading (DSD) by solving the wave action equation for the 1st and 2nd spectral moment of the wave energy frequency spectrum.

For the simulations of storm events a coupling of the above two models has been used.

4.3 Spectral Wave (SW) Model

A MIKE 21 Spectral Wave (SW) FM model was setup for the study site, extending offshore of King George Sound to an extent sufficiently east and west of the Albany region and offshore into the Southern Ocean. The model was used to determine the nearshore wave climate at the study site and gain an understanding of its effect on coastal processes.

4.3.1 Approach

Due to the various sources of wave data available for the study as seen in **Section 3.2**, the first step in the wave modelling approach is to determine the most suitable data to use as well as the parameterization of the solution technique. As such, a sensitivity testing exercise was undertaken to ensure that the correct model and dataset was used for the proposed modelling approach, especially for the long term hindcast. In this scenario any small discrepancies will be amplified in the final results due to the length of time that the inconsistency may compound.

In order to determine the most appropriate data source to use for the wave modelling we must determine which time periods have the greatest overlap in the number of recording devices to ensure calibration incorporates the maximum number of concurrent recorded datasets. From the data summary in **Section 3**, it can be seen that we are constrained by the period of which the high resolution AUSWAVE data is available; ending July 2014.

As the Middleton Beach AWAC was not installed until September 2015, we were not able to calibrate to this device during this period (for the model to be driven by the AUSWAVE data). However, comparisons were made from both the Emu Point AWAC and the DoT Offshore Directional Waverider Buoy (DWRB) for that period. Upon consideration of the results of the initial SW calibration runs, a determination was made to either use the NOAA or the AUSWAVE data to drive the model boundary of the hindcast model; 38 years for NOAA or 35 years for AUSWAVE.

4.3.2 Model Setup

Domain

The initial SW model domain was setup with offshore extents that encompassed both the DoT Directional Waverider Buoy (DWRB), located adjacent to Cape Howe and the two closest NOAA WWIII model extraction points; {-35.5, 118} {-35, 119}. The extent of the initial SW calibration domain can be seen in Figure 37**.**

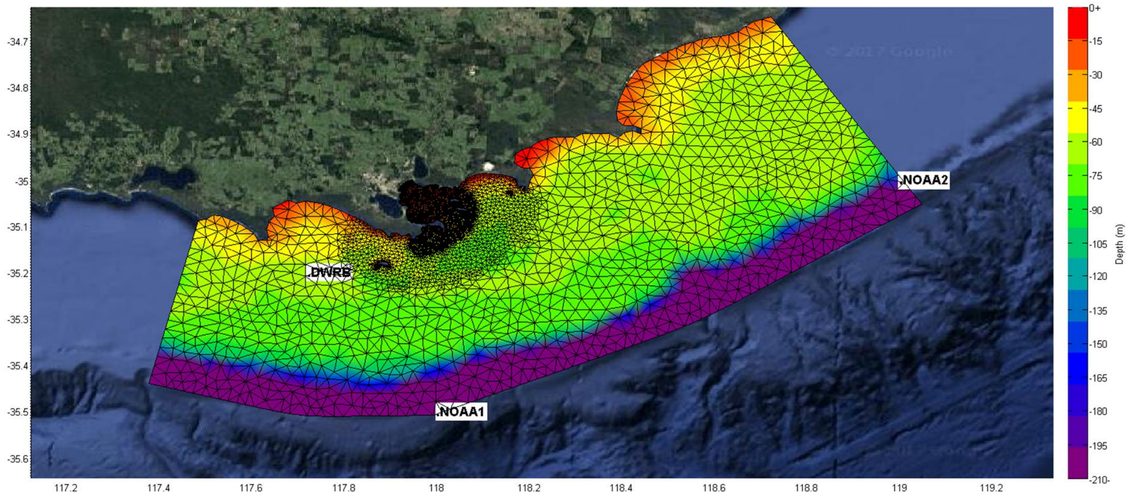


Figure 33 Regional view of MIKE21FM SW mesh including NOAA boundary points and DoT DWRB extraction point

The bathymetric data was taken from a combination of navigational charts for deeper offshore regions and the more recent 2016 DoT hydrographic survey for the nearshore areas adjacent to the study site. The raw data points were interpolated onto a flexible, unstructured mesh of some 13,500 cells, varying in resolution in the offshore areas from 2.5km in the Southern Ocean to 20m in the nearshore zone, as seen in **Figure 34.**

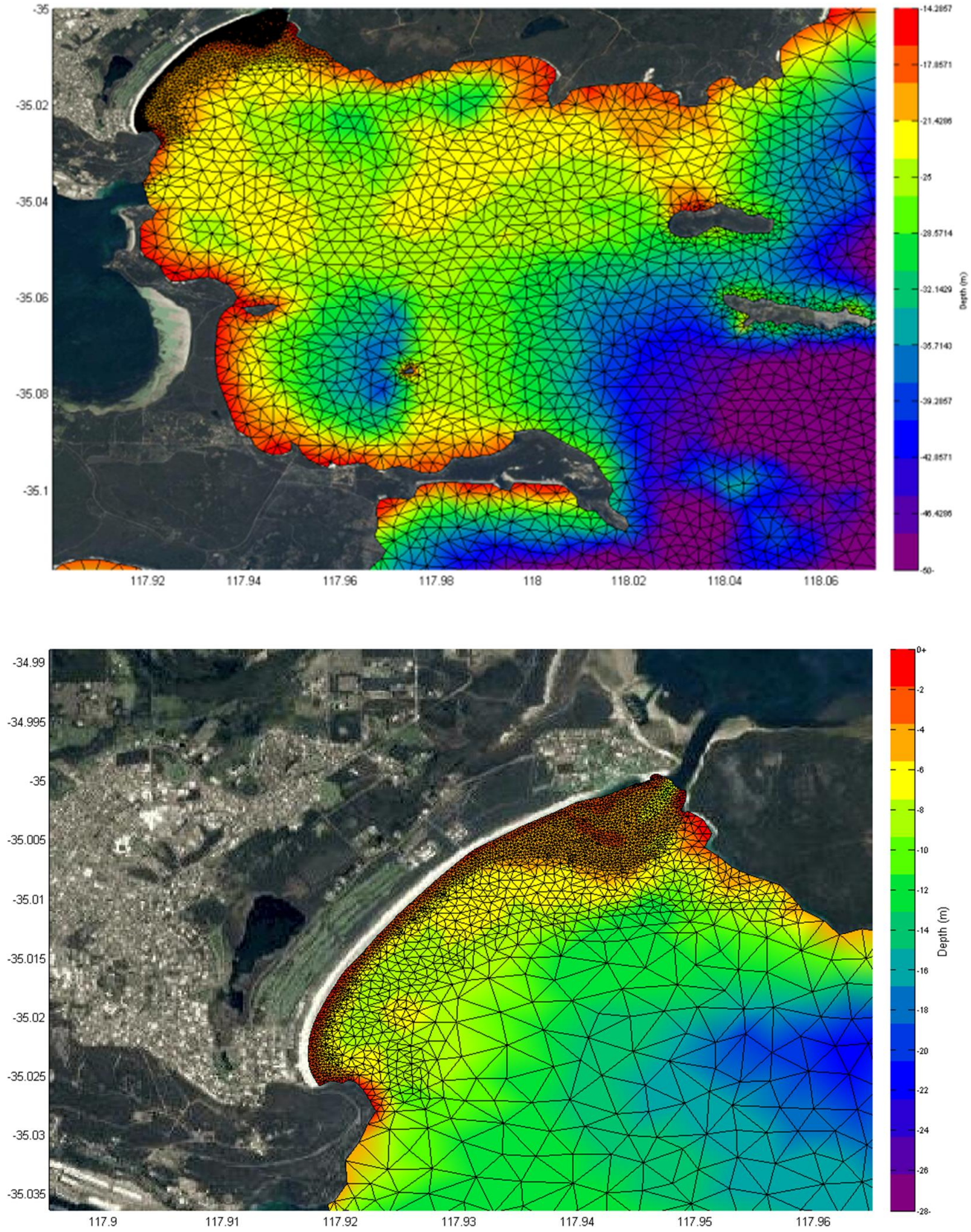


Figure 34 King George Sound and nearshore view of the MIKE21FM SW mesh showing increasing spatial definition in areas of bathymetric complexity

It can be seen that Princess Royal Harbour and Oyster Harbour as well as their upstream reaches have been omitted from the initial SW modelling domain. This has been done to ensure faster run times as it is expected that wave penetration from King George Sound into these areas will be minimal. Additionally, wind waves generated within each of the enclosed waterways (Princess Royal and Oyster Harbour) is not expected to have a significant impact on the wave field in the study site. The fetches across King George Sound are included in the model domain.

Boundary Conditions

The SW model was driven by a variety of wave boundary conditions, varying in their application by both type and spatial extent. The offshore boundary of the model was divided into four main regions dependant on their polar orientation; W, SW, SE and E. Wave conditions were applied to these boundaries to be transformed into the model domain in one of two ways; as point source varying in time but constant along its extent or as a line series varying in both time and along the extent of the boundary.

4.3.3 Model Calibration

The SW model calibration was setup in three distinct phases; calibration of offshore swell waves into in the Sound, calibration of wind-wave growth within the model domain and the verification of an appropriate offshore wave boundary source driven by global wave model data.

The first calibration stage involves the selection of an appropriate mesh resolution, bathymetry and hydraulic roughness for the model domain. This is to ensure that longer period swell waves entering the Sound from the Southern Ocean are correctly transformed into the nearshore (and model calibration points). A suitable period that covers all three wave recording deployments (DWRB, RHDHV and DoT AWACs) as well as the Emu Point (and NOAA) wind data periods was selected. This can be seen as the four month period from September 2015 to January 2016.

The model was run for a two week period from the 15th September to the 29th of September 2015. In addition to the reasons stated above, this calibration period was selected as it was observed to have a combination of long period south westerly swells offshore of the Sound (recorded at the offshore DWRB), as well as locally generated south to south-south easterly wind waves (experienced at both the DoT and RHDHV AWACs). Initial runs used recorded DWRB wave parameters as boundary conditions to the model domain. This was to ensure longer period swell waves were transformed correctly into the Sound and the study area.

Following initial testing, a clear data gap was seen in that the only available (complete) survey of the Sound and both Emu Point and the greater Middleton Beach was that of April 1976. This survey was most probably undertaken using a single beam recorder due to its vintage. Areas of bathymetric significance, such as the deep holes observed offshore of Emu Point (in approximately 20m water depth) were seen to be resolved over only a limited number of points (as well as contours from navigation charts).

A follow up search of bathymetric data was initiated by the CoA, DoT and PoA and additional higher-resolution data was obtained from the PoA for a selection of areas and extents within the Sound post 1987, seen in **Appendix B-2**.

The additional data was incorporated in the model where significant gaps were seen and spatial resolution was appropriately adjusted in order to correctly represent the wave transformation occurring in this bathymetrically significant area. Several first phase calibration runs were performed using a quasi-stationary, directionally decoupled solution technique, until it was determined that the model domain could sufficiently transform swell waves from the offshore boundary into the nearshore domain (at the AWAC calibration locations). Parameters changes to achieve a good calibration included bathymetry (as described above) and seabed roughness.

Following the initial calibration phase it could be seen that lower period wave events were not being picked up at the nearshore AWAC devices. This was due to the concurrent longer wave period events having greater wave energy at the offshore DWRB location (and hence being recorded at this site); diminishing in energy by the time they are transformed to the nearshore AWAC locations, as seen in the RHDHV AWAC calibration in Figure 35(left).

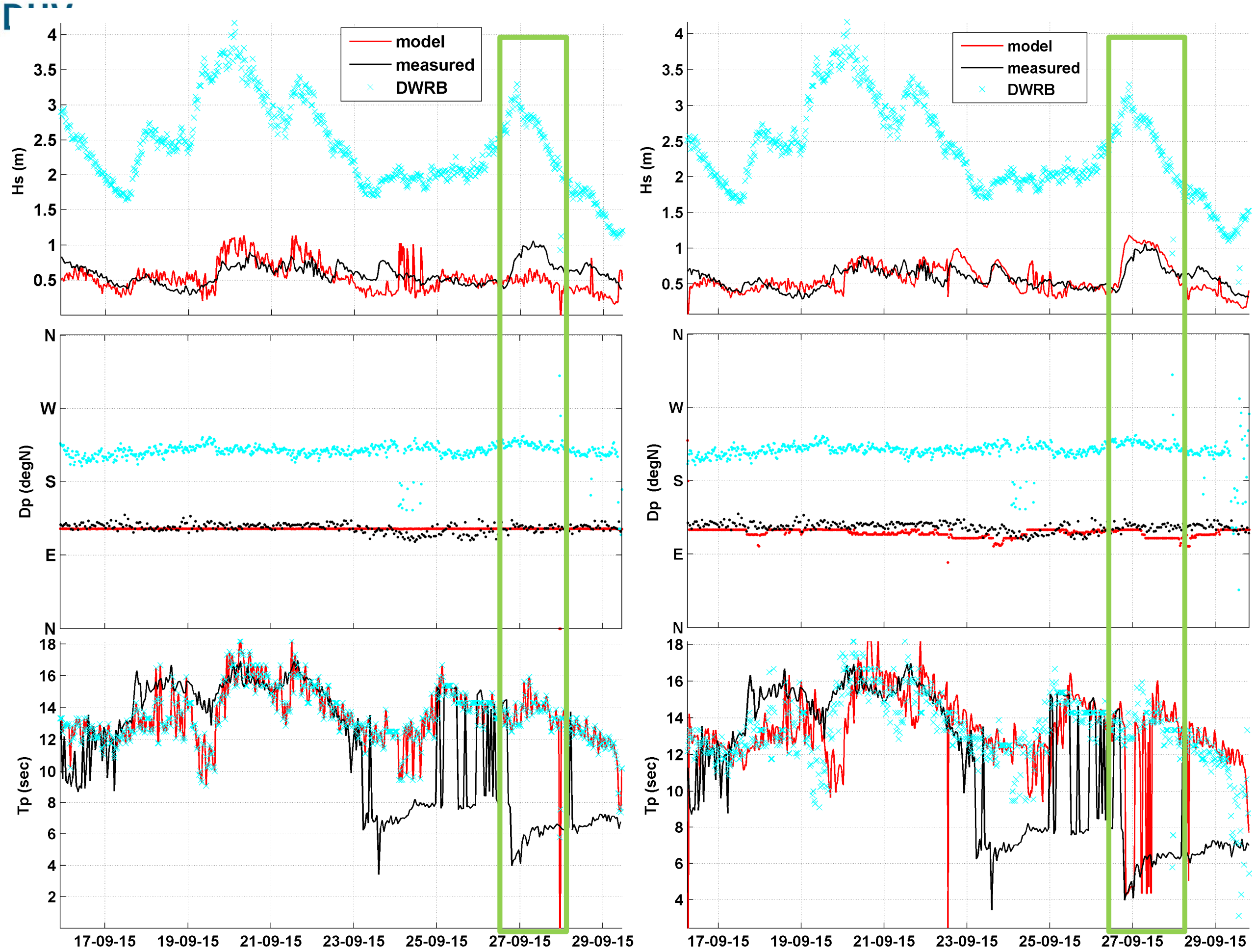


Figure 35 Calibration iterations at the RHDHV AWAC location for Hs, Dp and Tp; ***Left****: quasi-stationary, directionally de-coupled formulation of DWRB wave parameters transformed through domain.* ***Right****: fully spectral, in-stationary formulation of NOAA WWIII wave parameters transferred through model domain with NOAA wind speed and direction applied across model domain*

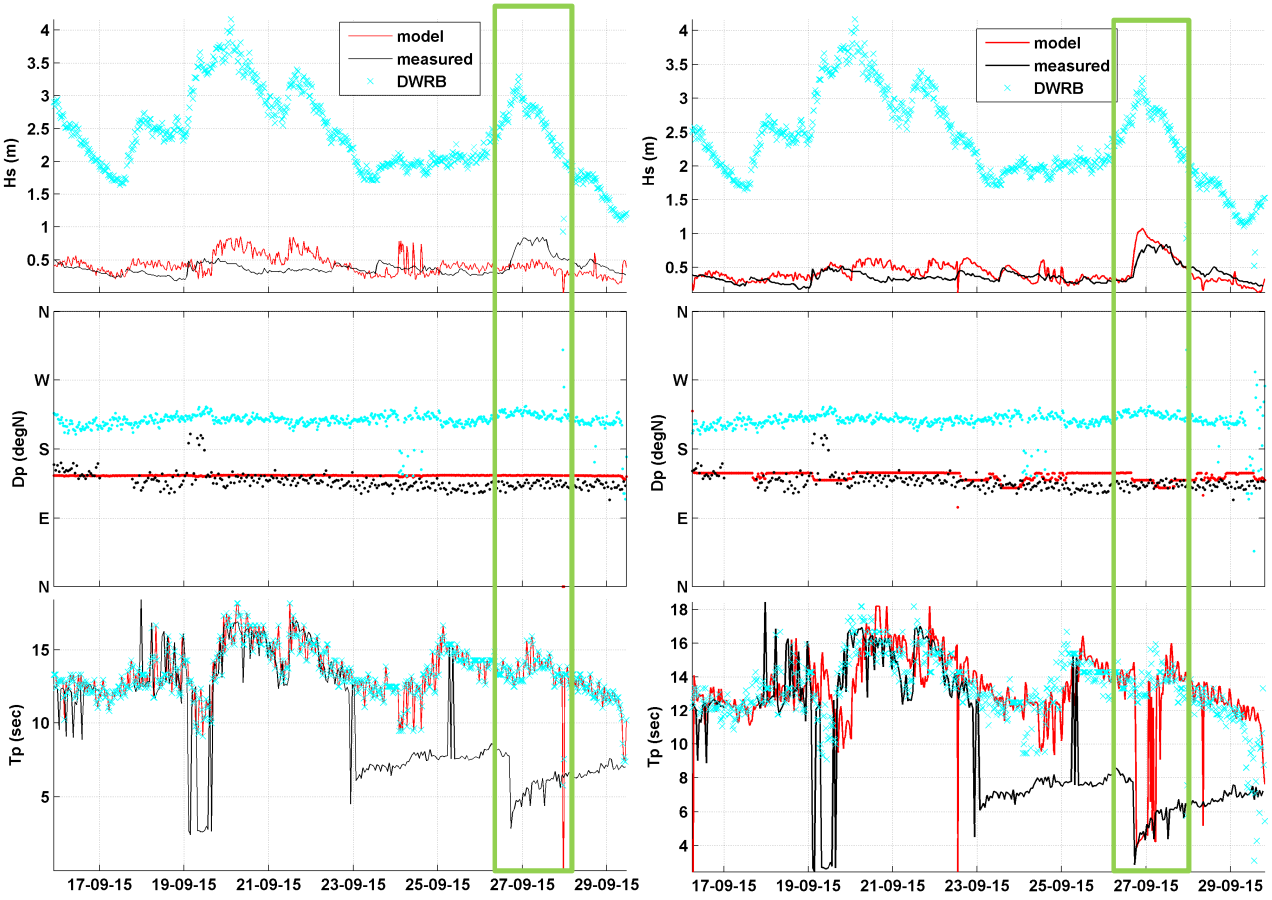


Figure 36 Calibration iterations at the DoT AWAC location for Hs, Dp and Tp;

***Left**: quasi-stationary, directionally de-coupled formulation of DWRB wave parameters transformed through domain. **Right**: fully spectral, in-stationary formulation of NOAA WWIII wave parameters transferred through model domain with NOAA wind speed and direction applied across model domain*

It was observed that the model was not representing lower period (<9 second) waves at the nearshore AWAC locations, as seen in **Figure 35** (left) where the modelled period at the AWAC location matched that of the offshore DWRB (cyan and red Tp curves). However in reality, the measured data at the AWAC device was recording shorter period (6-8 second) waves during these times. These lower period events tended to be from a more south to south-south-easterly direction during these occurrences. This inferred that they were locally generated wind wave events and as such the model domain along this fetch orientation was extended to sufficiently allow for this wave generation (as seen in **Figure 37)**. The extension of the domain in this direction and the change in solution technique of the SW model allowed for wind-wave growth along the south-south-easterly fetch into the Sound and sufficient calibration of the SW model (**Figure 35** (right)).

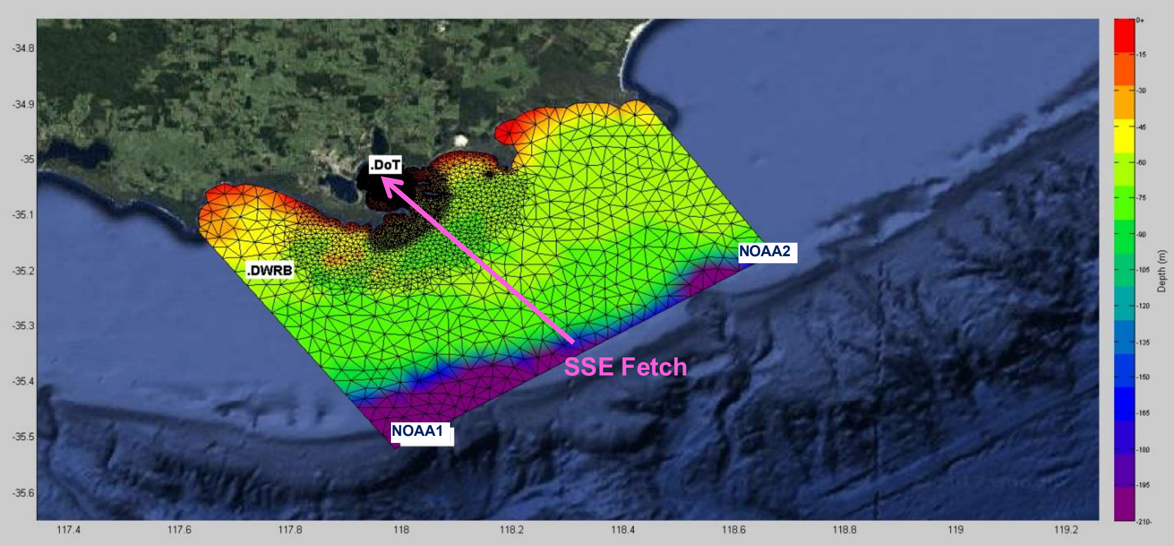


Figure 37 South-easterly extension of the model domain (from the NOAA1 wave parameter source) to account for locally generated wind-waves

In order to attain a long-term understanding of the nearshore in the study area, a hindcast for as long a period as possible is required. The longest available wave record comes from the two global hindcast models. As the transformation of swell waves (from the DWRB) and growth of wind waves into the SW domain was now sufficiently resolved, selection of an offshore wave source was needed to drive the long term SW model. In order to maintain a similar calibration of the SW model (as that described above) it is desirable to ensure that (at a minimum) the wave heights of the selected data source match as closely as possible that of the measured waves at the DWRB site.

The NOAA WWIII hindcast extraction point taken at -35°S, 119°E (NOAA2) was seen to closely match both the phase and magnitude of the recorded H_s signal at the DWRB location (**Figure 38**). This was deemed as a suitable proxy to drive the long term wave hindcast model. Initial calibration of this source of wave parameters used as a boundary condition can be seen in **Figure 35** (right). This model was run in conjunction with hindcast NOAA winds varying through time but constant over the model domain.

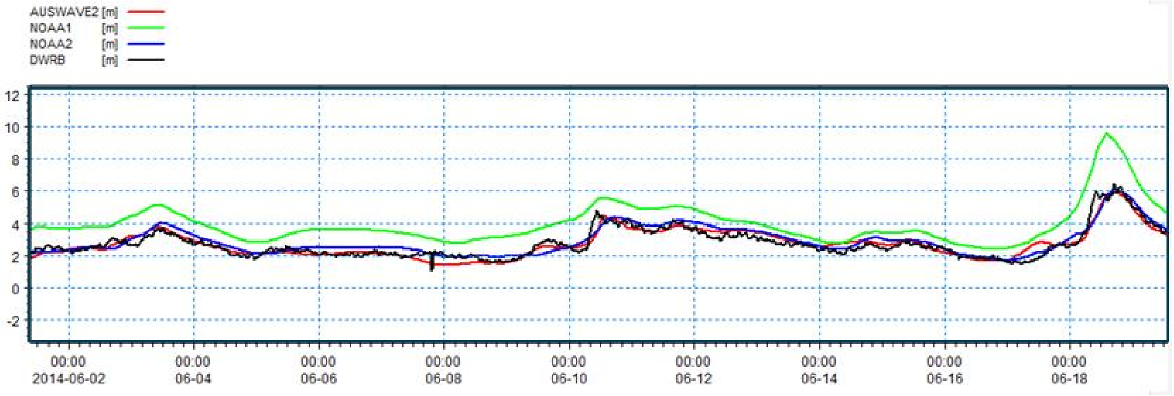


Figure 38 Comparison of Significant Wave Height, Hs (m) at the offshore boundary of the SW model domain

4.3.4 38-year Wave Hindcast

Nearshore Wave Climate

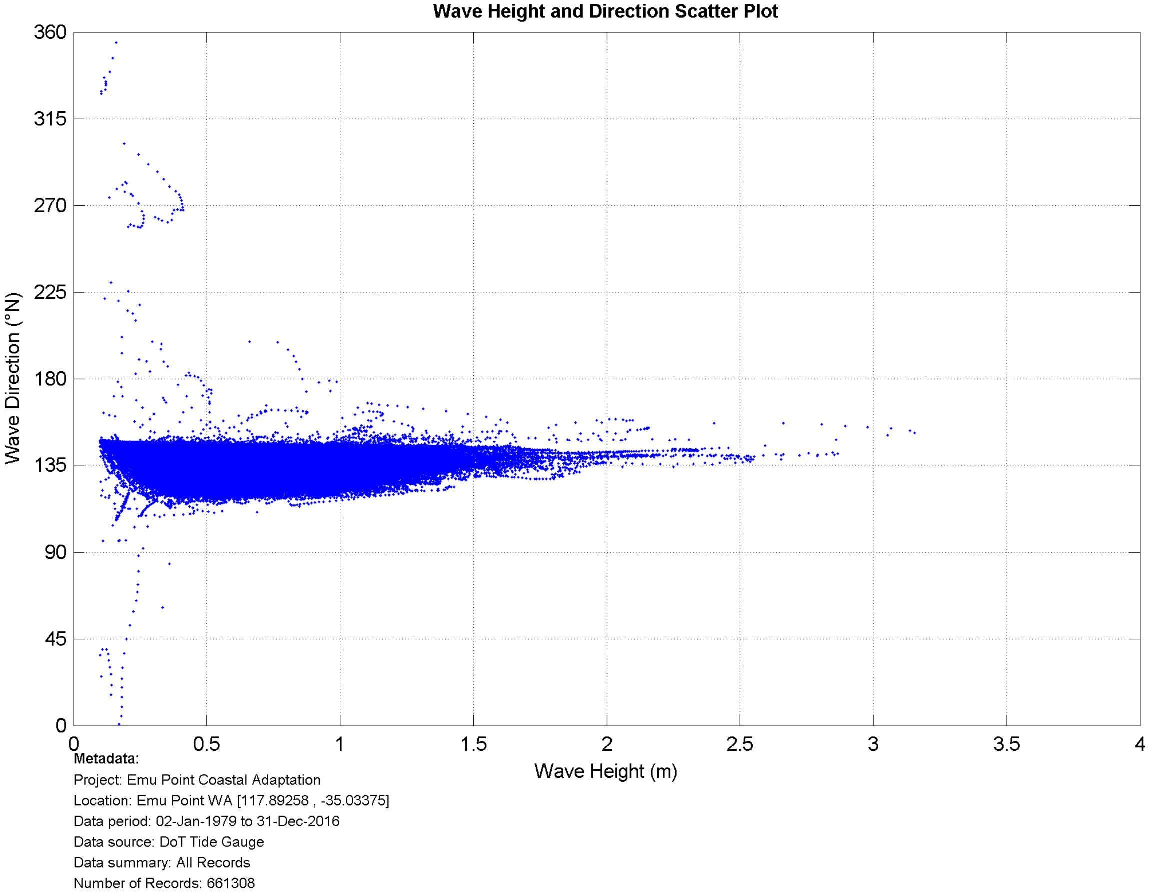
This section summarises the nearshore wave climate derived for the study area site based on the wave modelling methods. For the purposes of this summary, wave climate results are extracted from the model at the site of the DoT Emu Point AWAC. The water depth at this location is approximately 8m.

Table 14 provides a summary of the nearshore wave climate in terms of percentage probability of non-exceedance values (or percentiles) at the DoT Emu Point site. For example, 99% of the time in summer the significant wave height (H_s) at Emu Point is estimated to be less than 1.25m.

Table 14 Operational wave climate for the DoT Emu Point site; [117.944233° , -35.010700°].

Parameter	**Statistic**	**38-year hindcast record**				
		LTA	**Summer**	**Autumn**	**Winter**	**Spring**
Significant wave height (H_s) [m]	Mean	0.54	0.56	0.55	0.53	0.52
	20%ile	0.34	0.34	0.35	0.34	0.33
	50%ile	0.49	0.51	0.50	0.48	0.48
	75%ile	0.68	0.73	0.68	0.64	0.66
	90%ile	0.87	0.92	0.87	0.83	0.85
	99%ile	1.26	**1.25**	1.28	1.29	1.23
	99.5%ile	1.38	1.35	1.41	1.44	1.35
	Max	3.15	2.87	2.85	3.15	2.10
Peak wave period (T_p) [s]	Mean	12.9	11.7	13.2	13.9	12.8
	20%ile	11.5	10.2	12.1	12.5	11.5
	50%ile	13.4	12.3	13.5	13.8	13.4
	75%ile	14.6	13.5	14.6	15.0	14.6
	90%ile	15.5	14.7	15.5	16.3	15.4
	99%ile	18.2	17.0	18.2	18.2	18.2
	99.5%ile	18.2	18.2	18.2	18.2	18.2
	% of time sea (T_p < 8s)	10%	10%	0%	0%	10%
	% of time swell (T_p > 8s)	90%	90%	100%	100%	90%
Mean Wave Direction (MWD) [°TN]	Weighted Average	139	135	139	143	139
	Average	141	138	141	144	141
	St. Dev.	11	13	7	5	15

Figure 39 presents an overview of the directionality of the wave climate at the DoT Emu Point site. It is noted that the majority of wave energy is from the south-south-east (or approximately 135°N). A comprehensive analysis that includes joint occurrences tables, wave rose plots and scatter plots are provided in **Appendix C**.



Metadata:
Project: Emu Point Coastal Adaptation
Location: Emu Point WA [117.89258 , -35.03375]
Data period: 02-Jan-1979 to 31-Dec-2016
Data source: DoT Tide Gauge
Data summary: All Records
Number of Records: 661308

Figure 39 Wave height and direction scatter plot (based on 38-years of MIKE 21 hindcast data)

Nearshore Design Wave Conditions

Design wave conditions have been calculated based on the results of the 38-year wave hindcast. For the DoT Emu Point AWAC site, the independent event peak storm significant wave heights were subjected to an extreme value analysis using the maximum likelihood method, fitting to the Weibull distribution. Design wave conditions in terms of significant wave height are presented in **Figure 40** for the 1 to 500-year ARI. **Table 15** presents the recommended design wave conditions for the DoT Emu Point site for wave events with an ARI of 5, 10, 20, 50, 100, 200 and 500 years.

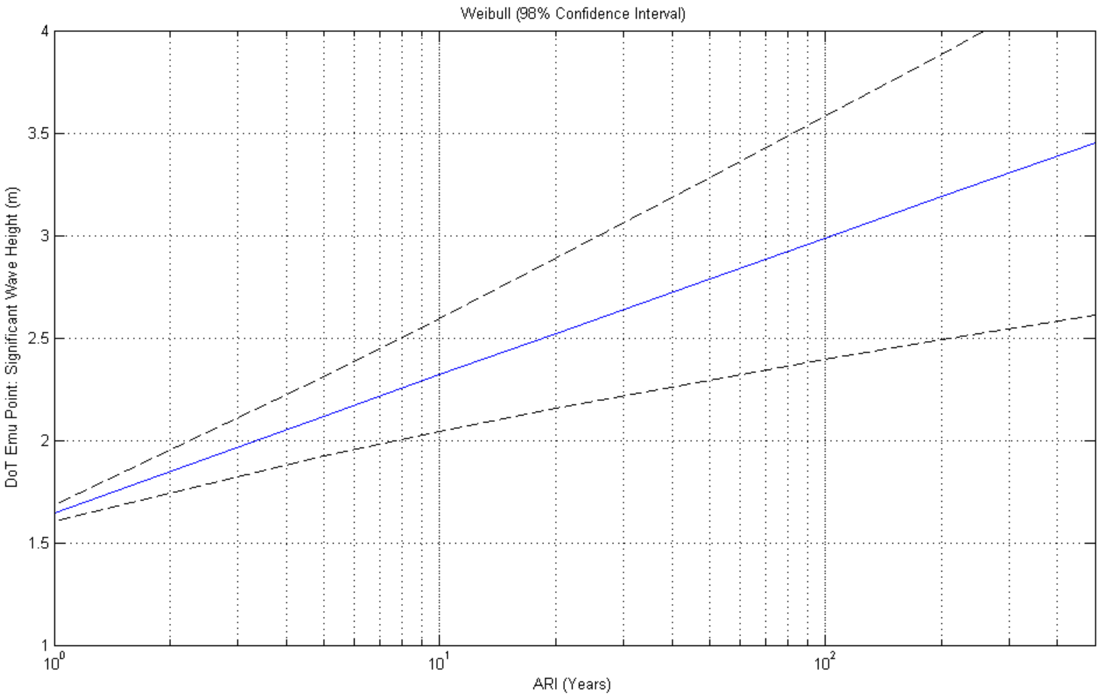


Figure 40 Design wave heights (Hs) (DoT Emu Point site) and associated peak wave directions (coloured dots)

ARI (year)	H_s (m)	H_s (98% Confidence Intervals)
5	2.12	1.60 - 1.68
10	2.32	1.92 - 2.31
20	2.52	2.04 - 2.60
50	2.79	2.16 - 2.89
100	2.99	2.30 - 3.28
200	3.19	2.40 - 3.58
500	3.45	2.49 - 3.89

Table 15 Design wave parameters for DoT Emu Point site

Coastal Storms

A listing of the most significant coastal storms over the 38-year hindcast period is given in **Table 16**, with the hindcast values for H_s, H_{max} and T_p (at the peak H_s of the storm) shown for the DoT Emu Point site. Here a coastal storm is defined as having a nearshore wave height (H_s) of greater than 1.5m (>99th percentile H_s) at a minimum of 48 hours of separation from the next peak. A total of 63 significant events were hindcast. This represents an average of 1 significant event every 0.6 years, in the 38-years of record. However, the time period between storms was not uniform. For example, there were no significant coastal storms from 2014 to 2016. When the data was available, **Table 16** also includes the peak water level of each storm as recorded at the Princess Harbour tide gauge.

The distribution of the 63 selected events throughout the 38 year hindcast (Hs) record can be seen in Figure 41 and provided individually in Appendix

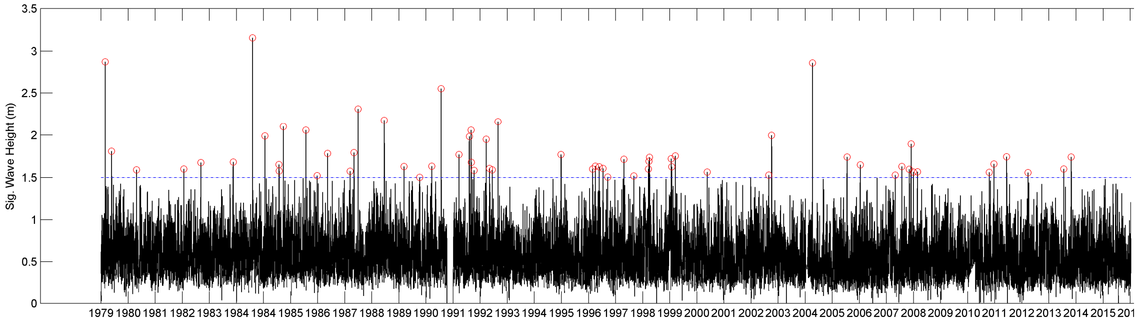


Figure 41 The 63 most' significant' coastal storms derived from the 38-year SW hindcast model at the DoT AWAC extraction location.

It is noted that the decade between 1984 and 1994 was particularly stormy with 7 of the largest 10 storms occurring in this period.

Table 16 Top 10 wave events at the DoT Emu Point site.

Note, the start and end date have been defined that Hs > 95th percentile

Start Date	End Date	Peak Date	Duration (days)	Peak Hs (m)	Mean Hs (m)	Peak Tp (s)	Peak Dir (˚N)	Peak Water Level (m LAT)
2/08/1984 18:00	6/08/1984 17:00	2/08/1984 23:00	4.0	3.16	1.86	12.0	151	-
25/02/1979 20:00	28/02/1979 23:30	26/02/1979 2:00	3.2	2.87	1.53	11.6	142	-
31/03/2005 7:00	2/04/2005 13:00	1/04/2005 13:30	2.3	2.85	1.74	9.2	141	1.19
19/07/1991 19:30	23/07/1991 9:30	20/07/1991 19:30	3.6	2.55	1.78	9.3	140	1.11
25/06/1988 10:30	25/06/1988 23:30	25/06/1988 14:00	0.5	2.31	1.55	6.2	149	1.06
13/06/1989 0:30	18/06/1989 8:00	14/06/1989 1:30	5.3	2.18	1.59	8.5	139	1.21
25/08/1993 12:00	26/08/1993 17:00	25/08/1993 19:30	1.2	2.16	1.48	5.1	154	0.78
22/09/1985 2:00	24/09/1985 22:00	22/09/1985 5:30	2.8	2.10	1.35	4.8	159	-
22/07/1986 20:30	26/07/1986 8:00	24/07/1986 17:00	3.5	2.06	1.40	11.3	142	-
28/08/1992 2:30	29/08/1992 4:00	28/08/1992 5:30	1.1	2.06	1.37	5.8	148	1.13

The modelled time step for the highest peak Hs (m) extracted from the DoT AWAC location from the 38 year hindcast SW model (2nd August, 1984) can be seen in Figure 42. Notice the difference in wave penetration into KGS as compared to Figure 10 due to the more easterly nature of the wave direction.

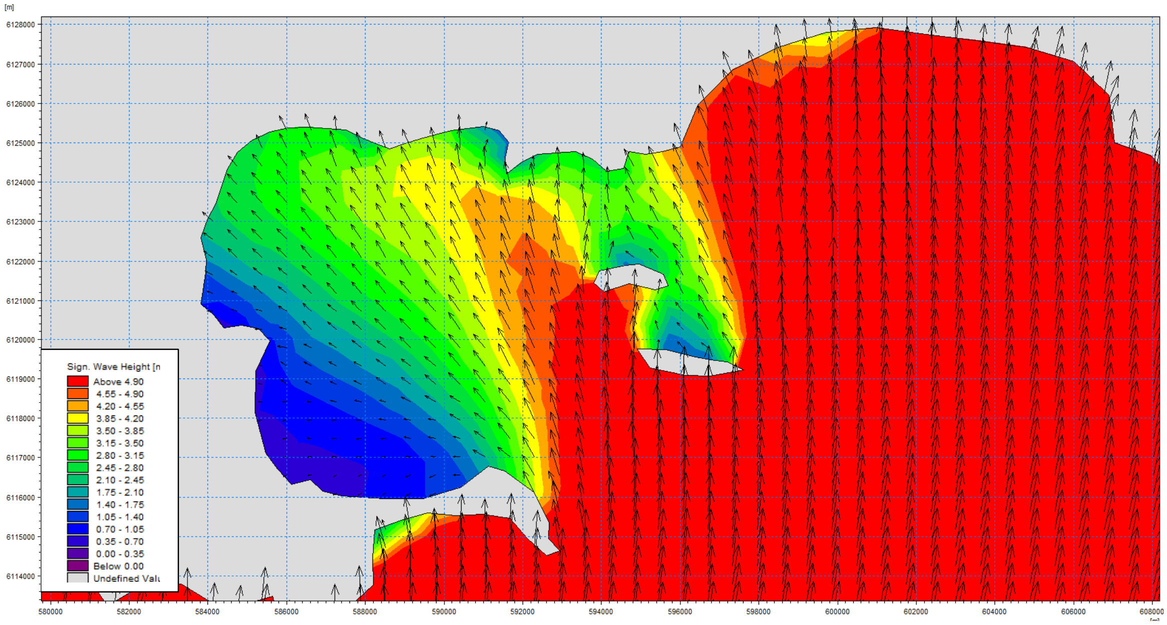


Figure 42 Time step of the maximum peak significant wave height, Hs (m) from the 38 year hindcast SW model extracted at the DoT AWAC location, (2/08/1984 18:00).

The time series of wind and wave parameters throughout the 1984 storm event can be seen in Figure 43

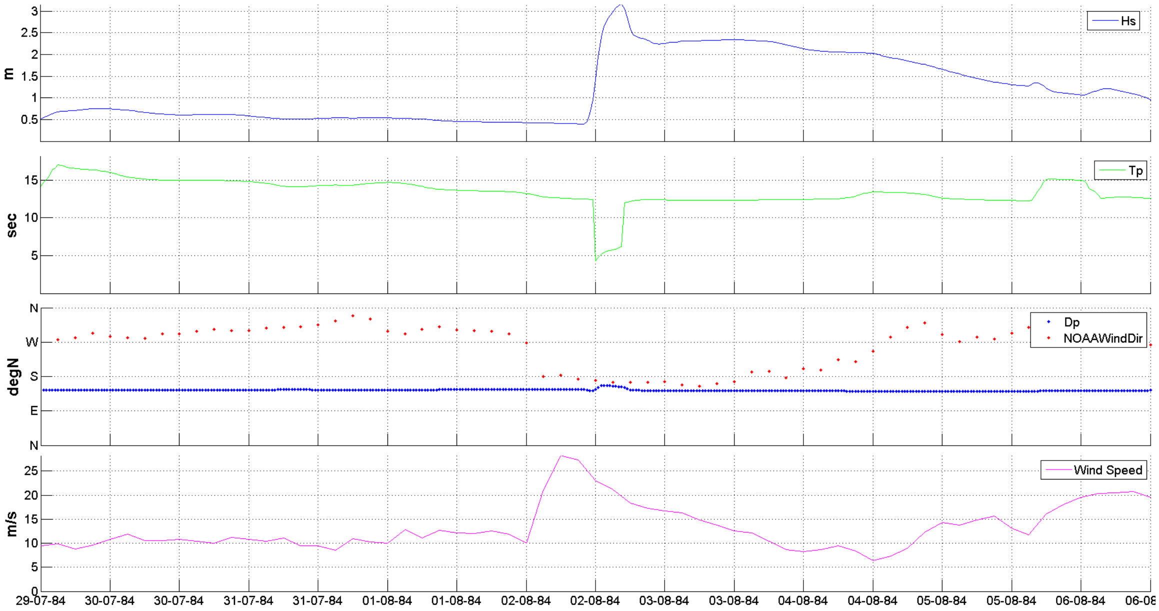


Figure 43 Time series of wind and wave parameters extracted for the August 1984 storm event at the DoT AWAC location

Annual Wave Energy and Storminess

Annual variation in the shoreline can be expected to correlate with wave energy, more so than wave height or wave period alone. For the 38-year wave hindcast period, the annual incoming wave energy was calculated for two conditions:

- The total cumulative incoming wave energy for the entire calendar year was calculated by summing the hourly wave energy (after CERC, 2006; units of J/m); and
- The cumulative incoming storm wave energy for the year was calculated by summing the incoming wave energy for all storm periods (i.e. when the nearshore wave height (H_s) exceeded 0.99m [95th percentile]). It is noted that individual storm duration could be considered as well as wave height and period. Inclusion of each storms duration in the analysis would be expected to provide a better measure of the wave energy or power associated with a storm.

The results of the annual wave energy calculations are presented in **Figure 44**. Shoreline variations can also be expected to correlate with elevated water levels. As such, included in this figure is the variation in annual Mean Sea Level (MSL) as recorded at the DoT Princess Harbour tide gauge.

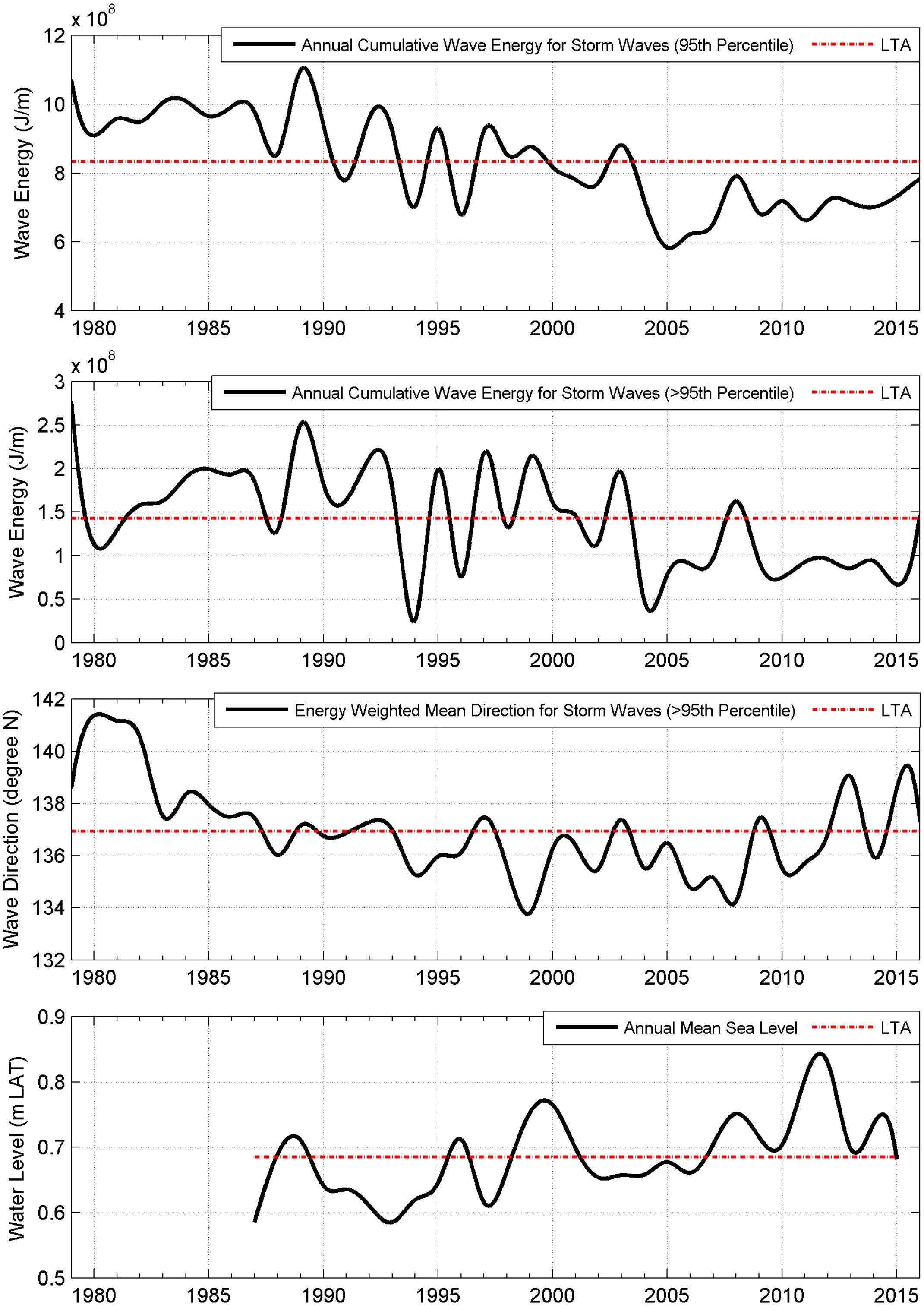


Figure 44 Annual nearshore wave energy for total (top), storm periods (2nd) and weighted mean directions during storm periods (3rd), along with annual MSL (bottom)

Joint Probability of Storm Waves and Elevated Water Levels

The joint occurrence and cumulative effects of wave conditions and water levels at Emu Point was assessed using the 38-year wave hindcast and the 30-year Princess Harbour tide gauge data. **Figure 45** demonstrates the joint occurrence of wave heights and associated water levels. All extreme wave events identified using the peak-over-threshold (POT) methods are highlighted in red.

No significant dependence is between large wave events and co-incident elevated water levels is evident, however, the third largest wave event (i.e. March 2005) coincided with an above average Mean High Water Spring (MHWS) water level. As expected, in the lower percentile corner of **Figure 45** (left) no correlation between the tidal water levels and wave heights was present. Therefore, no significant tidal modulation of the wave climate at the DoT Emu Point site was evident.

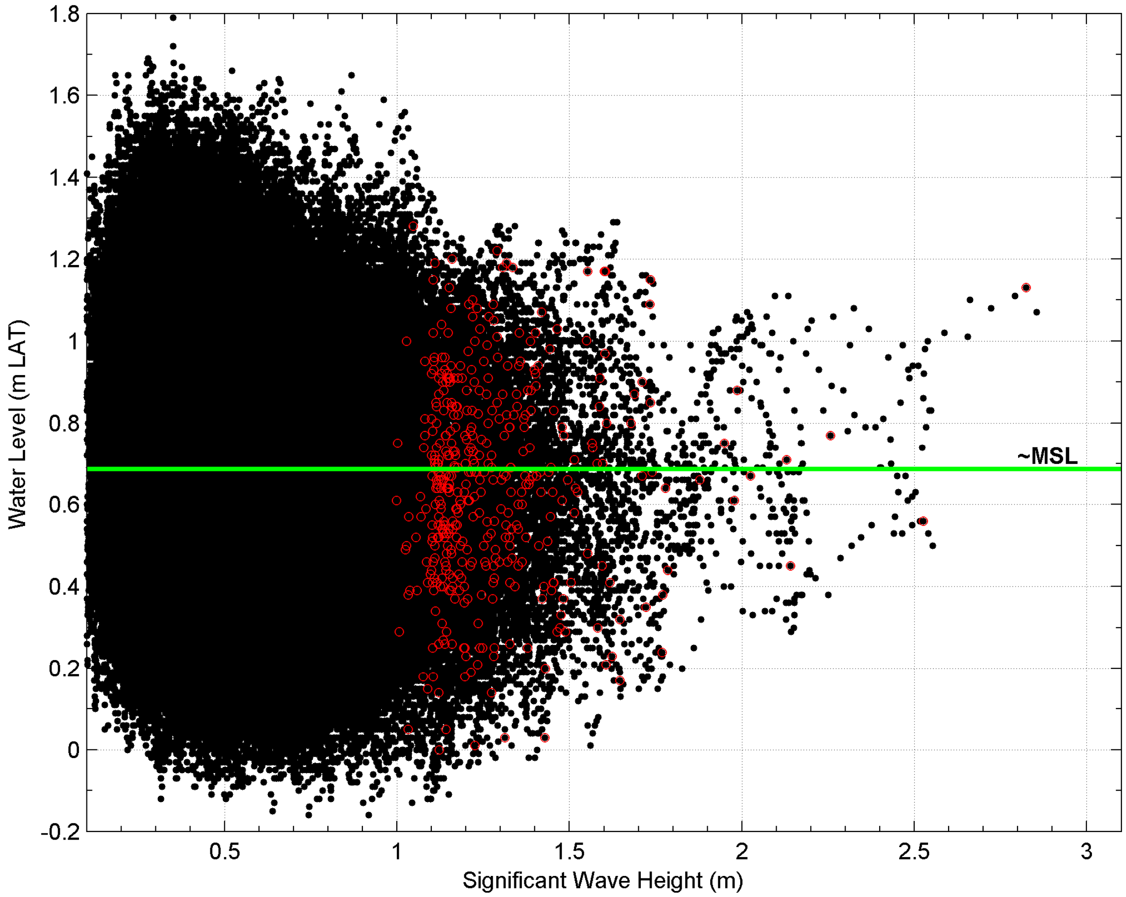


Figure 45 Correlation between water level and significant wave height at the DoT Emu Point site. (The red dots indicate the selected independent peak over threshold (POT) wave events during the EVA)

This top three extreme water level recordings observed at the Princess Royal Harbour gauge (Table 8) were plotted against wave height, direction and wind speed and direction extracted from the NOAA2 location to determine the validity of the above claim. The non-tidal residual was also compared. It can be seen that there is no apparent correlation between these forcing parameters and elevated water levels must be attributed to differing oceanic and meteorological contributors.

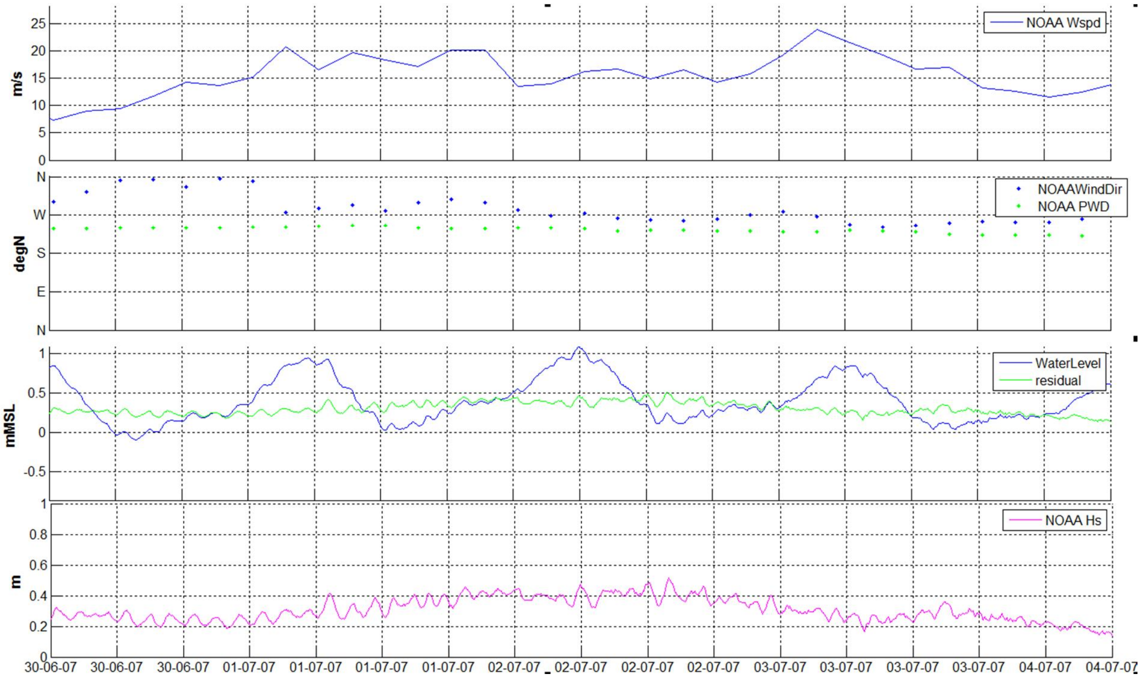


Figure 46 Extreme water level event 1; 02/07/2007. Panel 1: NOAA2 extraction point wind speed, panel 2: NOAA2 extraction point wind and peak wave direction. Panel 3: PRH recorded water level and calculated residual. Panel4: NOAA2 extraction point significant wave height

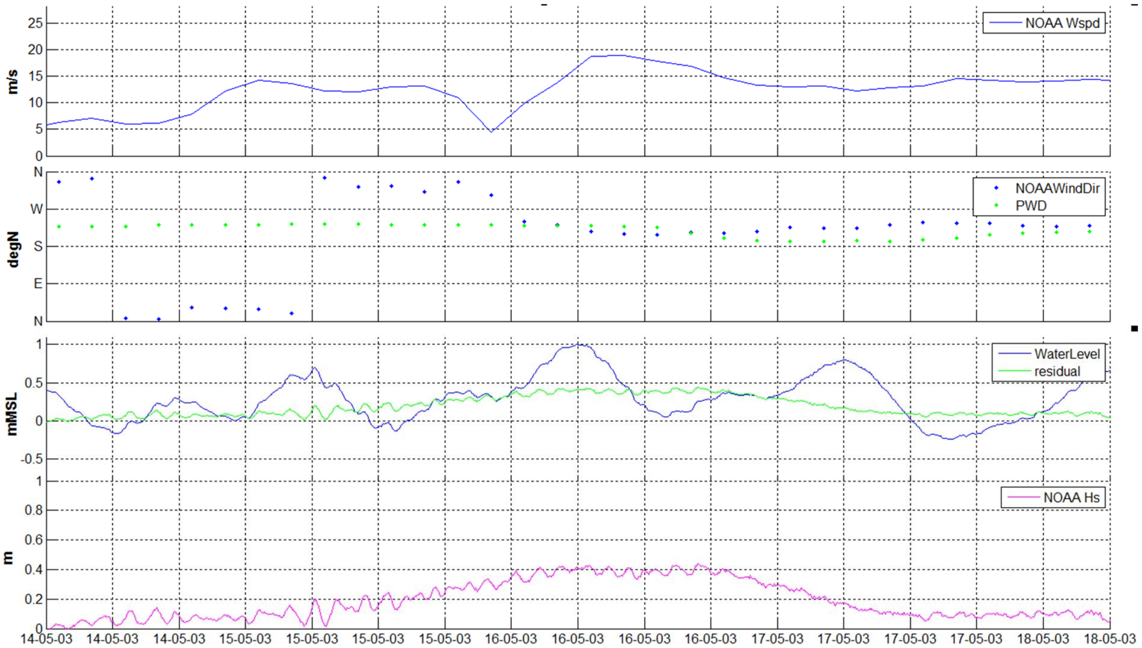


Figure 47 Extreme water level event 2; 16/05/2003. Panel 1: NOAA2 extraction point wind speed, panel 2: NOAA2 extraction point wind and peak wave direction. Panel 3: PRH recorded water level and calculated residual. Panel4: NOAA2 extraction point significant wave height

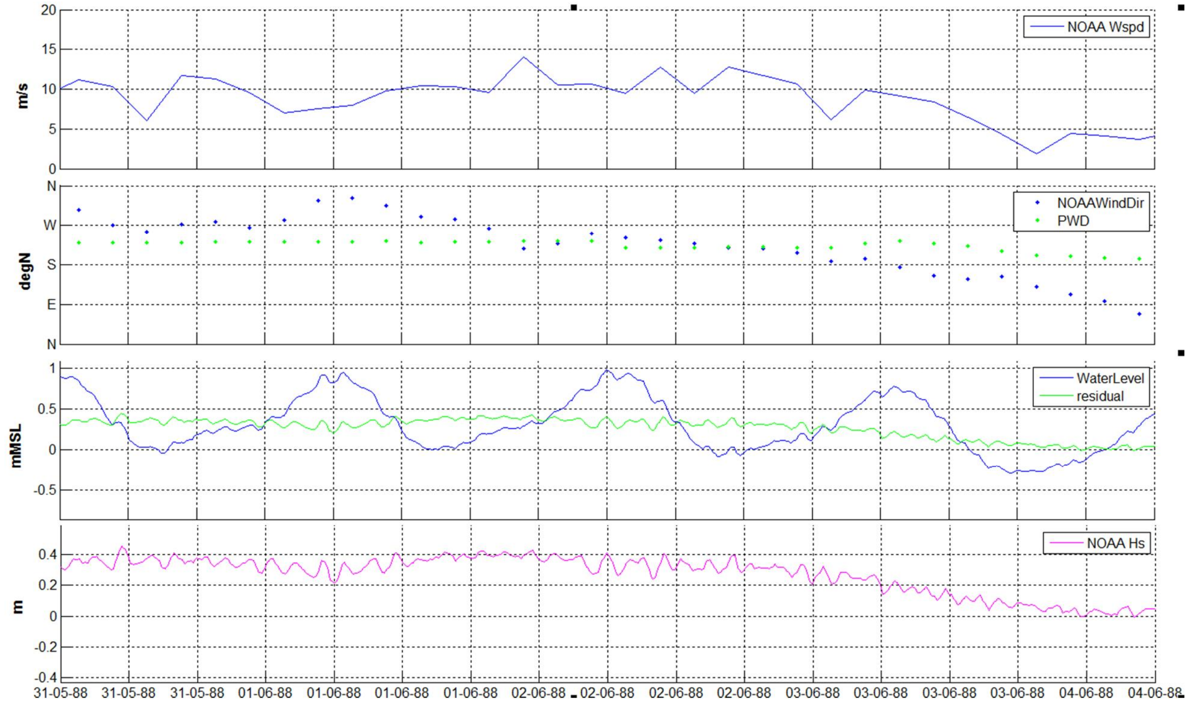


Figure 48 Extreme water level event 3; 02/06/2008. Panel 1: NOAA2 extraction point wind speed, panel 2: NOAA2 extraction point wind and peak wave direction. Panel 3: PRH recorded water level and calculated residual. Panel4: NOAA2 extraction point significant wave height

4.3.5 Oyster Harbour Spectral Wave Model

Oyster Harbour Beach is within the study area but located within Oyster Harbour is not included in the 38-year wave hindcast as it is not exposed to ocean swells. From the results of the 38-year wave hindcast and by examination of 2D spatial maps of modelled significant wave heights, it was quite apparent that very little wave energy generated through the SW model domain had the capacity to enter Oyster Harbour and the study site. Waves arriving at Oyster Harbour Beach will therefore only be generated by local wind wave growth along the fetches of Oyster Harbour, the longest of which is seen to come from the northerly sector.

In order to determine an appropriate wind speed to use for analysis of design conditions within Oyster Harbour an extreme value analysis (EVA) was undertaken on the 38-year wind hindcast data taken from the closest NOAA extraction point. The EVA was undertaken on 10-minute wind speeds from **all** directions for the 38-year data set. The results of the wind speed EVA can be seen in **Figure 49**. The 100-year ARI wind speed from the EVA can be seen as being approximately 27m/s.

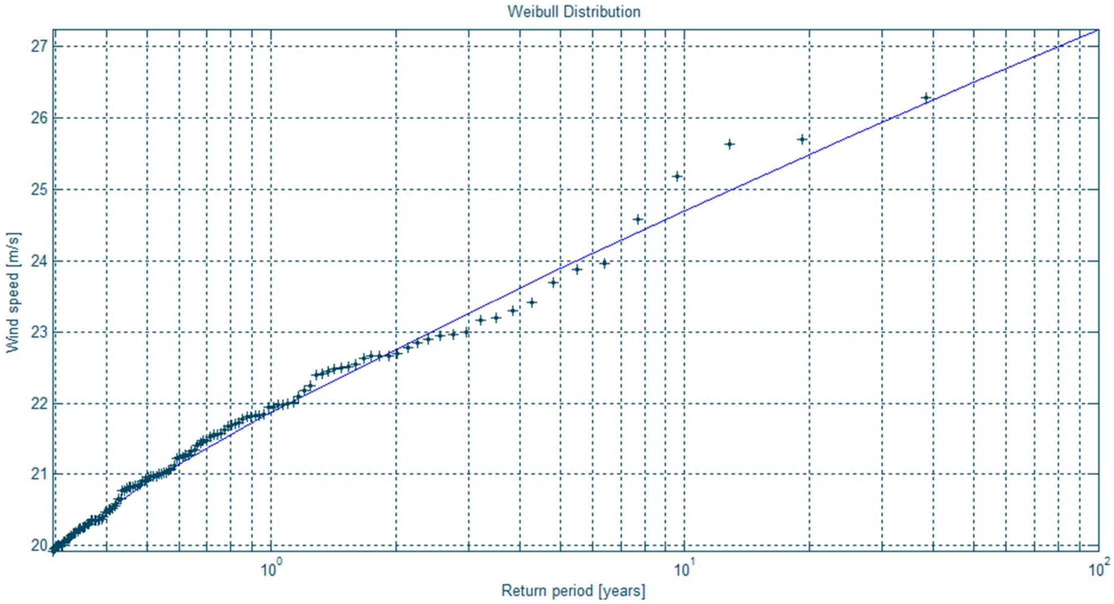


Figure 49 Extreme Value Analysis of wind speed from the 38 year NOAA hindcast dataset from the Albany extraction point

As seen in the wind analysis undertaken in **Section 3.4.2**, the strongest winds in Albany are usually experienced from the southerly sector, a direction which would not generate wind-wave growth into the Oyster Harbour study site. As such, incorporation of the 27m/s for modelling maximum waves into the study site (which would most probably occur from the north) can be considered a conservative approach.

A local FM model domain was set up for Oyster Harbour, incorporating the upper beach and inland of the study site, as seen in **Figure 50**.

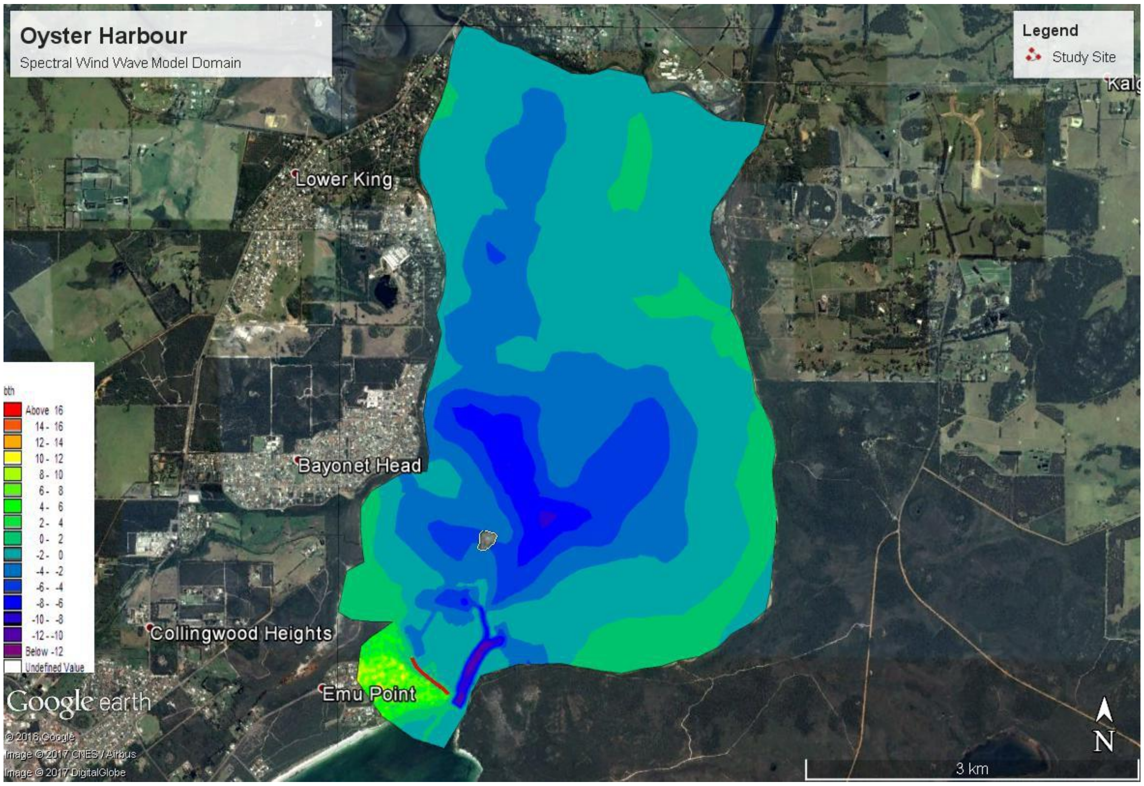


Figure 50 MIKE21 FM SW model domain of Oyster Harbour

The model was driven in a fully-spectral formulation, forced by a 27m/s wind speed from NW, N, NE and E instationary direction to determine the maximum wave heights that could be generated at the study site. The 100-year return period water level was also applied to the domain, again a conservative approach in a tidal environment. This approach was incorporated to ensure maximum wave growth within the domain was supported. As there have been no wave measurements undertaken within Oyster Harbour, calibration of this model is not possible.

The output time series of the largest significant wave heights (~0.8m) and periods (~3sec) from the most vulnerable direction (NE) were taken forward into the erosion modelling phase to inform the hazard mapping (see **Section 6**). This time series was taken at a point tangential to the beach orientation sufficiently offshore so as to ensure wave heights were at a maximum, prior to reaching the beach.

4.4 Hydrodynamic (HD) Model

4.4.1 Model Setup

Domain

A MIKE 21 Hydrodynamic (HD) model was setup using the same offshore spatial extent as that described for the SW model in **Section 4.3.2**. As this model will be used to describe the flow regimes at the study site, both Oyster and Princess Royal Harbours were now also included in the modelled domain as flux in and out of these bodies will be critical to representing the flow regime of the study site.

The nearshore representation of these sites can be seen in **Figure 51**.

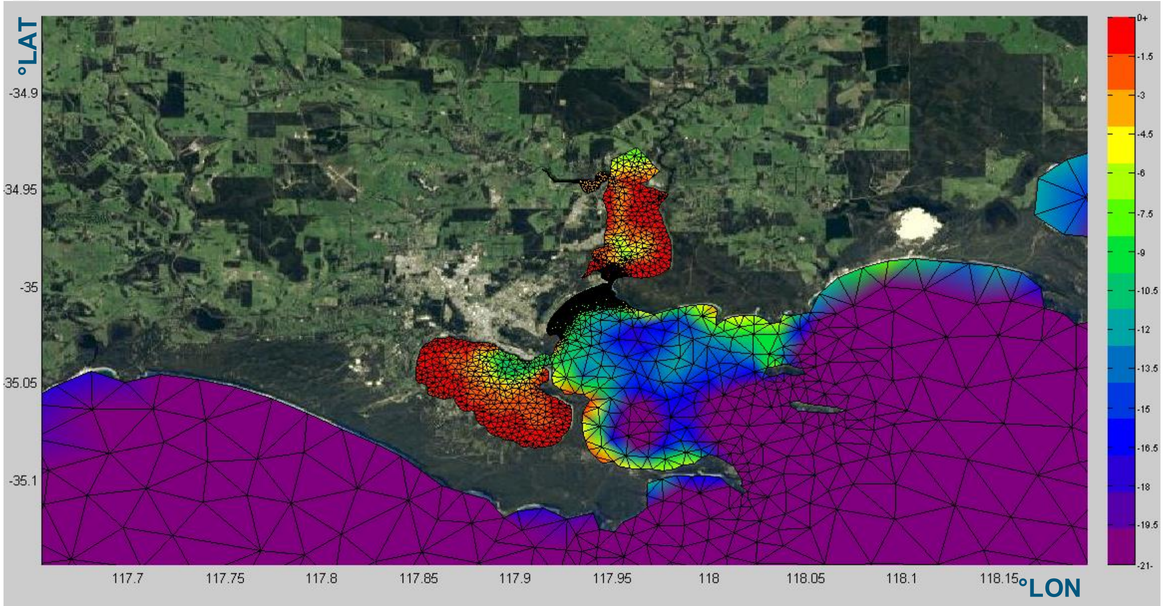


Figure 51 The nearshore (<-20m depth) representation of the HD model domain, including both Oyster and Royal Princess Harbours

Bathymetry

As the nearshore bathymetry has changed significantly over the length of time covered by the 38-year SW hindcast, it was important that the schematisation of the nearshore model domain was flexible enough to incorporate any significant changes (including anthropogenic) for the purpose of comparison between study years.

The most significant changes to both topography and bathymetry have occurred along the foreshore of the Emu Point area, with the introduction of several engineering structures for coastal protection, as detailed in **Section 3.3**. Model resolution was increased in this area with the structures represented as seen in **Figure 52**.

The height of the structures was representative of the actual structure height (taken from LiDAR and site visit) to ensure inundation landward of the structures was possible within the HD model.

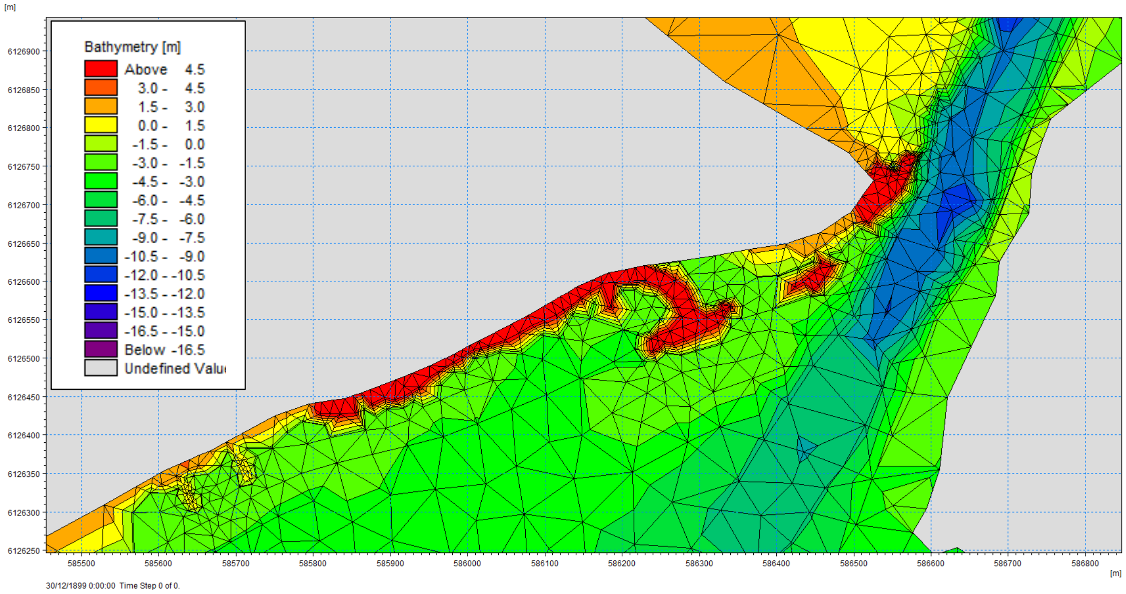


Figure 52 Representation of the Emu Point coastal protection structures within the HD model domain. The area has been schematised with a high resolution flexible mesh (~5m dx/dy grid resolution)

The bathymetry through the domain was updated for each study year based on available survey data. In general the areas with the most change were those frequently covered by surveys, Emu Point to Middleton Beach. As previously mentioned in the gap analysis, the only surveys covering the greater King George Sound area were 1976 and 1987, with the offshore areas around the entrance to the Sound represented by admiralty charts.

Boundary Conditions

The HD runs were driven by three major sources; predicted tidal boundaries, wave radiation stresses (taken from the SW runs) and wind (obtained from the global NOAA WWIII hindcast as it was found to be the most complete dataset). Solution parameters that could be changed during the calibration phase included hydraulic roughness, eddy viscosity and wind friction.

Tidal data was extracted from DHIôs 0.125° x 0.125° resolution global tidal model at the offshore model boundary location. The model utilises the latest 17 years multi-mission measurements from the TOPEX/Poseidon (phase A and B), Jason-1 (phase A and B) and Jason-2 satellite altimetry for sea level residuals analysis. Due to the datasets accuracy in representing the major 8 tidal harmonics, the offshore boundary of the HD model was left at the same location as that of the SW runs, both for completeness and to reduce shallow water impacts on the tidal prediction.

A search was completed for measured tidal constituents near the model boundaries but the closest sites where considered to be too far away and not representative of open ocean tides (ANN, 2016).

4.4.2 Model Calibration

Due to the complexity of the model domain and the number of contributing processes affecting the hydrodynamics of the study site, the HD model calibration was undertaken in a staged approach. The first stage was to calibrate the transformation of predicted tide from the offshore boundary through the model domain, into the nearshore and harbours. A period of low wind and wave energy was selected from the Emu Point AWAC record as well as the NOAA hindcast to ensure that wave and wind setup was minimised in the water level signal recorded by the AWACs.

The tidal calibration was undertaken during a low wave energy period from the 9th to the 21st of November 2016 and can be seen in **Figure 53**.

Small inconsistencies in the calibration levels were noted due to frequency of the AWAC records, local wave and wind setup not accounted for in this initial *‘Tide-Only’* calibration run as well as inconsistencies in the resolution of the TOPEX global tide model. Ideally, a longer term offshore tide gauge would be used for such a modelling exercise however lack of any tidal records outside of the Sound and in close proximity to Albany meant that the best available modelled data (TOPEX) was used.

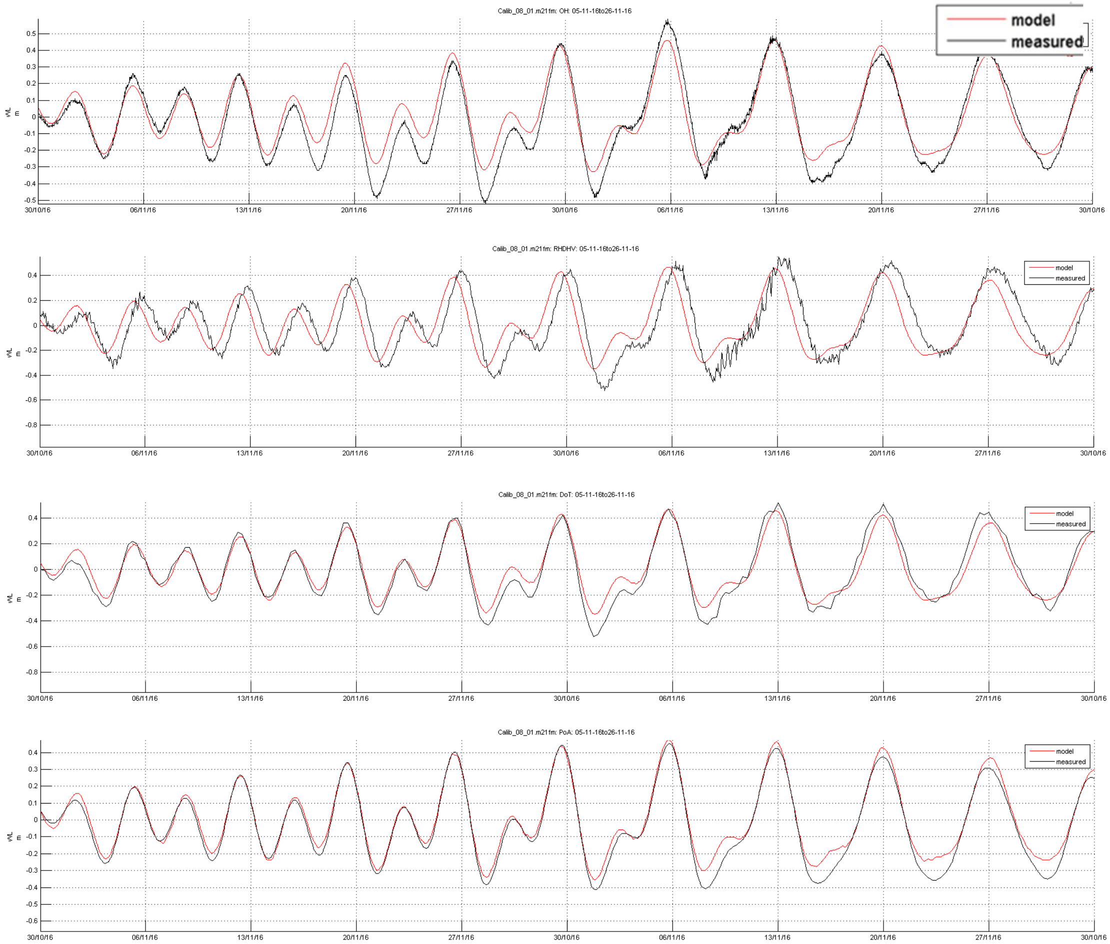


Figure 53 Water level calibration at the Oyster Harbour Boat Pens (plot 1), RHDHV AWAC (plot 2), DoT AWAC (plot 3) and at PoA (plot 4) sites for the Tide-Only HD model calibration run

Following several iterations of mesh and temporal resolution as well as the solution technique surrounding and flooding and drying depths within the HD model setup, the model was deemed sufficiently calibrated to water levels for both periods of recorded water level data. Similar discrepancies were experienced during this calibration, however, the overall calibration was considered suitable for the representation of circulation patterns for the purposes of this study as both tidal phase and magnitude were within calibration limits.

Review of the current speed profile from both the RHDHV and DoT AWAC deployments revealed that for both recording periods, the higher magnitude depth-averaged current speeds were experienced at the DoT AWAC**;** this can be seen in the comparison of the current roses for each AWAC**; Figure C3-1** and **Figure C3-3 (Appendix C-3)**. It can be seen that the DoT location regularly (10-15% of the time) has depth-averaged current speeds in excess of 0.3m/s due to its proximity to the entrance to Oyster Harbour. It is expected that these peaks in current speeds are associated with either flood or ebb currents entering/leaving Oyster Harbour. It was deemed that calibration of currents in this location would be key to best describing current patterns within the greater study site.

Conversely, the RHDHV AWAC location is located in an area with very low depth-averaged current speeds. It is assumed that due to the low magnitude of these ambient currents, calibration at this site will be of less importance and possibly very difficult to attain (especially for current direction) due to both the limitations of the recording device (AWAC) and the directional discretization of the model.

A period with recorded high current speeds at the DoT AWAC location was selected for the calibration period in order to provide an adequate representation of the current regime at this location. The period from the 27th June to 7th July 2015 was chosen for the current calibration as it coincided with a period of successive ebb-flows from Oyster Harbour in excess of 0.3m/s as seen in **Figure 54.** During this calibration run, wave radiation stresses taken from the results of the 2015 SW run were also applied across the model domain in conjunction with the NOAA wind data to simulate any additional surface currents that may have occurred.

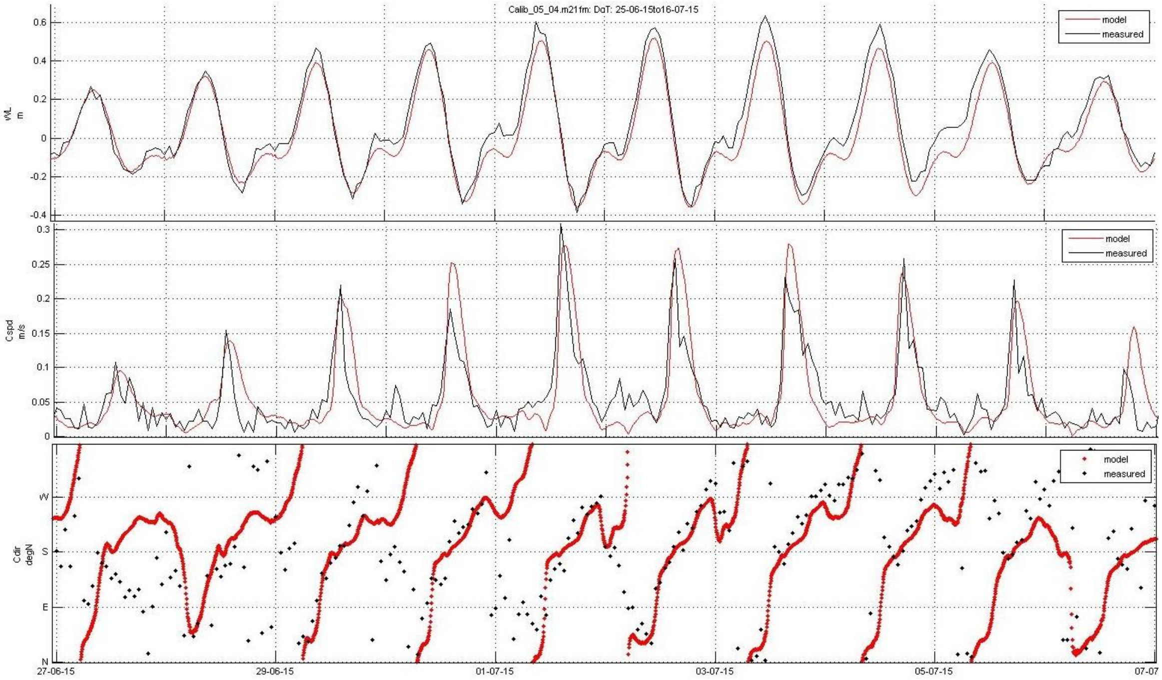
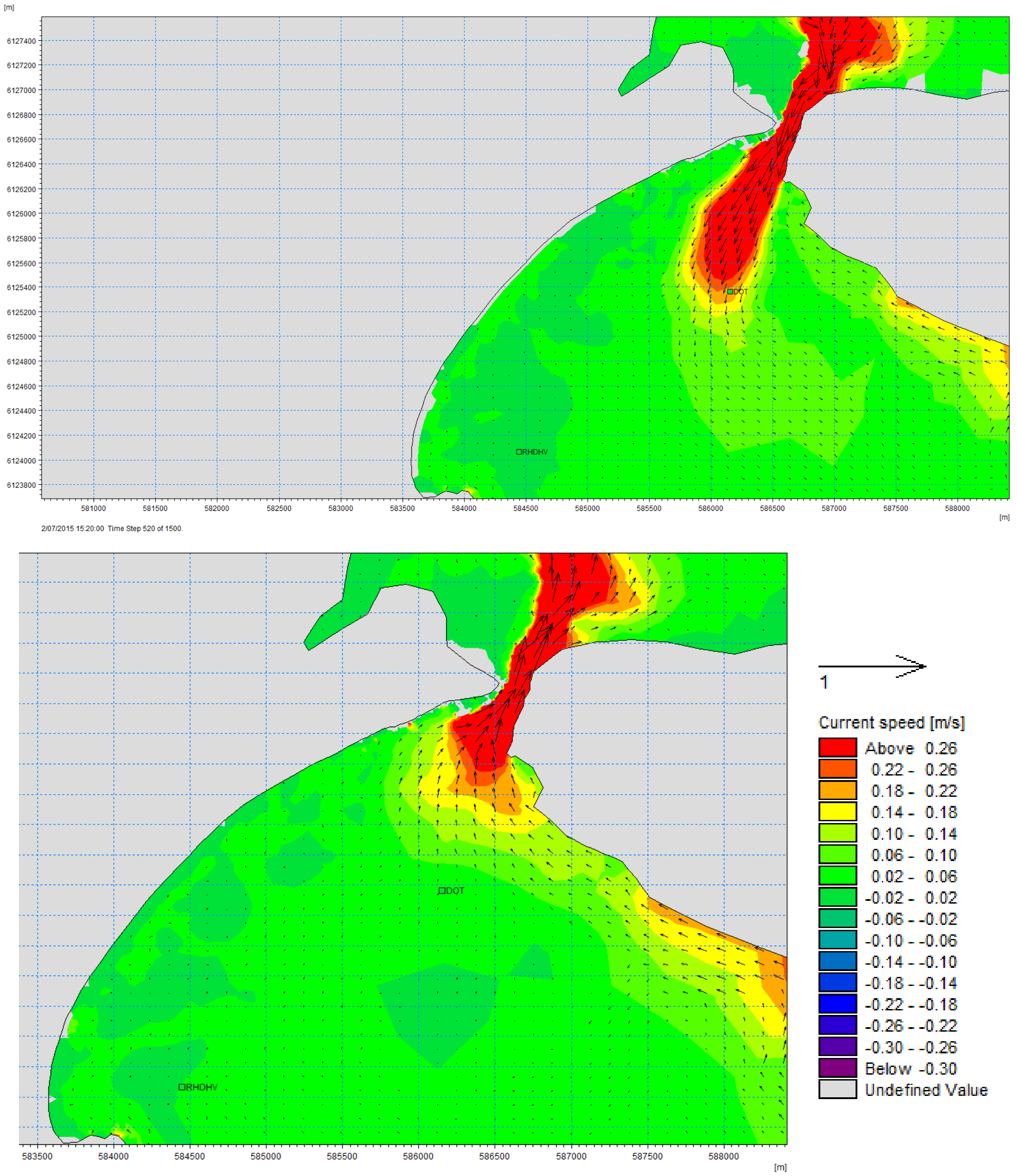


Figure 54 Current speed and direction and water level calibration at the DoT for spring tidal cycle from 27th June to 7th July 2015

The HD model is seen to represent the high ebb flows from the Oyster Harbour entrance in magnitude, phase and direction in the bathymetrically complex location of which the DoT AWAC is situated. A two dimensional representation of the current flow field during the modelled peak ebb/flood regime can be seen **Figure 55**.



2/07/2015 15:20:00 Time Step 520 of 1500.

Figure 55 2D representation of peak Ebb and flood tides into Oyster Harbour from the HD model verification run for the period 27th June to 7th July 2015

These ebb/flood current patterns were seen to mirror the results of the University of Western Australia (UWA) *Currents and Suspended Particle Matter (SPM) study* in both current direction and current magnitude; ñThe currents flowing out of the channel averaged 34 cm/s [sic]. Seaward water currents (out of the channel) were generally linear with a south-westerly directionò(UWA, 2014) (**Figure 56**).

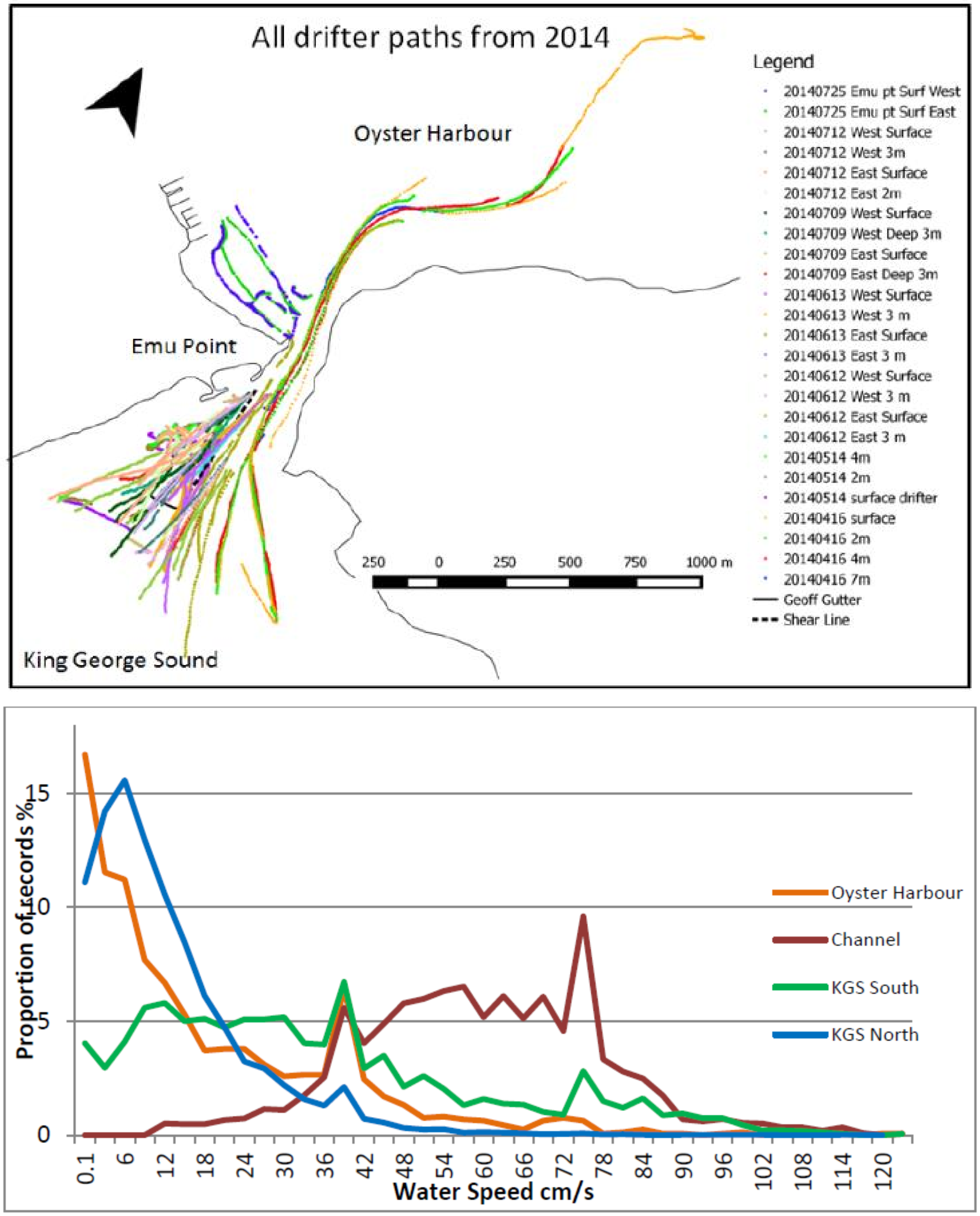


Figure 56 GPS Drifter ebb & flood tide current patterns (top) and current speeds (bottom) from the UWA Current and SPM Study, (UWA, 2014)

4.4.3 Scenario Testing

Historic Geomorphologic Assessment

An assessment of current regimes was undertaken for both historic periods where bathymetry was closest to a survey date and geomorphic change was at its most extreme (1976 and 2016). As 1976 sits just outside the 38-year hindcast period, 1979 will be used as a proxy in this instance. This date is also prior to the 1984 storm which was reported to have caused major morphologic change.

Both bathymetries were schematised as described in the previous section (with structures represented on the 2016 bathymetry). The same tidal cycle that was represented in the peak ebb/flood calibration (**Figure 55**) was used for the two bathymetries. Each HD model was then run for this tidal cycle under the same model parameters. A comparison of peak ebb and flood current speeds and directions can be seen in **Figure 57** to **Figure 59** below.

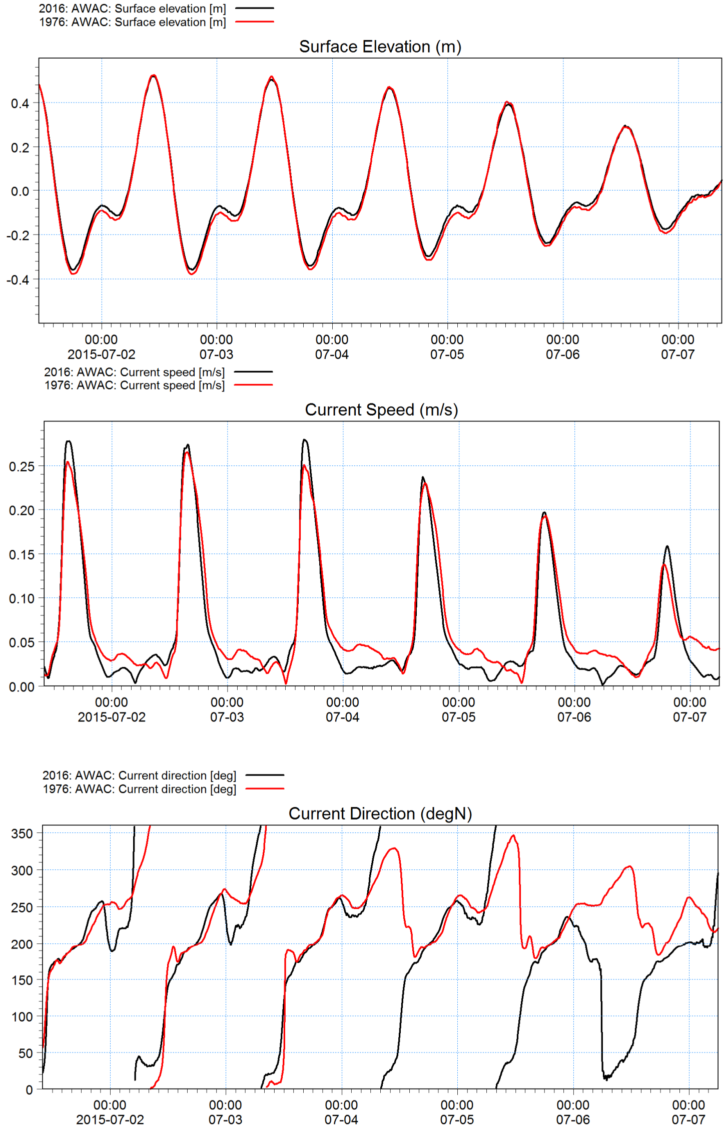


Figure 57 Point extract of surface elevation (top), current speed (middle) and current direction (bottom) comparing peak ebb/flood currents of the 3rd July 2015 at Emu Point on both 1976 (red line) and 2016 (black line) bathymetries

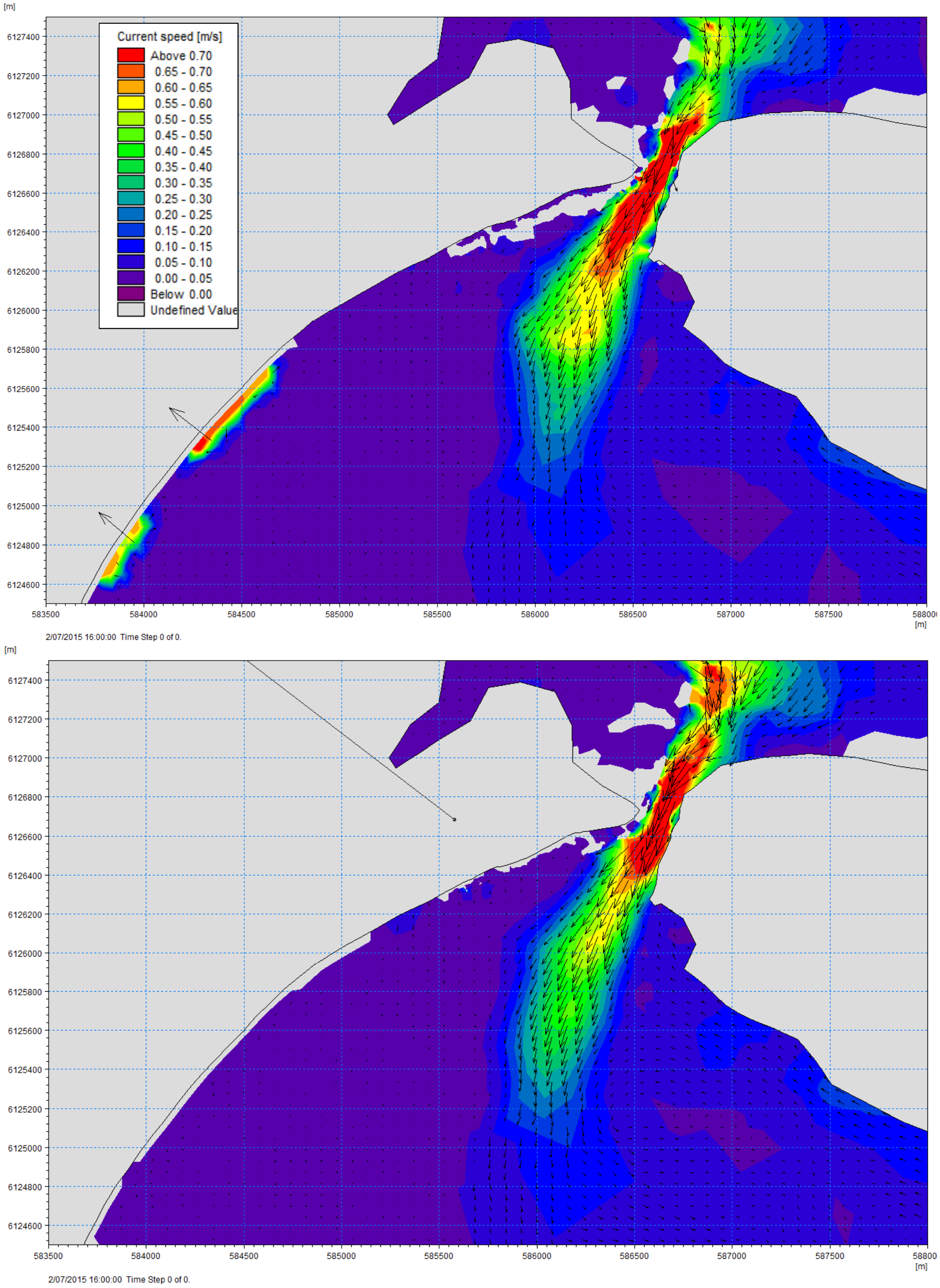


Figure 58 Current speed and direction 2D spatial plots of peak ebb currents of the 3rd July 2015 at Emu Point on both 1976 (top) and 2016 (bottom) bathymetries.

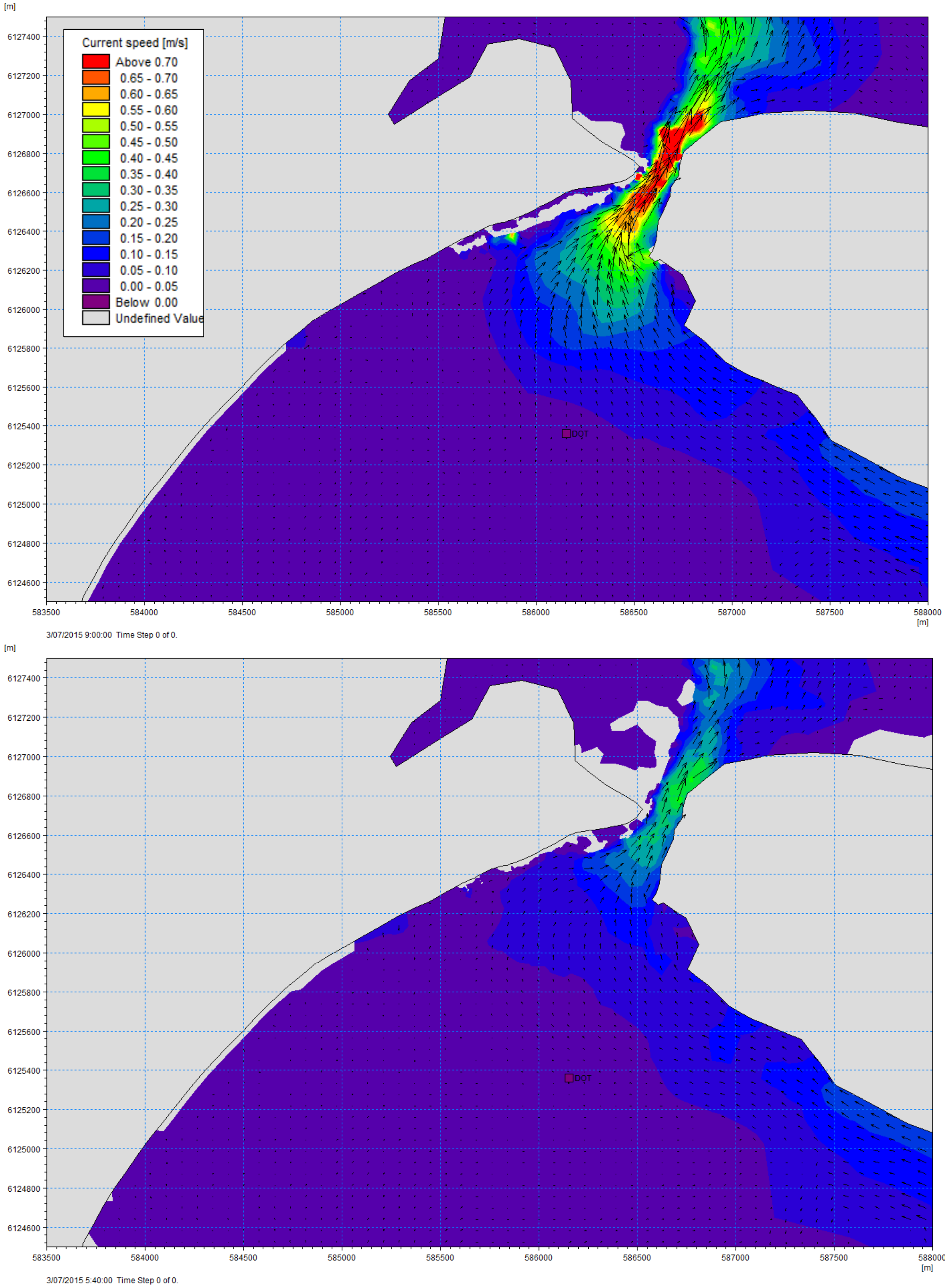


Figure 59 Current Speed and Direction 2D spatial plots of peak flood currents of the 3rd July 2015 at Emu Point on both 1976 (left) and 2016 (right) bathymetries

Synthetic Storm Response

Coupled HD / SW models were setup to determine the difference in hypothetical storm response in the study area between the 1979 and 2016 bathymetries. Each model domain had the week-long, 500 year synthetic wave event as seen in Figure 60 as a boundary condition as well as predicted water level from the 1984 storm HD calibration run.

From the synthetic storm event, it can be seen that peak wave heights (Hs) occur at **2/08/1984 20:30**, prior to this, the model can be seen to run through a fairly mild wave climate (Hs~0.6m) for an approximate 40 hour period. Modelled results during this ñCalmòperiod were extracted over a full tidal cycle period to determine mean current speed and directions, the results can be seen in Figure 61.

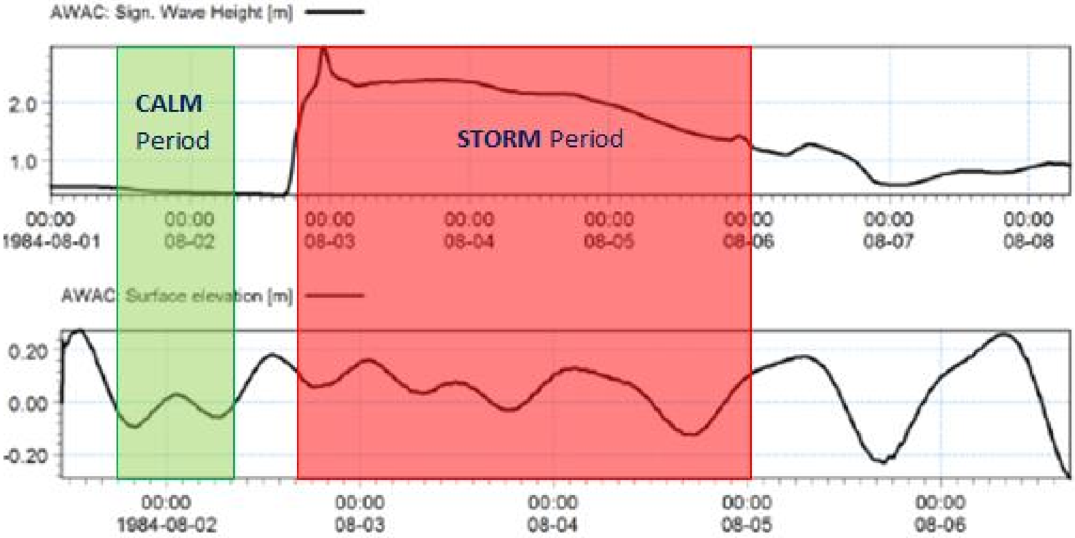


Figure 60 Synthetic 500 year storm; Hs (top) and Surface Elevation (bottom) with “Calm” and “Storm” study periods designated.

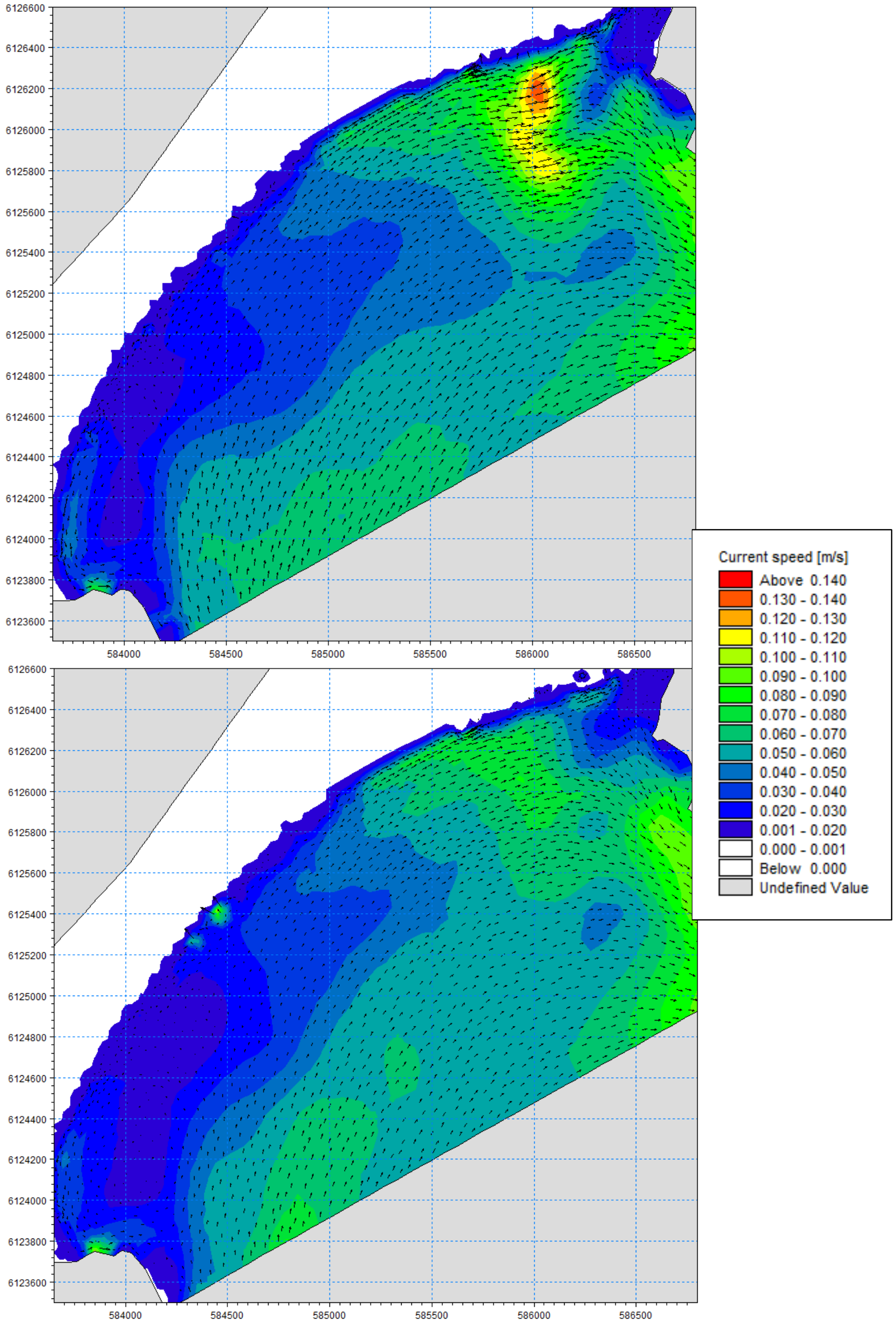


Figure 61 Mean current speed and direction modelled through "calm" wave conditions through a full tidal cycle on the 1979 bathymetry (top) and the 2016 bathymetry (bottom)

Both bathymetries are seen to have a net clockwise circulation within the study area. Current speeds (and sediment transport potential) are seen to be more pronounced towards the east in the 1979 bathymetric model. This is due to the greater refraction experienced by the incoming waves over the Lockyer Shoal. The depth of the bar itself will also increase current speeds.

A typical ebb tide current pattern during the ñCalmòmodel period of the synthetic storm runs can be seen in Figure 62. The main difference in current patterns between the 1979 and 2016 bathymetries is the formation of a circulation cell in the lee of the Lockyer Shoal. This cell is seen to feed the ebb current jetting out of Oyster Harbour. Sediment transported within the easterly current would be deposited at the edge of the Oyster Harbour stream, feeding the Lockyer Shoal. During flood currents this sediment would be deposited within Oyster Harbour or within the channel, to be redistributed to the shoal on the subsequent outgoing tide due to the ebb-dominated asymmetry in tidal current velocities.

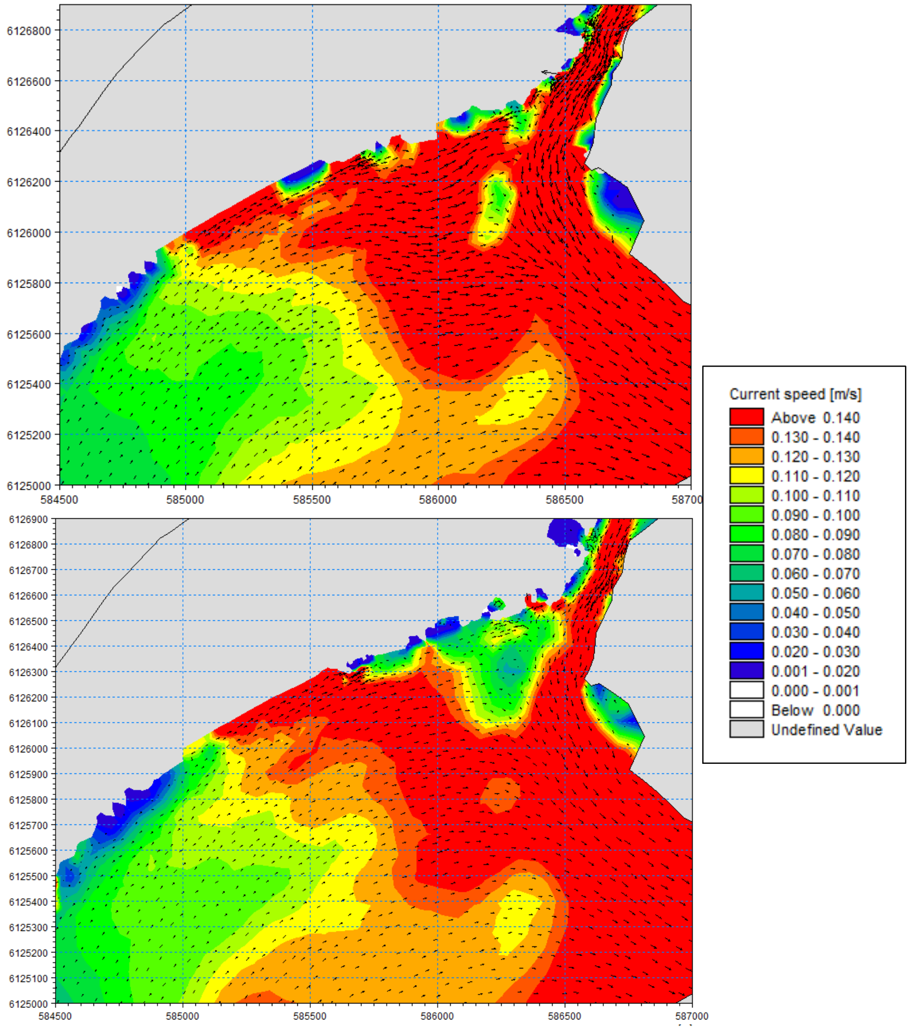


Figure 62 Current speed and direction modelled through “calm” wave conditions during a typical ebb tide period on the 1979 bathymetry (top) and the 2016 bathymetry (bottom).

The synthetic ñstormòperiod is seen to commence on 02/08 at 18:30 and last until 06/08 at 18:00, during this period Hs is sustained greater than 1m at the DoT AWAC location. Hs >1m was determined as the 90th percentile Hs from the 38 year wave hindcast. Mean current speed and directions were calculated for this period for each bathymetric model and can be seen in Figure 63.

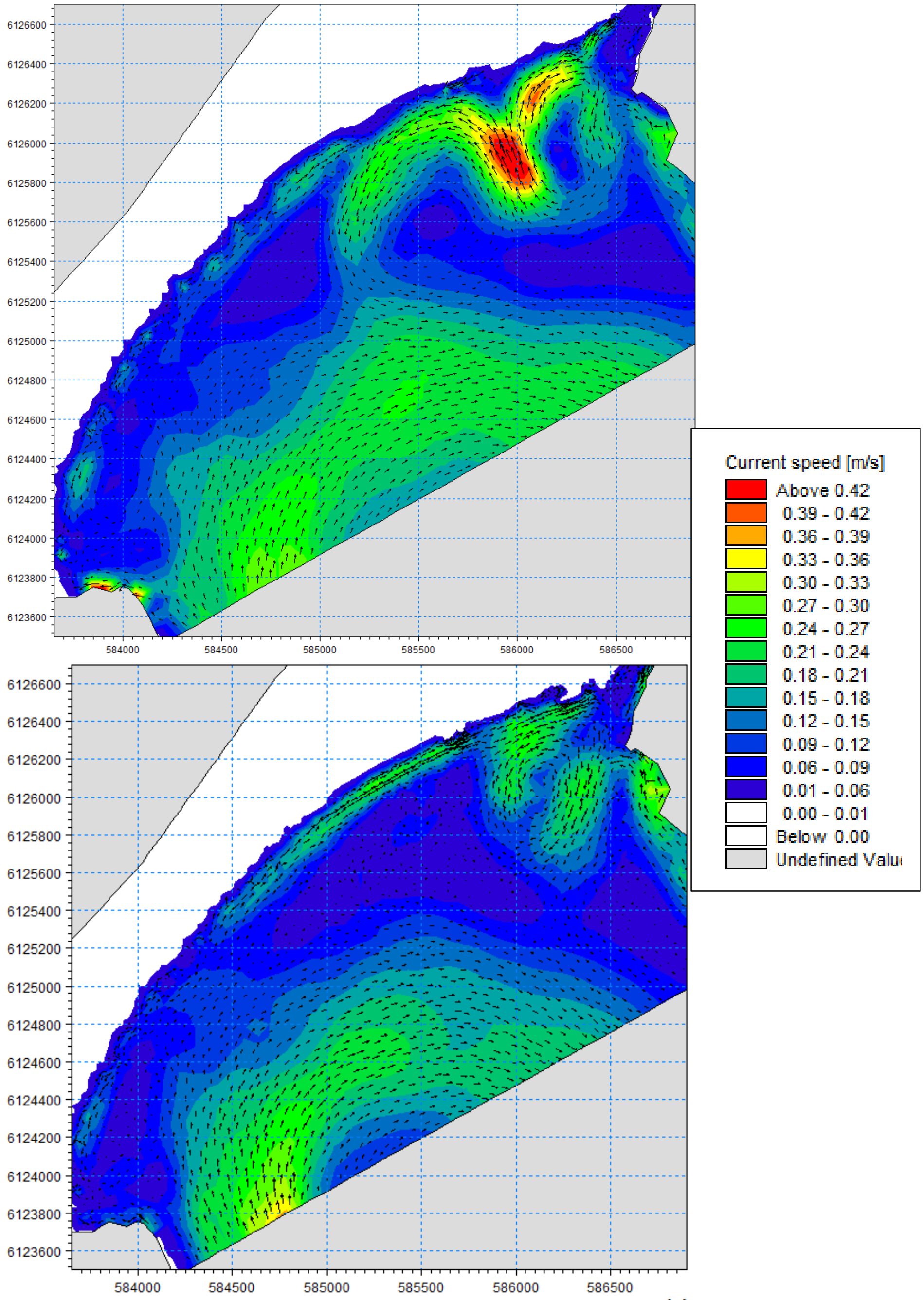


Figure 63 Mean current speed and direction modelled through 500 year synthetic storm conditions on the 1979 bathymetry (top) and the 2016 bathymetry (bottom). Please note the different limits on the legend compared to previous plots.

The most apparent disparity between the two flow regimes is the increased shoreward flow experienced over the Lockyer shoal in the 1979 bathymetry and the subsequent circulation cells setup on either side of the shoal directing flow (and sediment) offshore. This double circulation cell is in contrast to the single cell setup in the 2016 bathymetric case.

It can also be seen that the current speeds seen in the 1979 bathymetric run are located further offshore than the highest current speeds in the 2016 case. This is predominantly due to the shallower contours and the shoreline being located further offshore in 1979. These differences will impact shoreline movement, localised setup and storm bite in both bathymetric instances. Although current speeds were greatly increased in the 1979 bathymetric case, it can be seen that due to the offshore position of the shoreline and the presence of the Lockyer Shoal, the area where the current shoreline is located was afforded protection by the shoal.

The difference in mean surface elevation during the synthetic storm event between 1979 and 2016 can be seen in Figure 64. In general it can be seen that surface elevation was higher over most of the domain in the 1979 bathymetry compared to that of 2016. The 2016 bathymetry appears to have more localised setup along the Emu Point Shoreline compared to a more dispersed surface elevation increase experienced in 1979.

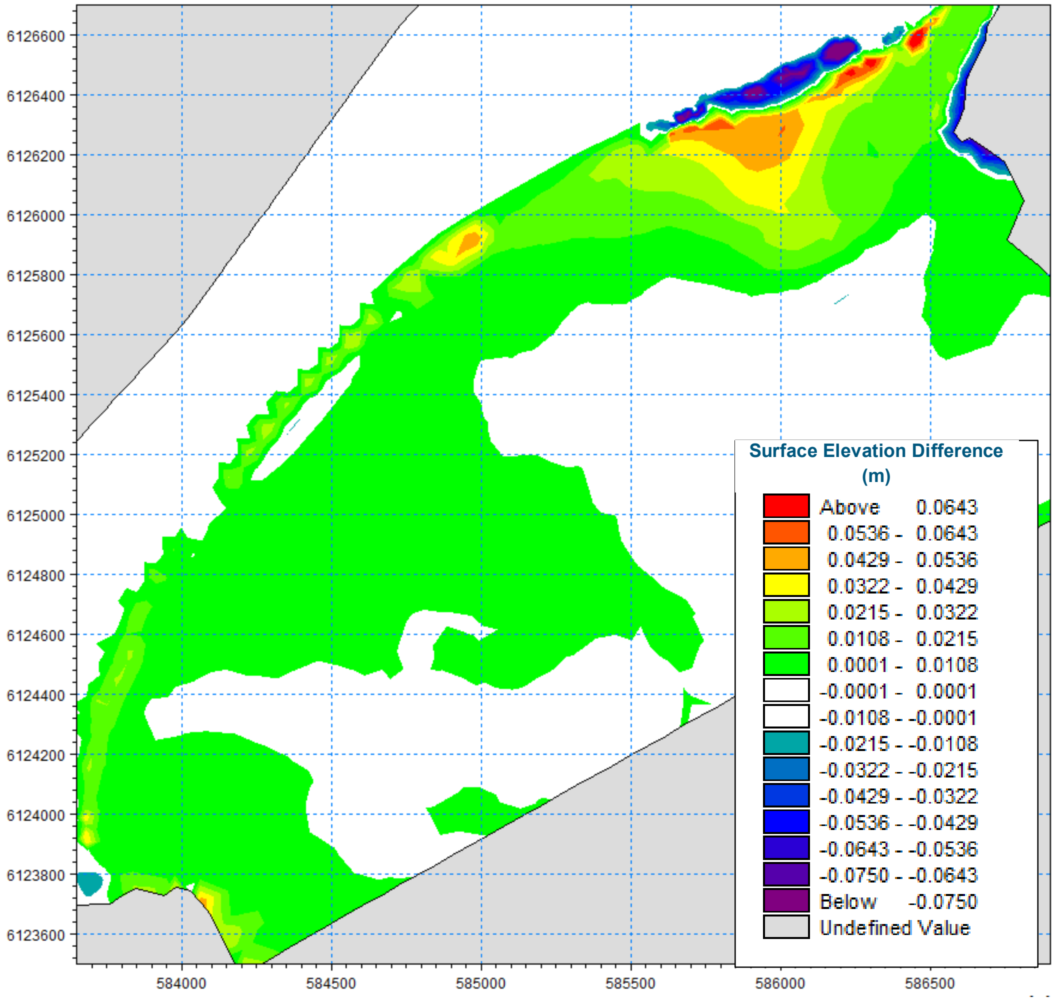


Figure 64 Mean surface elevation difference 1979 – 2016 bathymetry from the 500 year synthetic storm runs.

S4 – Coastal Inundation

Presently, the DoT recommends using the recorded storm from the 15th to the 19th of July 1996 to quantify the potential storm-induced acute erosion across south-west Western Australia beaches (Ilich, 2009), using several iterations of the S-Beach model.

The storm analysis undertaken in **Section 4.3.4** however, shows that this storm does not rate this as a significant (top ten) event along the Middleton Beach study site due to its embayed location. The Extreme Value Analysis (EVA) undertaken on nearshore wave heights showed that the 100-year return interval for significant wave height, Hs (m) was found to be ~3m at the location of the DoT AWAC in our study site. This height correlates closely to the August 1984 storm event, noted as having particular significance to the Emu Point and Middleton Beach areas in terms of erosion.

It is recommended that due to its known impacts and implication to the study site that this storm be employed for coastal inundation analysis at the study site.

As a comparison, a coupled HD / SW inundation model was setup, utilising the wave radiation stresses from the increased (15%) 1984 storm event. Recorded wind as well as predicted water level + 100 year ARI surge was placed on the boundary and the 2016 bathymetry was adopted. The maximum surface elevation recorded over the synthetic storm duration (in the nearshore domain) can be seen in **Figure 65**. It should be noted that wave run-up and overtopping are not described by this modelling approach. These model results should be viewed as a tool for recognising at risk zones of the study area. The levels and inundation extents presented in **Section 6.7** include consideration of wave run-up and overtopping and should be used for planning purposes.

Figure 65 Maximum surface elevation recorded over the synthetic storm duration (in the nearshore domain)

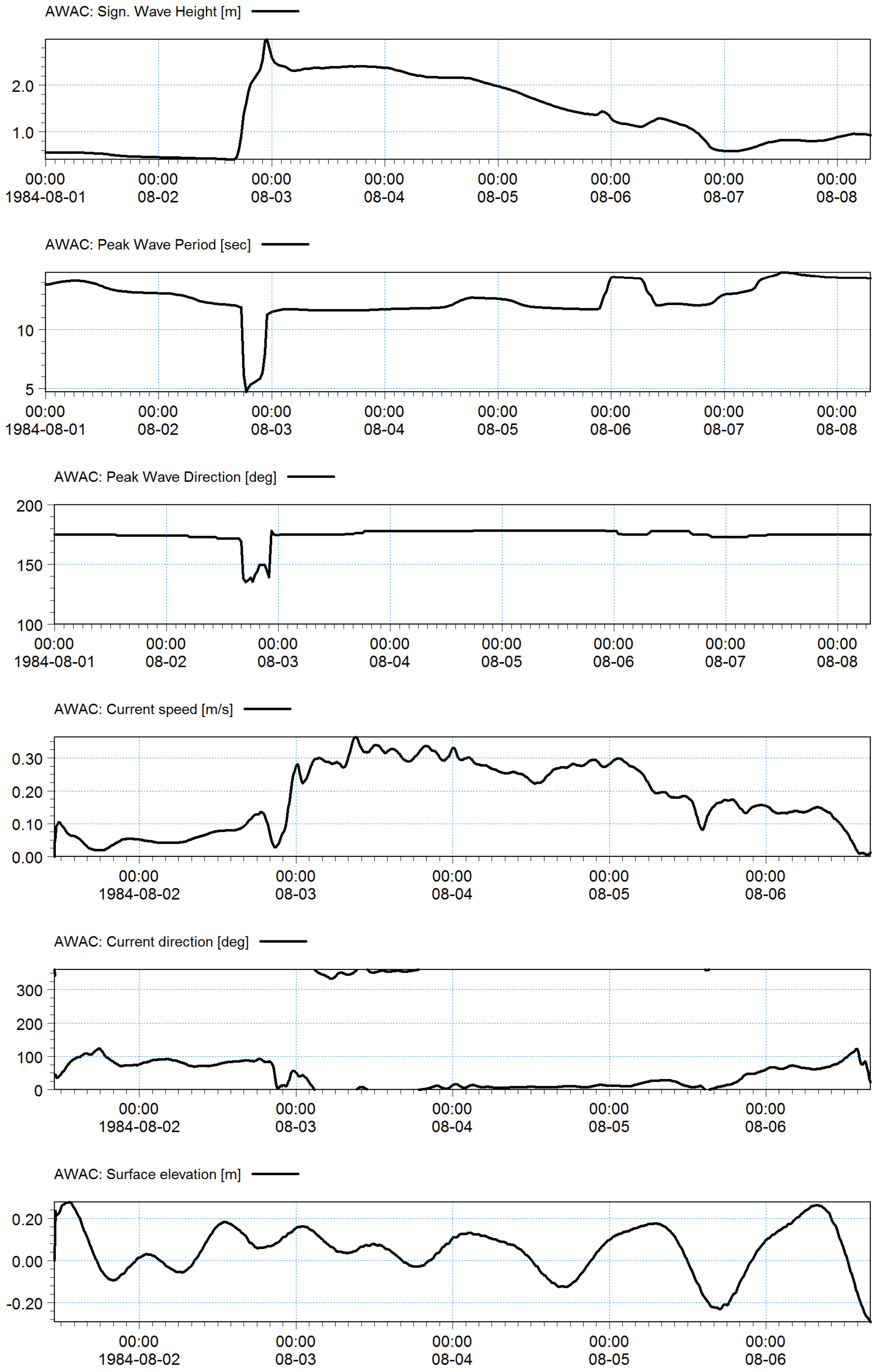


Figure 66 Wave, current and water level parameters extracted from the DoT AWA C location from the coupled HD/SW inundation model run. Note wind parameters have been applied as seen in figure 42.

4.5 Longshore Drift and Shoreline Evolution Models

4.5.1 Longshore Sediment Transport Model

To better understand longshore sediment transport processes along Middleton Beach, sediment transport modelling has been undertaken as part of this study. DHIôs sediment transport modelling package LITPACK has been used to assess typical longshore sediment transport rates along Middleton Beach. The primary LITPACK modelling engine used in this study was LITDRIFT. LITDRIFT models sediment transport for defined cross-shore profiles and hydrodynamic regimes and enables the calculation of net/gross littoral transport over a specific period. In this study LITDRIFT has been used to model the longshore drift rates at set locations along the shoreline. The method and data sources for the utilisation of LITDRIFT in this study are further discussed in the following subsections.

4.5.2 Model Setup

LITDRIFT is a deterministic numerical model; the sediment transport is modelled as a function of a cross-shore profile (including shape and sediment properties) and wave climate. The main input data required for LITDRIFT include:

- Beach bathymetric profile data;
- Sedimentological data;
- Wave data; and,
- Water level data.

Data input into the LITDRIFT model for this study has been summarised in the following sub headings.

Beach Profile Data

Between October 2013 to December 2016, CoA has undertaken regular beach profile surveys at various locations along Middleton Beach. The extent and orientation for each profile has been presented earlier in Figure 19**.** The most recent beach profile surveys (December 2016) were extracted and used as input into the LITDRIFT model. Each cross shore profile (MB02 ï EP01) was extracted perpendicular to the coastline and interpolated to provide a profile chainage resolution of 10m. It is important to note that cross shore profiles MB01 and MB08 were not modelled in LTIDRIFT. Transect MB08 was not modelled as the orientation of the transect line is not aligned perpendicular to the coastline. MB09 is located approximately 100m to the west of MB08 and is therefore considered close enough to resolve longshore sediment transport rates in the area of MB08.

Profile MB01, located in the south-western corner of Middleton Beach is positioned in a location where limited longshore transport would be expected. The south-west corner of Middleton Beach represents a crenulated bay shape, whereby refraction around the adjacent headland results in the incident waves being perpendicular to the shore. This orientation would result in the net longshore transport in this region to be zero. The LITDRIFT software package was primarily developed to model sediment transport along long open stretches of exposed shorelines and is therefore not suitable for modelling longshore transport within crenulated bays.

Sedimentological Data

Sediment samples were taken by GBA and CoA at each of the profile transects in 2013. Sediment samples were taken at five locations spread along the length of each profile. As part of this sampling campaign each sample was analysed for their particle size distribution (PSD). Samples were taken from both the sub aerial beach and intertidal zone in order to best characterise beach sediments across the profile (see **Figure 32** for sample locations). Sediment data collected as part of these works has been used as input into the LITDRIFT model.

Wave Data

A single year time series of modelled wave data has been used to estimate the annual longshore sediment transport rates at each of the modelled profiles. Wave data generated as part of the 38-year spectral wave hindcast exercise (**Section 4.3.4**) was analysed to identify average wave conditions expected under a typical year. From the wave power and Long Term Average (LTA) wave conditions it was determined that wave conditions modelled for 2015 represented a typical year (in terms of wave energy). Therefore the 2015 modelled wave data time series (3-hour resolution) has been used as input into the LITDRIFT model varying mean PSD values along each of the transects to ensure transport rates were representative of each location (even though PSD was seen to be fairly uniform across the study site).

Separate wave data time series (wave height, period and direction) were extracted from the SW model for each of the modelled profiles at the point where the transect ends. The LITDRIFT model then applies these wave time series as each profile boundary condition and transforms the wave conditions to the shoreline with respect to the shape of the cross-shore profile. Each wave series input into the LITDRIFT model extended over the entire 2015 calendar year.

Water Level Data

2015 water level data (concurrent to the wave data) for Middleton Beach, generated as part of the metocean data analysis (**Section 3.4**) was also input into the LITDRIFT model.

4.5.3 Model Run

The cross shore profiles modelled in LITDRIFT were specifically chosen to best characterise sediment transport rates along the length of Middleton Beach. LITDRIFT was run for each beach profile (MB02 ï EP01) on the basis of their individual wave climates to estimate annual longshore sediment drift rates at each profile location. As tide and wind induced flows are expected to be relatively weak along Middleton Beach, with transport primarily dominated by waves, no current or wind influences were included in the simulations. This can be seen from the analysis of the three largest water level events (Figure 46 to Figure 48) having little effect on the current magnitude and direction at each AWAC location.

4.5.4 Sensitivity Testing and Model Validation

As part of the LITDRIFT model development a high level model validation process was undertaken to ensure the model is generally representative of what may be inferred from an historic aerial imagery analysis (see **Section 3.3.1**), historical bathymetric surveys and past coastal process investigations. Further discussion on the model results and comparisons made as part of this validation process has been provided in the analysis subsection below.

It is important to note that the LITDRIFT model is particularly sensitive to the difference in angle between the profile orientation and the incident wave angle. For this reason care was taken to ensure the orientation of the modelled profiles best represented their true orientation perpendicular to the shoreline (and offshore contours). When interpreting the model results it is important to note that small changes in the orientation of the shoreline of even 1 or 2 degrees has the potential to result in significant changes to the modelled net sediment transport rates.

4.5.5 Analysis

Results from the LITDRIFT modelling exercise have been presented in **Figure 67 to Figure 69**. **Figure 67** illustrates the modelled net sediment transport rates at each of the profile locations along Middleton Beach, **Figure 68** presents the modelled annual gross sediment transport rates at each of the profile locations and **Figure 69** presents a time series of longshore sediment transport modelled at profile MB04 for an energetically ótypicalôyear (2015). The longshore transport time series at MB04 has been presented as it represents a location approximately midway along Middleton Beach. Key findings which can be inferred from the LITDRIFT modelling results have been discussed below:

- Sediment transport rates modelled at all profiles can be considered to be relatively low, with transport rates not exceeding 10,000m^3/year at any one location. This is consistent with previous assessments made by SKM (1993) which estimated an annual net easterly longshore transport rate of approximately 10,000 m^3/year. It is noted that our study has used the latest bathymetry over Lockyer Shoal and this, along with the high degree of sensitivity to shoreline orientation, may account for the difference in the net direction of transport.

- The modelling results suggest that the net direction of sediment transport along the western extent of Middleton Beach is to the east, while the net direction of sediment transport along the eastern extent of Middleton Beach is to the west (**Figure 67**). This results in a convergence of net sediment transport pathways in the vicinity of the Golf Course. This convergence is likely to result in an accumulation of sand and widening of the beach in this area. This is consistent with the 176,000m^3 of net accretion observed adjacent to the Golf Course which was calculated from historical bathymetric survey data (**Section 3.3.3**). It is also evident from recent aerial photography that the beach is generally wider in this vicinity, also suggesting net sediment accumulation in this area.

- The net westerly longshore transport modelled at the eastern extent of Middleton Beach (**Figure 67**) suggests that on a net annual basis, sand is being transport from the Emu Point end westwards along Middleton Beach. Without an upstream (or offshore) supply of sediment to this area, this net sediment transport regime would suggest shoreline recession in the vicinity of Emu Point. This finding is consistent with long-term shoreline recession recently observed in this area and the need for coastal protection works (offshore break wall and seawall) at Emu Point.

- It is evident from the time series graph in **Figure 69** that both the rate and direction of longshore transport varies considerably between the seasons. During the winter months longer period swells originating from the south-west dominate the local wave climate and are responsible for a bias net easterly transport during these months. While during the summer months, locally generated waves from the south-east are more dominant and responsible for a bias net westerly longshore transport. Longshore sediment transport regimes along Middleton Beach are therefore considered to be largely dependent on the seasonal wave conditions.

- When comparing the difference between the net and gross sediment transport rates presented in **Figure 67** and **Figure 68**, it can be determined that similar transport rates occur in both directions at the modelled MB09 profile with a slight bias towards the west (profile adjacent to the trial groyne structures). A review of aerial photography in this region suggests that the construction of these trial groynes has resulted in only minor accumulation on the eastern side of the groynes

(**Section 3.3.4**). This outcome is consistent with model results which suggest annual longshore transport rates in this region are similar in both directions with a slight westward bias.

Key findings inferred from the LITPACK modelling have been further used to inform the conceptual coastal processes model described in **Section 5**.

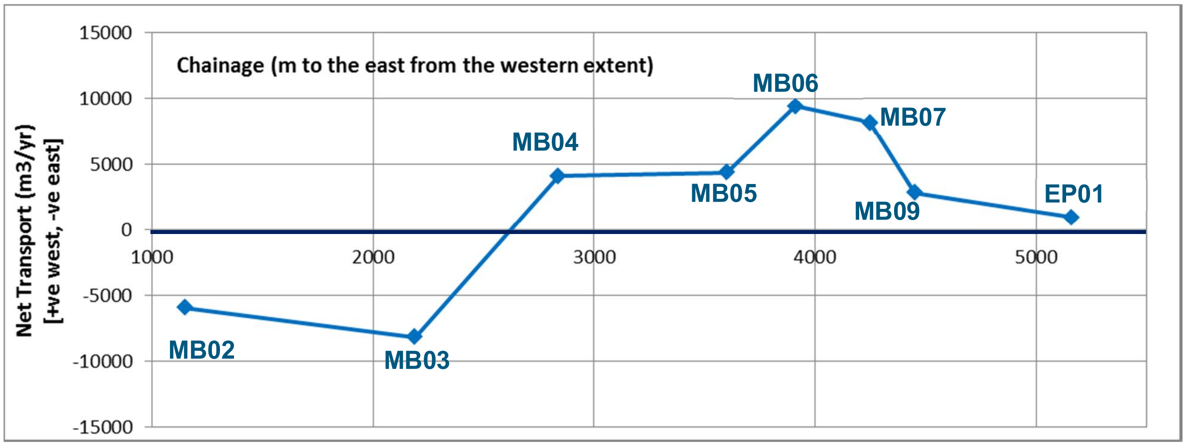


Figure 67 LITDRIFT modelling results; Annual net longshore sediment transport rates, noting positive transport is to the west and negative transport is to the east

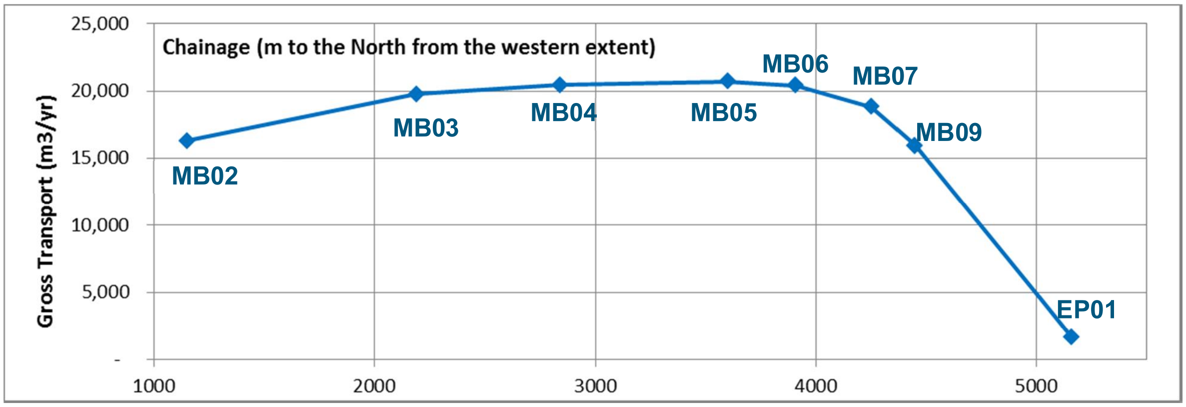


Figure 68 LITDRIFT modelling results; Annual gross longshore sediment transport rates

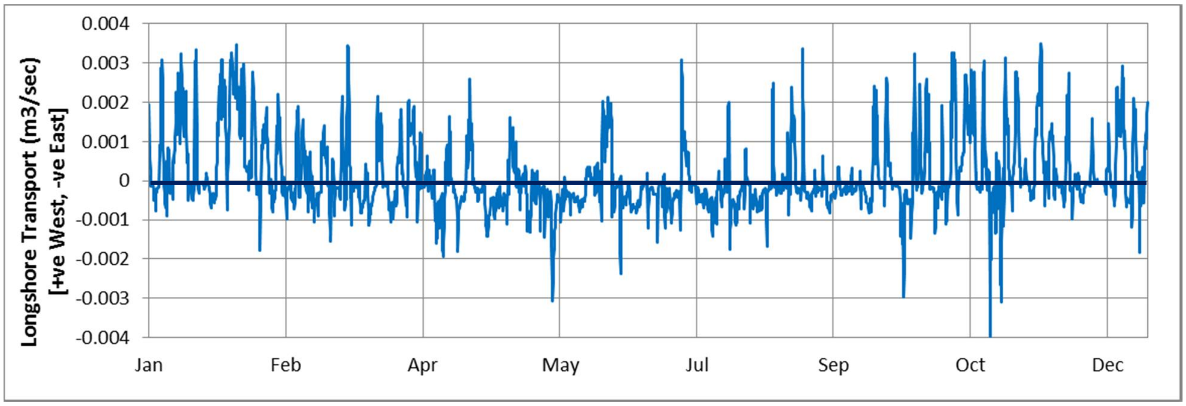


Figure 69 LITDRIFT modelling results; Time series of longshore sediment transport modelled at profile MB04, noting positive transport is to the west and negative transport is to the east

Assumptions and Limitations

When interpreting the LITPACK modelling results, it is important to keep in mind the limitations of the model and the key assumptions applied throughout this modelling exercise. These key assumptions and limitations have been summarised below.

- Given that a high level model validation exercise has been undertaken to ensure the LITDRIFT model is generally representing the sediment transport processes which can be inferred from aerial imagery, historical bathymetric surveys and past coastal process investigations. Sediment transport rates presented in this section should not be taken to be definitive or absolute but rather provide a general understanding of longshore sediment transport trends at each modelled profile location.
- The LITPACK software package was primarily developed to model sediment transport along long open stretches of exposed shorelines. This particular study site can be assumed to be relatively complex to model given the concave alignment of the shoreline. Despite this, RHDHV believe LITPACK represents one of the best commercially available software to model sediment transport processes along Middleton Beach.
- The results provided in this section represent longshore transport rates predicted after a model run time of one year. The primary modelling forcing data (waves and tides) represent conditions observed and subsequently modelled over the 2015 calendar year in order to represent what may be considered average annual conditions. It is therefore important to consider that the results are only representative of the 2015 calendar year and do not account for factors such as sea level rise, extreme storm events and longer term variations in meteorological conditions.
- This study analysed sediment transport conditions under a typical year (in this case represented by conditions during calendar year 2015). Note that sediment transport patterns under extreme storm events or a stormier year could be considerably different than a typical year. Understanding potential change in sediment transport patterns under these conditions are key for the coastal adaptation decision making process. It is recommended that the effectiveness of future coastal adaptation is analysed under typical and extreme storm events or a stormier year conditions, prior to further consideration/implementation.

5 Coastal Processes Assessment

5.1 Preamble

Based on review of available data and literature, site observations, numerical modelling and understanding of coastal processes, a conceptual model of sediment transport processes in the study area has been developed. The conceptual model identifies sediment sources, sinks, pathways and vulnerable areas for focus in subsequent stages of the study.

The conceptual model is described in the following section and includes figures that can form a suitable basis for communication of the historic and current coastal processes to the community and stakeholders.

5.2 Conceptual Coastal Process Model

Figure 70 provides a graphical overview of the conceptual coastal processes model, while the additional figures below described specific points below. The conceptual coastal processes model is described in the below six (6) concepts.

5.2.1 Item 1 – Onshore Sediment Supply

The Middleton Beach and Emu Point sediment cell is supplied with sediment and has been accreting over recent history. This is evidenced by the long term accretion observed along Middleton Beach. Moreover, it is noted that the prograding trend was present in the period 1943 to1976, prior to any anthropogenic influences such as the placement of dredge spoil or introduction of coastal structures. The rate of sediment supply has been estimated as being between 15,000 to 30,000m^3/yr.

There are two possible sources of sediment supply: (i) sediment outflow from Oyster Harbour or (ii) onshore movement of sediment from deeper areas of King George Sound. It has been assumed that the bulk of the sediment inflow is supplied from offshore sources. The Sound is a drowned river valley that has been infilled with marine sand since the last ice age. The wave climate in the Sound is dominated by persistent long period swells that refract into the embayment. Sand in the deeper areas of the Sound is transported onshore by these long period swells. This is supported by the following observations:

- A general pattern of erosion has been observed in the long term bathymetry below depths around 7-8m (see **Figure 21**). This eroded sediment onshore and it is noted that the area with the highest nearshore erosion (excluding Lockyer Shoal) corresponds to the Surfers/Ellen Cove area which is adjacent to the areas of highest accretion on the beach.
- The rate of onshore transport would be expected to be proportional to incoming wave energy (i.e. high accumulation rates where wave energy is highest). The beach at Surfers is the location with the highest rate of accretion and also corresponds with a óstreakôof incoming wave energy.
- A second potential onshore pathway is along the northern shoreline of the Sound. The bathymetry in this area is generally shallower supplying sediment to the Lockyer Shoal area by Stokes drift, flood tidal currents and wave driven currents set-up along the shoreline.

The potential sediment transport pathways describing this onshore sediment transport are provided in **Figure 71**.

In some situations, onshore sediment supply might be explained as a recovery response following the erosion caused by large storms (e.g. return of sediment moved offshore during storms). Large storms are known to have occurred in 1921 and 1984; however, evidence from the aerial photography suggests that the bulk of the shoreline along Middleton Beach recovered from the 1984 event in less than a decade. Given the overall steady rate of accretion observed over the 71-year period and the above supporting observations it is considered more likely that the onshore sediment is an ongoing morphological response to the rise in sea levels following the last glaciation.

Sediment inflow from Oyster Harbour has been discounted as a significant sediment source. Previous studies have indicated that the rivers that flow into Oyster Harbour are no longer a source of sediment (DAF, 2007). There is no evidence to suggest that Oyster Harbour is scouring and exporting sediment to Middleton Beach, however, repeat surveys are not available to confirm this.

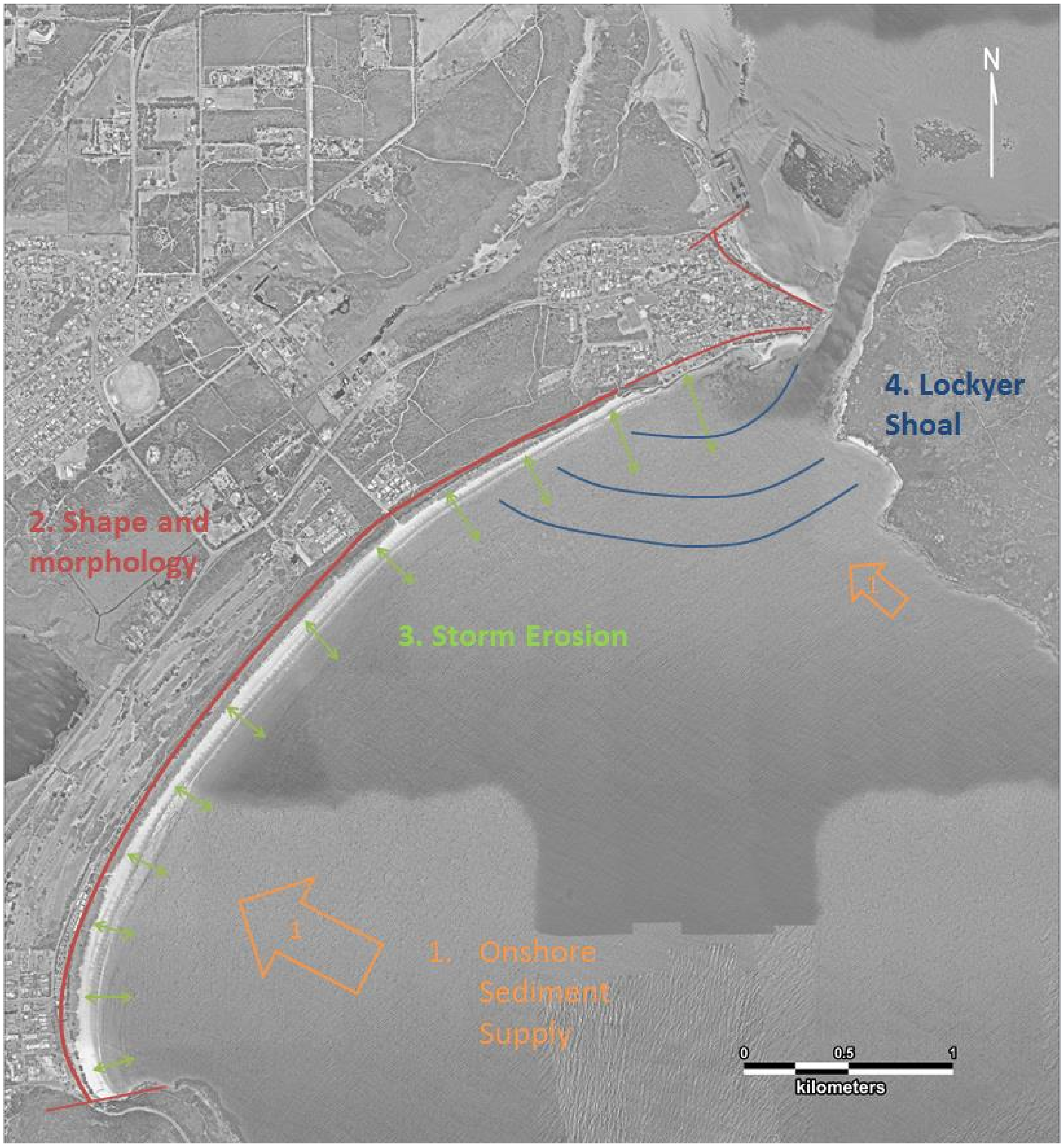


Figure 70 Conceptual coastal processes model (overview) for this study area.

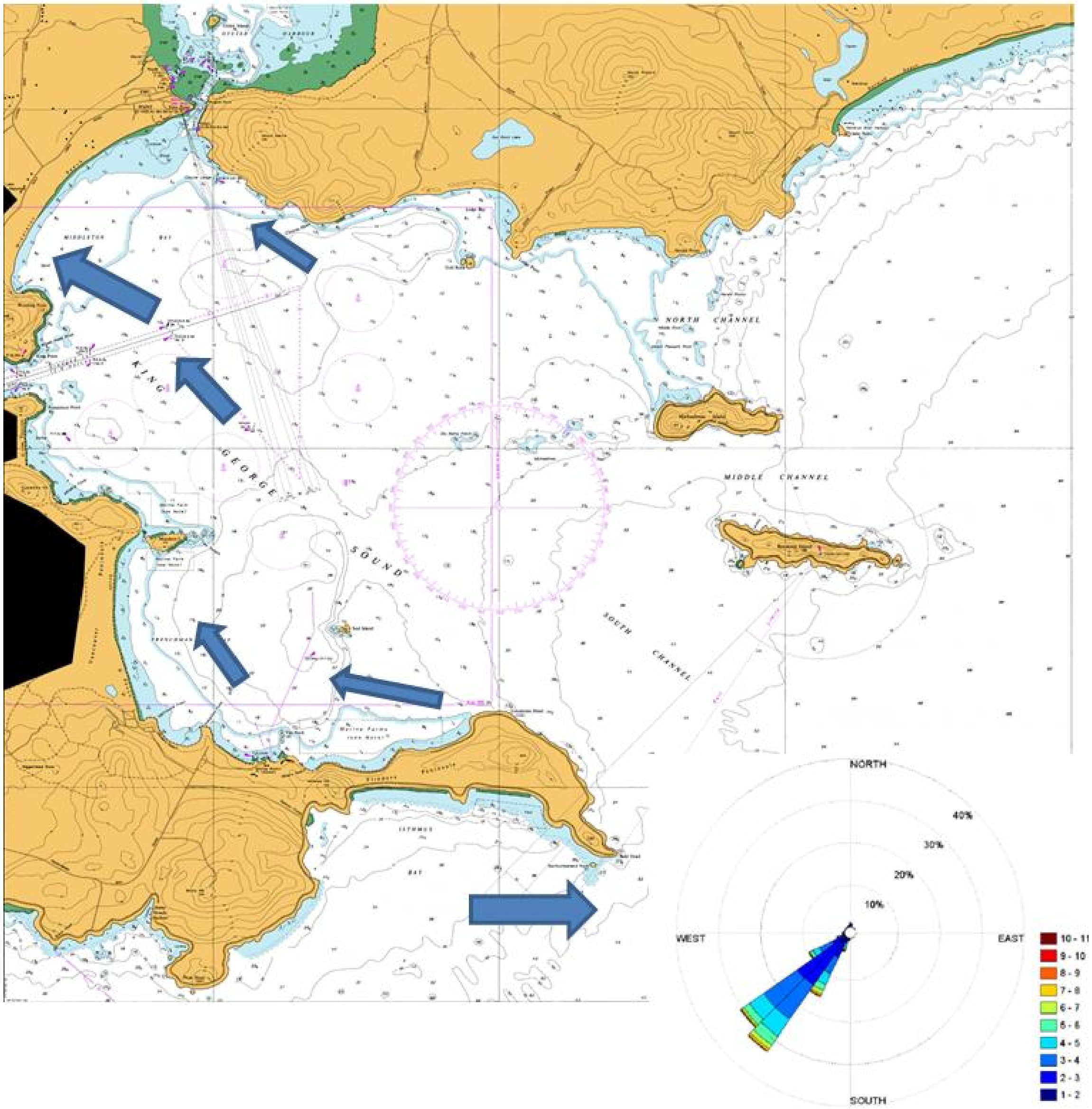


Figure 71 Conceptual sediment pathways that described the onshore supply of sediment to the study area (note – wave roses provide offshore wave direction at DoT wave rider buoy location).

5.2.2 Item 2 – Shape and Morphology

The classic crenulated bay shape of Middleton Beach is an important factor to consider in determining sediment transport processes. In general the shape is explained as it is well aligned to the incoming swell wave crests. It is worth noting the following features:

a. Wooding Point is a rocky headland and represents a ófixedôpoint with the ózetaôor log-spiral shaped shoreline along Ellen Cove strongly controlled by the position of this fixed headland.

b. Between Surfers and Griffiths street, there is a more gently curving section of beach that is very well aligned to the incoming swell direction. The coastal profile along this section is very uniform with a beach slope of around 1:25 transitioning to a gentler offshore slope of 1:100 to 1: 200 seaward of the 6-7m contour. Along this section of beach, longshore sediment transport rates are low.

Note, there is a small area off Surfers where these is a persistent kink.

c. At Griffith Street there is a subtle kink in the beach, east from which the shoreline is slightly more aligned east-west. The subtle change in the shoreline occurs where the beach profile changes. East of this point the shallow Lockyer Shoal, coupled with the thick seagrass bed, start to influence the coastal processes. The presence of this shore attached ebb bar system refracts wave energy and starts to influence the rates and direction of longshore sediment transport. This is discussed further below.

d. There is no hard point at the eastern end of the beach to assist in ‘fixing’ in the location of the shoreline. The eastern end of the beach terminates at the Emu Point Channel.

The above is best visualised by reference to **Figure 8** and **Figure B2-6 (Appendix B)**, which show the topographic features (based on LiDAR data) and nearshore bathymetry respectively.

5.2.3 Item 3 – Storm Erosion

In its natural state, sediment transport along much of Middleton Beach is dominated by cross-shore transport with the coastal profile adjusting to intermittent storm waves and elevated water levels. Emu Point has historically been vulnerable to this storm erosion.

Emu Point area has been developed with residential infrastructure and private property particularly around Boongarrie Street, Firth Street and Cunningham Street.

The normal wave climate is governed by long period swell of low amplitude with a nearshore gradient in wave heights from west to east (i.e. lower day-to-day wave heights at Emu Point). Every now and then large storm waves with an offshore wave direction from the south-east impact the study area. These extreme storm waves have a more uniform longshore distribution meaning the effects are felt very keenly at Emu Point.

The shallow Lockyer Shoal also has the potential to allow for more wave setup in storm conditions. Wave set up can raise the water level at the shoreline which increases the storm erosion.

Storm erosion is largely responsible for the dynamic nature of the Emu Point and Middleton Beach coastline. The general accretion trend (see Item 1) along much of Middleton Beach can be reserved for short periods at particular locations due to the variation in storminess. For example, at the Middleton Beach Section 2, Chainage 1600m, the 1986 vegetation line was 20 m landward of 1943 line. However, at the same location the 1992 vegetation line is 10 m seaward of the 1943 line (see **Section 3.3.1** and **Appendix B-1**).

The vulnerability to coastal erosion hazard at Emu Point is then a result of the (i) coastal development in the area (ii) large south-easterly storms such as those in 1921 and 1980’s and (iii) the local morphology allowing for higher storm water levels at the shoreline.

The decade from 1984 to 1994 was a particularly stormy period for the study area. 7 of the 10 largest nearshore wave events occurring in the 38-year wave hindcast period occurred over this period. Houses and other infrastructure at Emu Point were under threat from the storm erosion in this period and action was taken in the form of the series of coastal protection structure built along the shoreline at Emu Point and within Emu Point Channel.

5.2.4 Item 4 – Dynamics of Lockyer Shoal

Lockyer Shoal is the ebb tide delta complex area where sediment transport is a fine balance between wave driven and tidal currents. In 1976, prior to the 1984 storm and construction of the Emu Point coastal structures, Lockyer Shoal was significantly larger than it is today. That is, the area of shallow water was more expansive. This had significant implication of the incoming waves and sediment transport. The general sediment transport pathways at Emu Point/Lockyer Shoal in both a natural (large shoal with no shoreline control structure) and in a developed state (small shoal with shoreline control structure) are described as:

The below features are shown graphically in **Figure 72**.

Large shoal, natural shoreline structures

e. Incoming waves are strongly refracted over the shoal, bending waves east. The incident wave angle creates an eastward transport gradient.

f. The resulting net eastward longshore transport is supplied by sand from Middleton Beach (an ample source of sediment).

g. Over time the shoreline accretes to be perpendicular to the incoming wave crests (i.e. rotates to be more aligned east-west).

h. Over the widest part of Lockyer Shoal wave breaking and bottom friction cause a reduction in wave heights. The reduced wave energy creates a longshore transport gradient differential (i.e. lower transport rates to the east) and sediment accumulation to form the salient at Firth Street.

i. The net eastward longshore transport continued along the beach and is deposited on Emu Point and within Oyster Harbour.

j. Within Oyster Channel ebb currents are greater than flood currents. Excess sediment deposited at Emu Point, within Emu Point Channel or within Oyster Harbour is reworked back onto the ebb tide bar (i.e. Lockyer Shoal). This supply of sediment maintaining the bars morphology.

k. Sand deposited on the ebb bar can then be reworked onshore by waves (i.e. a self-sustaining clockwise circulation of sediment transport occurs).

Small shoal with coastal structures along shoreline

a. Incoming waves refracted less and continue on without bending as much to the east. A westward transport gradient is setup by less refracted waves.

b. The resulting net westward longshore transport canôt be sufficiently supplied by Oyster Harbour and must be supplied by sand on the beach at Emu Point. Oyster Harbour is unable to supply sufficient sediment because (i) the shoreline control structure block longshore transport and (ii) Oyster Harbour has historical been a sediment sink with no process to drive a net supply of sediment towards Emu Point.

c. Over time the shoreline erodes to be more perpendicular to the incoming wave direction (i.e. rotates to be aligned more north-south).

d. The salient at Firth Street erodes to supply sand to the longshore transport. The smaller size of Lockyer Shoal means that there is less reduction in wave energy reaching the shore.

e. Sand from the westward longshore transport is supplied to Middleton Beach. This increased supply is evidence by the recent increase in the long term rate of accretion (see **Figure 14** and **Section 3.3.1**).

f. While the coastal structures are effective at halting further shoreline recession they reduced eastward longshore transport, resulting in a reduction in the supply of sediment to the ebb tide bar.

g. Sand deposited on the ebb bar can still be reworked onshore by waves but is now preferentially transported to the west by the net westward longshore transport.

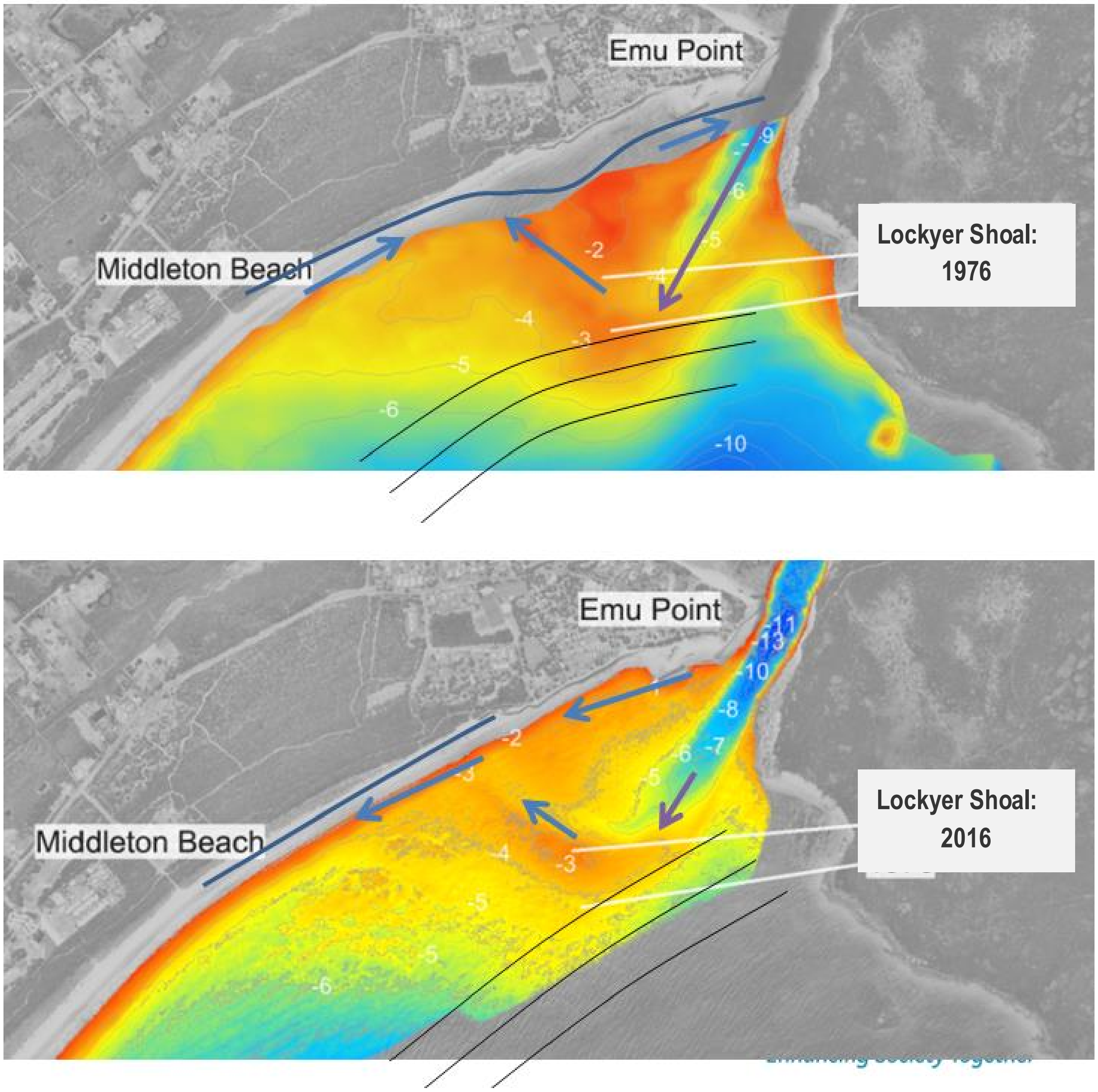


Figure 72 Conceptual sediment pathways around Emu Point/Lockyer Shoal for pre-developed (top) and developed (bottom) that described different coastal processes in each scenario.

Notes of above figure:

- The pre-developed scenario shows the 1976 bathymetry while the post-developed scenario shows the 2016 bathymetry.
- Incoming wave crests are shown as the thin black lines.
- Wave driven sediment transport pathways are shown with the blue arrows.
- Tidally driven sediment transport pathways are shown with the purple arrows.
- The indicative shorelines in both scenarios are shown as the dark blue line.

5.2.5 Item 5 – Emu Point Coastal Structures

The above point explains the relative sediment transport pathways between the two scenarios, however, the question remains; what caused the reduction in the size of Lockyer Shoal?

There has been debate about whether this was a result of the 1984 storms or if it was due to the introduction of the coastal structures, or a combination of the two. On the balance of evidence available, the following section provides our guided opinion of the most likely explanation:

- Eastward longshore transport formerly infilled Emu Point Channel, creating a more constricted passage for tidal flows and caused higher current speeds in the channel proper. As a result the magnitude of the ebb jet was stronger and pushed the ebb bar (i.e. outer Lockyer Shoal) further offshore. There was sufficient sediment supplied by the continuing eastward longshore transport to maintain a stable or growing ebb bar.
- Realignment of the Emu Point Channel in the mid-1980ôs, due to the introduction of the training wall groynes, resulted in a less constricted channel and a reduction in the speed of the ebb jet as it exited (see **Figure 58** in **Section 4.4.3**). Coupled with a slowly reducing sediment supply the shoal started to reduce in size (i.e. the outer contours of the shoal moved landward).[1] Evidence of this comes from the observed changes in the bar morphology between 1976 and 1987 (see **Appendix B2** including **Figures B2-2 to B2-5**).
- These changes to bar morphology meant that the whole area began to erode, with the erosion moving from offshore to inshore. Much of the eroding areas were covered in thick beds of seagrass. The persistent erosion of Lockyer Shoal resulted in the well documented loss of these seagrass meadows. Prior to its slow degradation, the seagrass added to attenuate wave energy in most (non-storm) conditions.

  The loss of the seagrass meant that:

  1. areas of Lockyer Shoal where seagrass was lost were now more susceptible to erosion and;
  2. Additional wave energy was able to reach the shoreline, exacerbating shoreline erosion.

  Appendix D includes a detailed description of the seagrasses in Middleton Bay based on the data and observations of Geoff Bastyan.
- Erosion started along Emu Point Beach, progressing from east to west. The construction of additional coastal protection structures also followed this same pattern, i.e. being progressively built from east to west during the storm affected decade from 1984 to the mid-1990s.
- Construction of the steep rock revetment at Emu Point lead to scour of sediment in front of the structure due to reflected waves increasing the overall nearshore wave energy. The seawall is thought to have had a significant contribution to the observed scour of Lockyer Shoal. Again this is evidenced by the sequence of changes in the bar morphology, particularly the accelerated erosion observed over the inner shoal area after its construction commencing in the mid-1990s (see **Appendix B2** including **Figures B2-2 to B2-5**).

While the 1984 storm and the general storminess in the mid-1980s to mid-1990s certainly had an impact on Lockyer Shoal and Emu Point without the introduction of the coastal structures, it is reasoned that the

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[1] *It is noted that the location of the ebb bar is determined by the balance between (i) ebb directed flows (i.e. ebb tide and fluvial input) that tend to push the location of the bar further offshore and (ii) wave driven sediment transport that tends to want to transport the bar onshore (i.e. weld the bar to the shoreline as per the morphology further west along Middleton Beach).*

area would have been able to naturally restore itself to an equilibrium position with a larger Lockyer Shoal and beach plan form similar to that which was present in 1976. The restoring mechanisms, however, relied on the sediment transport processes of the pre-structure ônaturalô system (described above).

5.2.6 Item 6 – A New Equilibrium

A new equilibrium at Emu Point/Lockyer Shoal is likely to be established. There is evidence that Lockyer Shoal has now started to stabilise, establishing a new equilibrium size that is in harmony with the present system (i.e. structures in place, no new sediment supply). The evidence for this comes from:

- Erosion of Lockyer Shoal appears to have slowed or stopped (see **Appendix B2** including **Figures B2-2 to B2-5**);
- Seagrass has started to return and recolonise areas of Lockyer Shoal (Geoff Bastyan, 2016).

This new equilibrium (or new normal) has a bar morphology that appears to be stabilising around a reduce footprint/volume and a shoreline that is controlled by the location of the structures.

The development at Emu Point is afforded terminal protection against erosion from coastal storms by the coastal structures. In terms of coastal protection this is an improvement over the pre-structures scenario. However, it may come at a loss of amenity with the sandy beach along Emu Point unlikely to return to its formed state.

It is noted that this new equilibrium has formed in the absence of a sequence of significant coastal storms. Since the run of storms in the mid-1980ôs to mid-1990ôs, storms in the study area has been relatively small with the exception of a single storm in 2005 that was the 3rd highest in the past 38 years in terms of nearshore wave heights.

5.3 Summary and Limitations

The study area is highly likely to benefit from a net supply of sediment. Most of this sediment is accumulating on Middleton Beach with the maximum accumulation around ôSurfersô

Additional confidence in the longevity and rate of sediment supply could be achieved by observations that support this conclusion, such as:

- onshore directed bed forms (i.e. sand ripples/mounds/waves) within King George Sound at depths less than 7-8m;
- A differential pattern of siltation (infilling) in the Southern Ports ï Albany dredge channel such that a greater siltation was observed on the ocean (southern) side of the channel. In the absence of other tidal or fluvial processes or vessel scour, this would be evidence of on-shore directed transport by swell; and
- Confirmation that King George Sound is supplied by littoral drift sand from the east.

The areas and rates of sediment accumulation should be reviewed as part of the planning for any future coastal management schemes.

The construction of the various coastal protection structures after the 1984 and 1987 storms has been effective as a last line of defence and prevented further infrastructure losses. However, had the structures not been introduced, Emu Point may well have been on the path to slowly restoring itself, particularly given that the following decades (from mid-1990ôs) were less stormy. The structures have probably changed the dynamics to such an extent that natural restoration of the area will not occur.

The key remaining questions are in regard to the likelihood of on-going downdrift erosion west of the Emu Point structures. This area of highly localised erosion is caused by the end effect from construction of the rock seawall extension in 2005 and then, more recently the sandbag revetment in 2011. The extent of the erosion was confined to an area of less than 200m immediately west of the sandbag revetment. The erosion in this localised area was around 25 to 30m, most noted in 2012-13 when the dual use pathway was relocated landward. The analysis completed in Section 4.5.1 has shown that around this area there is a slight westerly net longshore transport. In 2014, the trail geotextile groynes and relatively minor sand nourishment seems to have stabilised the area. It is unclear if these measures are only temporary or if the area is in fact stabilised around a new equilibrium position, adjusting to the formal Emu Point coastal structures further to the east.

In regard to this remaining uncertainty, it is understood that that CoA are undertaking significant monitoring of this area. Future studies will benefit from the longer term data in resolving the likelihood of any on-going coastal erosion response. In the meantime and in the event that erosion was observed to continue, beach scrapping (or similar) and low volume transfers of sand from the adjacent and accreting section of Middleton Beach would seem to be a viable option from a coastal processes perspective. Alternatively any regular maintenance dredge in the area (e.g. Oyster Harbour) could also be used for opportunistic beach nourishment.

6 Hazard Mapping

6.1 Preamble

The following sections present an overview of the methodology and outcomes from the coastal hazard assessment. The resulting hazard maps are presented at the end of this section in **Maps 1 to Map 12**.

6.2 State Coastal Planning Policy

SPP2.6 was released in July 2013 to assist land use planning and development issues specifically as they relate to the protection of the coast (Western Australian Planning Commission, 2013). Schedule One of SPP2.6 provides direction for calculating the appropriate Coastal Processes Setback (CPS) distance for new development on the Western Australian coast.

The intention of the CPS is to provide a buffer zone between the shoreline and development in which coastline changes in the short term (severe storms), the medium term (shoreline movement) and the longer term (sea level rise and fluctuation of natural processes) can occur. The calculation of the CPS distance is based on the combined result of the following factors:

1. S1 Allowance - Distance For Absorbing Acute Erosion (Extreme Storm Sequence)
2. S2 Allowance - Distance to Allow for Historic Trends (Chronic Erosion or Accretion)
3. S3 Allowance - Distance to Allow for Sea Level Change

These criteria are discussed in turn in the following sections of this report.

With respect to inundation, SPP2.6 requires that development consider the potential effects of an event with an Annual Encounter Probability (AEP) of 0.2% per year. This is equivalent to an inundation event with an Average Recurrence Interval (ARI) of 500 years. This is referred to as the S4 Allowance for coastal inundation.

This coastal hazards assessment has been completed for a 100 year planning horizon in accordance with SPP2.6 requirements. Interim planning horizons of 2017 (current), 2030, 2050, 2070 and 2120 have also been considered in order to assess the changes to coastal vulnerability over time.

6.3 Coastal Protection Structures

SPP2.6 recommends that the setback allowances calculated for areas that benefit from coastal protection works be determined on a case by case basis taking into account the coastal processes and the works in question. This is particularly relevant for the Emu Point area were formal (or engineered) coastal protection structures have been in-place in the mid-1980s.

Following advice from CoA and the Department of Planning, two sets of coastal erosion hazard lines have been prepared for the Emu Point area. The hazard lines are prepared based for both with and without the structures in place for each of the planning periods. For later stages of the CHRMAP process it may be important to understand what the maximum extent of potential impacts for both scenarios. In preparing the erosion hazard lines, the following is assumed for each scenario:

- With coastal protection structures ï The existing structures at Emu Point have been designed to withstand erosion from a 100-year ARI event and it is assumed that these structures are effective at providing that level of protection. The extent of erosions also assumes the ongoing maintenance and upgrade of the protection structures. While this is not guaranteed, it is one possible option for the City of Albany to consider in the future.

- Without coastal protection structures ï For this scenario it has been assumed that the current shoreline sits at the location of the coastal protection structures. Scenarios have been hypothesized so as to determine inundation and setback assuming there is no significant change in the hydrodynamics of the system following the removal of the structures. This assumption is based on direction received from the City.

In regard to the smaller and less formal structures at Ellen Cove and Oyster Harbour, these are treated as being erodible given that they arenôt robust coastal protection structures.

6.4 S1 Storm Erosion

SPP2.6 outlines that the S1 allowance should provide an adequate buffer to accommodate the potential erosion caused by a storm with an annual encounter probability (AEP) of 1%. This is equivalent to a 100 year average recurrence interval (ARI) storm.

Storm erosion was investigated using the SBEACH numerical model. SBEACH models the impact to the beach profile resulting from a severe storm event and shows the erosion and deposition of sand as large waves and elevated water levels reshape the shoreline.

Consequent loss of beach area following large storm events is investigated to provide a measure of the beach area at risk from short term storm events (S1). SBEACH has been used extensively for this purpose in Western Australia and has been validated on a number of sandy coastlines (Rogers et al, 2005).

This validation has shown that SBEACH can provide useful and relevant predictions of the storm induced erosion, provided the inputs are correctly applied. The main inputs include a time series of storm wave heights, wave period and water level, as well as pre-storm beach profile and median sediment grain size.

The inputs used in this study were:

Pre-storm beach profiles

A series of shoreline profiles were established across the study area and subjected to design water levels and wave heights representative of a 100-year ARI storm. The input beach profiles for the model were taken from the latest quarterly beach profile transects undertaken by City of Albany, supported by DoT grant funding.

The selected profiles; MB01, MB02, MB04 and MB07 (see Section 3.3.2) were selected as they are representative of each of the beach sectors within the Middleton Beach/Emu Point part of the study area.

An additional transect was located within the Oyster Harbour study site tangential to the shoreline orientation , located centrally to both the Emu Point Boat Pens and the Northern Rock Groyne.

For the case of without coastal protection structure it has been assumed that the pre-storm beach profile is represented as if the shoreline is located where the current coastal protection structures are situated. The coastal profile was based nearshore bathymetry combined with a representative upper beach profile taken from an area of Middleton Beach adjacent to the Emu Point structures.

Grain Size

Following on from the sediment sampling and analysis and the subsequent LITPACK modelling, the mean D_{50} (mm) for each of the selected transects was used as a parameter for the SBEACH modelling. These values ranged from 0.20 ï 0.23mm. A maximum avalanching slope of 30° to the horizontal has also been incorporated into the model calculation based on historic literature.

Storm time series:

It is common practise in Western Australia to use three repeats of the severe storm sequence experienced in the south west of Western Australia during July 1996 to represent the 100-year ARI beach erosion event. This event had a duration of approximately 111 hours.

Middleton Beach is located within King George Sound and sheltered from some storms that might have caused 100-year ARI coastal erosion in other areas. For example, the 1996 storm was not a significant storm for this study area. For such sheltered areas SPP2.6 recommends that the storm event be selected on a case-by-case basis.

Following the results of the 38-year wave hindcast, we have selected the August 1984 event as being the most appropriate event representative of the 100-year ARI beach erosion event at Middleton Beach and Emu Point.

This event had an event duration of 109 hours and was run three consecutive times following the previous methodology for a duration of 327 hours. Wave data from this storm were extracted from the SW model at the seaward end of each beach profile. The storm time series input into SBEACH can be seen in **Figure 73**.

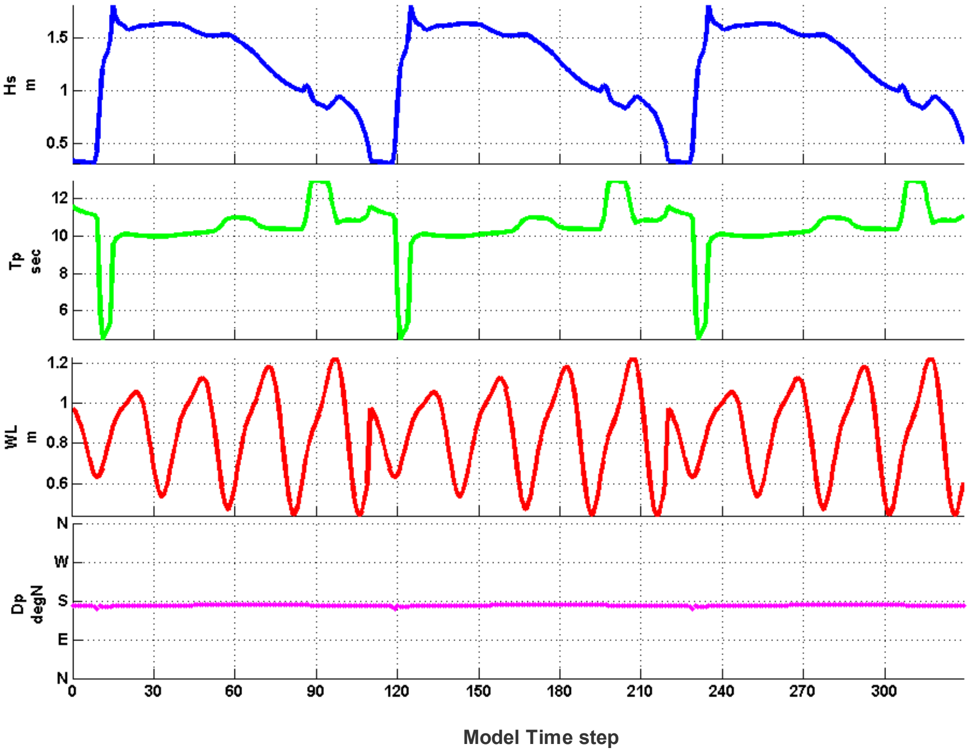

Figure 73 Example input time series for SBEACH analysis; 3 time 1984 storm at offshore extraction point for MB07 beach transect.

In addition, predicted water levels for the event (based on harmonic analysis of the PoA tide gauge) was used as a model forcing with the addition of 1m of surge for the duration of the event. Recorded wind speed and direction were also used as forcing conditions.

The wave time series used for the Oyster Harbour transect was synthesized to match that of the 1984 storm with the peak H_s set to 0.8m as per the results of the spectral wave modelling undertaken in **Section 4.3.** The Oyster Harbour water level time series was synthesised so that the peak water level aligned with the peak H_s in the wave time series. The wind speed in this model was set to the max value of 27m/s attained from the wind speed EVA, again a considerably conservative approach.

The severe storm erosion allowance is determined as the extent of erosion behind the Horizontal Shoreline Datum (HSD). The HSD corresponds to the seaward shoreline contour representing the peak steady water level of the modelled event. The location of the x=0 in the plots of **Figure 74** represents the benchmark taken from CoA quarterly beach transect surveys. The HSD varies in relation to this point along the different coastal compartments. Similarly to MP Rogersô shoreline analysis undertaken as part of the Middleton Beach Activity Centre, the HSD at this location is located at the base of the existing retaining wall at the rear of Middleton Beach (MP Rogers, 2015).

For the case without coastal structures the HSD has been based on the position of the coastal protection structures. .

The results of the SBEACH modelling are shown in **Figure 74**. These plots show that the severe storm erosion ranged from approximately 12m to 35m behind the HSD with approximately 45 to 95m^3/m eroded from the subaerial profile depending on the coastal compartment within the study area.

These values correlate well to anecdotal and photographic evidence from the 1984 storm (as seen in **Appendix A**). It was reported that during this event up to 35m of erosion was experienced just north of the present day Golf Course (approximately MB04) with 3 to 4m erosion scarp following the storm. Erosion around Ellen Cove (MB01) was reported as less than around 10m.

6.4.1 S1 Allowances

The S1 Allowances for each of the planning timeframes are presented in **Table 17**. It should be noted that the same allowance has been allocated to all planning timeframes as SPP2.6 specifies that the design storm should have an AEP of 1%, therefore the storm severity is the same, regardless of the timeframe being considered.

The Emu Point beach compartment (directly landward of the coastal structures) is considered to be at the last line of coastal defence. It is understood the current rock revetment, training wall and groyne structures were designed and constructed to withstand a 100 year ARI design event.

CoA are currently monitoring and maintaining these structures. For the case of with coastal protection structure it has been assumed this would continue in the future.

Any changes to these structures would necessitate a review of these hazard lines. This compartment currently has no available shoreward beach available to be eroded and as such the S1 Allowance for this location will be at the same location as the HSD.

For the case of without coastal protection structures, it has been assumed the shoreline is composed on unconsolidated sand and is subject to storm erosion.

Table 17 S1 Erosion Allowance by beach compartment

Planning period	S1 Allowance (m)					
	Middleton Beach (Sector 1)	Middleton Beach (Sector 2)	Middleton Beach (Sectors 3 and 4)	Emu Point (with hard structure)	Emu Point (without hard structure)	Oyster Harbour (OH)
Present Day (2017)	15	35	40	0	20	5
2030	15	35	40	0	20	5
2050	15	35	40	0	20	5
2070	15	35	40	0	20	5
2090	15	35	40	0	20	5
2120	15	35	40	0	20	5

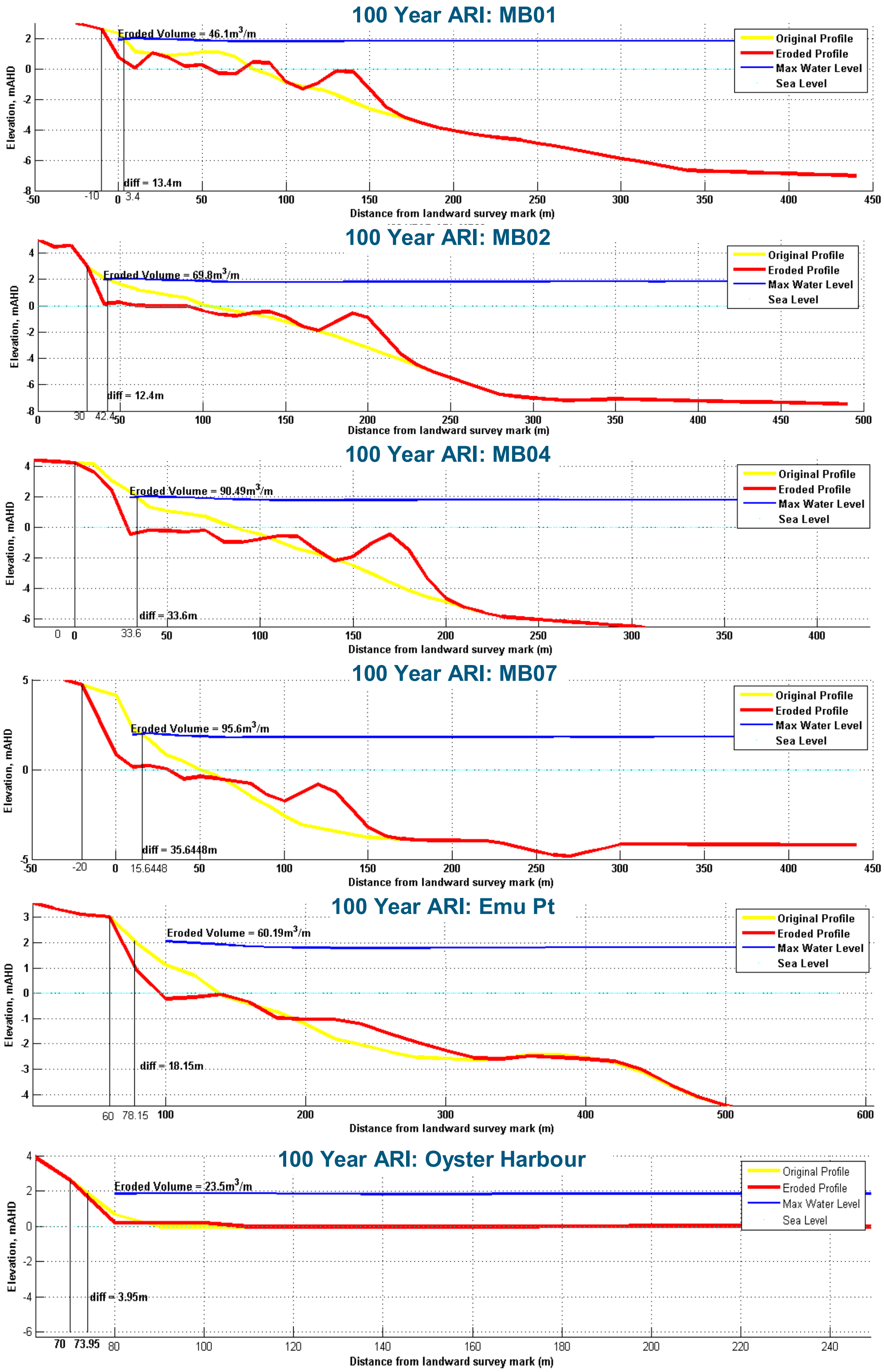

Figure 74 SBEACH storm erosion ï 100 year ARI at beach transect locations; MB01, MB02, MB04, MB07, Emu Point and Oyster Harbour

6.5 S2 Historical Shoreline Change

The S2 Allowance accounts for the long term trends in historical vegetation line position that may occur within the planning timeframes. To estimate the S2 Allowance, long term historical shoreline movement trends were examined and likely future shoreline movements predicted.

Based on the aerial photography covering a 71 year period, **Section 3.3.1** discusses how the rates of long term shoreline change provided in **Table 4** were determined.

This analysis showed that large sections of Middleton Beach were significantly accreting, while the eastern and western ends were relatively stable (apart from some highly localised erosion around at the end of the Emu Point coast structures). The SPP2.6 guidelines have been followed in the adoption of the S2 Allowance.

Where historical rates of accretion are less than 0.2m/yr., the allowance for shoreline movement has been set to zero. For historical rates of accretion greater than 0.2m/yr., SPP2.6 states that if there is compelling evidence that accretion is likely to continue into the future for a period of at least 50 years, then a reduction in the coastal setback distance is warranted.

Sector 2 of Middleton Beach was determined to have a long term rate or accretion of 0.6m/yr. **Point 1** of the conceptual coastal process model provides compelling evidence that the onshore supply of sediment underlying this accretion will continue for the next 50-years or more (see **Section 5.2**). Given these points and following the recommendation in SPP2.6, the S2 Allowance for Beach Sector 2 has been set as -0.3m/yr. (i.e. 50% of the long term rate of accretion).

In Sector 4 there is a localised area of recent erosion caused by the extension of the adjacent Emu Point coastal structures. The latest available data suggests that this localised erosion is stabilising, however, given the uncertainty adopting a shoreline recession rate equal to that observed across the sector in recent years (i.e. 0.3m/yr.) is considered to be an appropriately conservative assumption for this study. However, it is recommended that the on-going shoreline monitoring data in this area be reviewed at a later date to determine if the localised erosion has abated (i.e. shoreline has reached a new dynamic equilibrium position).

The Emu Point beach compartment is protected from future shoreline change by a series of coastal structures. CoA are currently monitoring and maintaining these structures. For the case of with coastal protection structures it has been assumed this would continue in the future and an S2 allowance of 0m/yr. has been adopted for this section. Any changes to these structures would necessitate a review of the coastal hazards including the S2 erosion allowance.

The other beach sector where there are coastal structures and beach management is present is Sector1 of Middleton Beach (i.e. Ellen Cove). A zero rate for the S2 Allowance was adopted for this section as the shoreline is controlled by the Wooding Point headland. It is noted that the MP Rogers (2015) report adopted a negative offset S2 Allowance of -0.4m/yr.

For Oyster Harbour Beach the adopted rate is based on the -0.2m/yr. erosion trend observed in the shoreline data over the more recent period from 1997 to 2016.

For the case of the coastal hazard lines without structures, the rate of shoreline recession should be based on the observed shoreline trends prior to the introduction of the coastal structures. In **Figure 16** (see **Section 3.3.1**) in it is noted that the shoreline (as represented by the Firth Street salient) had been generally accreting up until the mid-1980s. The equivalent rate of shoreline accretion over this period was 0.55m/yr. However, SPP2.6 cautions against the use of an accretion trend where these is uncertainty in the continuation of this trend into the future. Given that the coastal hazard lines are subject to greater uncertainty it is considered appropriate that a zero rate be applied to calculate the S2 allowance for Emu Point in this instance.

6.5.1 S2 Allowances

The S2 Allowances adopted for each of the planning timeframes are presented in **Table 18**. Negative allowances are taken as reductions in coastal setback distances.

Table 18 S2 Erosion allowance by beach sector

Planning period	S2 Allowance (m)						
	MB (Sector 1) [Adopted rate = 0m/yr.]	MB (Sector 2) [Adopted rate = -0.3m/yr.]	MB (Sectors 3) [Adopted rate = 0.0m/yr.]	MB (Sectors 4) [Adopted rate = +0.3m/yr.]	Emu Point (with hard structures) [Adopted rate = 0m/yr.]	Emu Point (without hard structures) [Adopted rate = 0m/yr.]	Oyster Harbour [Adopted rate = +0.2m/yr.]
Present Day (2017)	0	0	0	0	0	0	0
2030	0	-4	0	4	0	0	3
2050	0	-10	0	10	0	0	7
2070	0	-16	0	16	0	0	11
2090	0	-22	0	22	0	0	15
2120	0	-31	0	31	0	0	21

6.6 S3 Sea Level Change

In 2010 the magnitude of sea level rise (SLR) recommended for coastal setback planning in Western Australia was updated in SPP2.6 for planning periods up to 100 years. For the 100 year planning timeframe (2010 to 2110) DoT recommended a vertical SLR of 0.9m be adopted, whilst in the 50 year planning timeframe a vertical SLR of 0.3m is appropriate (DoT, 2010). This sea level rise scenario is presented in **Figure 75**.

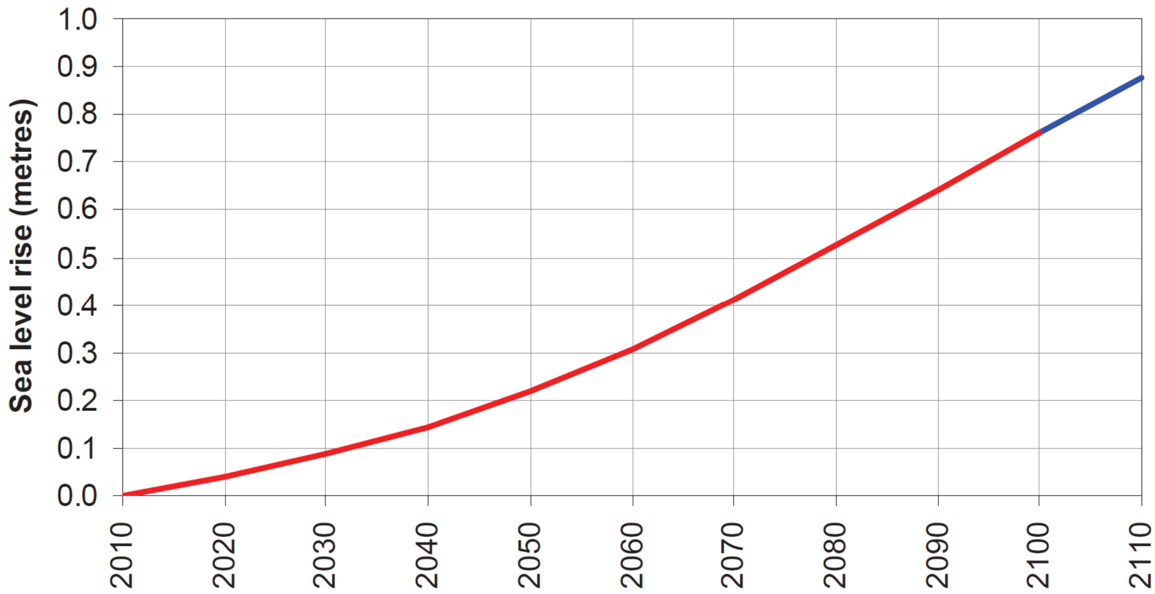

Figure 75 Recommended sea level rise (SLR) allowance for WA coast (source: DoT, 2010)

The recommended allowances for SLR for planning periods sooner than 2120 have been determined based on the graph in **Figure 75**. For the 2120 planning period DoT's recommended vertical sea level rise of 0.9m by 2110 plus 0.01m/yr. every year beyond 2110 has been adopted. The sea level rise allowances for each of the planning timeframes are presented in **Table 19**. It is noted that all values of sea level rise are provided relative to 2017 levels. That is, appropriate discounting has been made for sea level rise that occurred between the 2010 baseline used by DoT and the 2017 baseline used in this study.

Table 19 Adopted sea level rise values relative to 2017 baseline

Planning period	Sea level rise (m) (relative to 2017)
Present Day (2017)	0.00
2030	0.06
2050	0.19
2070	0.38
2090	0.61
2120	0.97

SPP2.6 recommends that a form of the Bruun rule (Bruun 1962) be used for calculation of a setback distance based on the vertical SLR component. For sandy shores, SPP2.6 specifies a multiplication factor of 100 be applied under the Bruun rule. For example, a 100 year planning timeframe a vertical SLR of 0.9m results in a horizontal setback distance (S3) of 90m. For the 50 year planning timeframe a setback distance (S3) of 38m is applicable. There are presently no features (i.e. obstacle to longshore sediment transport) in the study area that warrant consideration to increase the allowance for S3. Sea level rise will impact the entire study area

6.6.1 S3 Allowances

The S3 Allowances adopted for each of the planning timeframes are presented in **Table 20**.

Table 20 S3 Erosion Allowance (m) for shoreline recession due to sea level rise

Planning period	S3 Allowance (m)					
	Middleton Beach (Sector 1)	Middleton Beach (Sector 2)	Middleton Beach (Sectors 3 and 4)	Emu Point (with hard structures)	Emu Point (without hard structures)	Oyster Harbour
Present Day (2017)	0	0	0	0	0	0
2030	6	6	6	0	6	6
2050	19	19	19	0	19	19
2070	38	38	38	0	38	38
2090	61	61	61	0	61	61
2120	97	97	97	0	97	97

6.7 S4 Coastal Inundation

SPP2.6 requires that an assessment of the potential exposure of areas to coastal inundation or coastal flooding. Coastal inundation (or flooding) occurs as a result of seawater inundation from periods of elevated ocean water level (i.e. high tides and storm surges) and large waves that cause wave set-up and wave run-up. This is named the S4 Inundation allowance within the SPP2.6.

The S4 allowance for the current risk of inundation should be the maximum extent of storm inundation, defined as the peak steady water level plus wave-un-up. The coastal inundation assessment is to be completed with reference to an event with a 0.2% chance of exceedance per year, otherwise referred to as the 500-year ARI event. In order to define the peak steady water level and wave-run-up levels for a 500-year ARI storm within the study area, the analysis of metocean data (see **Section 3.4**) and numerical modelling (see **Section 4.4**) have been used.

From the extreme value analysis (EVA) detailed in **Section 4.3.4**, it can be seen that the 500-year ARI for wave height is estimated at being 3.8m. This is approximately a 15% increase in wave height from the 100-year ARI event. As such this increase factor will be applied to the H_s component of the wave boundary condition for the duration of the 1984 event in order to model this synthetic scenario.

Following on from the EVA of wave heights undertaken in **Section 4.3.4,** it can be seen that there is no clear linkage between extreme wave events and water levels. Unfortunately, concurrent water levels for the period of the 1984 storm were not made available for this study. As such an inference to water level needs to be made in order to model the event correctly. The EVA undertaken on water level (at óSouthern Portsô(Albany)) in **Section 3.4.1** shows that the 100-year ARI level is approximately 1.01m. An earlier study undertaken, based on 44 years of water level data at óSouthern Portsô(Albany), places this value at 1.08m, with a clear asymptotic levelling of the ARI curve for greater return periods around 1.1m, see **Figure 76** (Haigh, et al. 2012).

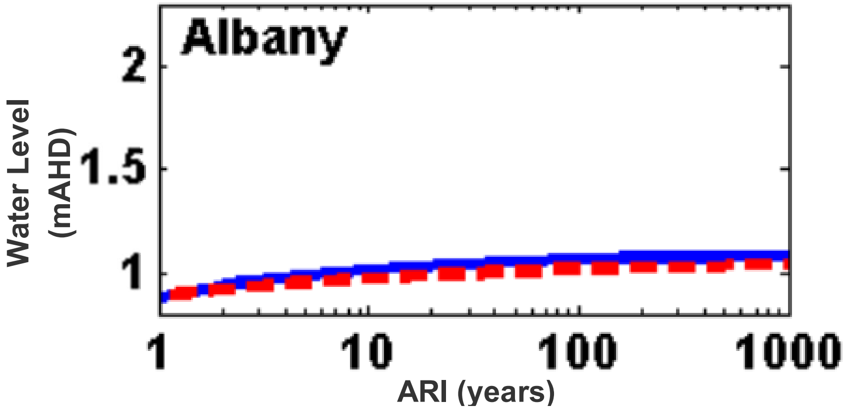

Figure 76 Comparison of measured (blue) and predicted(red) return period water level for Port of Albany for 2010 (relative to AHD) using the Annual Maxima Method fitted to a Generalised Extreme Value distribution (Haigh, et al., 2012)

Combining this level with the 500-year ARI Hs (3.8m) for modelling purposes will provide an overly conservative approach to the investigation as there appears to be no tangible correlation between water levels and wave heights at the study site. In order to overcome this problem, a combination of approaches have been used to understand the sensitivity to water level and wave height variations for this synthetic event and its hypothesized effects on coastal inundation.

Using the 30-year water level record from the Princesses Harbour tide gauge, **Section 3.4.1** presents the results of the extreme value analysis. Based on this analysis the 500-year ARI water level was estimated to be 1.15m AHD (see **Figure 24**).

At the shoreline, the peak steady water level during storm conditions is also expected to include a component of elevated water levels due to the effects of wave set-up. In order to include the effects of wave set-up, this study has determined representative values along swell exposed section of the coastline using two separate approaches:

- Based on extensive measurement of wave set-up on ocean exposed beaches wave set-up is typically between 10 to 15% off the offshore wave height. The 500-year Hs offshore of wave breaking is 3.8m, so this would be expected to result in wave set-up in the order of 0.38m to 0.57m.
- The Storm-induced Beach Change (SBEACH) numerical model (outlined in **Section 6.4**) was used to translate the water levels to the nearshore area to incorporate the effects of nearshore wave setup. It was found that wave setup in the order of 0.45m at beach transect site MB07 (deemed to be the most vulnerable to coastal inundation, see **Section 6.6**). This was within the range that would typically be expected based on previous measurements of wave set-up.

Based on the above a value of 0.5m was adopted as being in the upper range that would be typically expected from previous measurements and slightly above that this was modelled in SBEACH. This value was adopted for the swell exposed zone of the study area.

For Oyster Harbour Beach a small allowance of wave set-up has been adopted as 0.1m, again this is in the upper range of 10 to 15% of the unbroken wave height (Hs 100-yr is 0.8m).

The effects of wave run-up and overtopping have been considered and areas that a potentially susceptible to inundation from wave run-up have been identified. Hanslow and Nielsen (1995) provide guidance on calculating wave run-up <u>on beaches</u>. They found that the run-up above the still water level was given by:

$$R = 0.9 H_s \left(\frac{L_s}{H_s} \right)^{0.5} \tan \beta$$

Where R is the run-up exceeded by 2% of waves, H_s is the significant wave height, L_s is the significant Wave length, and tan ß is the beach slope. Using the 500-year ARI metocean conditions (Hs = 3.45m) along the swell exposed areas, the wave run-up level (including wave set-up) is 3.8m AHD.

6.7.1 S4 Allowances

The S4 Allowances for inundation along all WA coasts is specified to be the maximum extent of inundation calculated as the sum of S4 inundation plus the predicted extent of sea level rise. The adopted inundation levels for the ocean exposed coastline for each of the planning timeframes are presented **Table 21**.

The resulting inundation hazard maps presented in the next section are based on:

- The 2012 topographic LiDAR provided by the CoA;
- Mapping of the peak steady water levels (excluding and including wave set-up) for the 2017 condition along each section of the study area. Distinct is made between the swell exposed areas from Middleton Beach to Emu Point and the protected Oyster Harbour area.
- Mapping of the peak steady water levels (excluding and including wave set-up) for the 2120 conditions including the allowance for sea level rise.
- Mapping of the 3.8m AHD wave run-up level along the swell exposed coastline. Where low-lying land is uncounted areas potentially susceptible to wave run-up and overtopping have been identified. For these areas where the coastal barrier does not contain the wave run-up an indicative landward extent of the 2017 wave run-up is included. It should be noted that the extent of wave run-up can be difficult to predict accurately and as such the landward extent should be considered as highlighting areas of concern for further consideration.

Table 21 S4 - 500 year ARI inundation levels (swell exposed areas) for each of the planning timeframes

Component	Planning Horizon					
	2017	2030	2050	2070	2090	2120
500yr ARI peak water level offshore of wave breaking (no wave setup), (mAHD)	1.15	1.15	1.15	1.15	1.15	1.15
Allowance for nearshore setup (wind and wave), (m)	0.50	0.50	0.50	0.50	0.50	0.50
Allowance for Sea Level Rise (m) ï from S3	0.00	0.06	0.19	0.38	0.61	0.97
Peak steady water level at the shoreline (mAHD)	**1.65**	**1.71**	**1.84**	**2.03**	**2.26**	**2.62**

6.8 Coastal Hazard Mapping

The allowances for coastal processes (i.e. sandy coast erosion setbacks), as determined in the preceding sections are presented in **Table 22**. As required by SPP2.6 a 0.2 m/yr. allowance for uncertainty has been included due to total vulnerability. The total allowances are the sum of the S1, S2, S3 and uncertainty components. The landward setback is measured from the HSD.

Map 1 to Map 6 present the resulting coastal erosion hazard maps showing all required planning periods for the study area from Ellen Cove to the Oyster Harbour Boat Pens.

Map 6 to Map 12 present the resulting coastal inundation hazard maps showing all required planning periods for the study area from Ellen Cove to the Oyster Harbour Boat Pens.

Table 22 Summary of erosion allowances (m), S1, S2 and S3 and uncertainty for study area.

Planning period	Allowances	Sandy coast setback allowances (measured landward from HSD)						
		MB (Sector 1)	MB (Sector 2)	MB (Sector 3)	MB (Sector 4)	Emu Point (with hard structures)	Emu Point (without hard structures)	Oyster Harbour Beach
Present Day (2017)	S1	15	35	40	40	0	20	5
	S2	0	0	0	0	0	0	0
	S3	0	0	0	0	0	0	0
	Uncertainly [Rate =0.2m/yr.]	0	0	0	0	0	0	0
	Total setback	**15**	**35**	**40**	**40**	**0**	**20**	**5**
2030	S1	15	35	40	40	0	20	5
	S2	0	-4	0	4	0	0	3
	S3	6	6	6	6	0	6	6
	Uncertainly [Rate =0.2m/yr.]	3	3	3	3	0	3	3
	Total setback	**24**	**40**	**49**	**53**	**0**	**29**	**16**
2050	S1	15	35	40	40	0	20	5
	S2	0	-10	0	10	0	0	7
	S3	19	19	19	19	0	19	19
	Uncertainly [Rate =0.2m/yr.]	7	7	7	7	0	7	7
	Total setback	**41**	**51**	**66**	**76**	**0**	**46**	**37**
2070	S1	15	35	40	40	0	20	5
	S2	0	-16	0	16	0	0	11
	S3	38	38	38	38	0	38	38
	Uncertainly [Rate =0.2m/yr.]	11	11	11	11	0	11	11
	Total setback	**64**	**68**	**89**	**105**	**0**	**69**	**64**
2090	S1	15	35	40	40	0	20	5
	S2	0	-22	0	22	0	0	15
	S3	61	61	61	61	0	61	61
	Uncertainly [Rate =0.2m/yr.]	15	15	15	15	0	15	15
	Total setback	**91**	**89**	**116**	**138**	**0**	**96**	**95**
2120	S1	15	35	40	40		20	5
	S2	0	-31	0	31	0	0	21
	S3	97	97	97	97	0	97	97
	Uncertainly [Rate =0.2m/yr.]	21	21	21	21	0	21	21
	Total setback	**133**	**122**	**158**	**189**	**0**	**138**	**143**

7 References

Australian Hydrographic Service (2010), *Australian National Tide Tables 2011*, Australian Hydrographic Publication 11, Department of Defence, ISSN 0812-2245.

Bastyan G. (2014) *Sediment sampling and analysis –maps and data*. Maps and data files prepared for Department of Transport and City of Albany.

Bastyan G. (2015) *The Seagrass Distribution of Middleton Bay*. Report prepared for Department of Transport and City of Albany.

Bruun, Per (1962), *Sea Level Rise as a Cause of Shore Erosion*, Journal of the Waterways and Harbors Division, Proceedings of the American Society of Civil Engineers, Volume 88, No. WW1, February, pp. 117-130.

Bruun, Per (1983), *Review of Conditions for Uses of the Bruun Rule of Erosion*, Coastal Engineering, Volume 7, Elsevier, pp. 77-89.

DAF (2007) *Oyster Harbour Catchment Appraisal*, Resource Management Technical Report 320, Department of Agriculture and Food.

Department of Marine and Harbours (1992) *Albany- Emu Point: Beach stabilisation works*.

DHI (2011) *MIKE by DHI Marine Modelling Suite*.

DPI (2004) *Emu Beach (Albany) Seagrass Status Investigation*, Technical Report 429.

Douglas Partners (2007). *Report on Geotechnical and Preliminary Acid Sulphate Soil Investigation. Lots 1512 and 1523 Emu Point Driven Albany, WA*. Project 22531 prepared for LandCorp.

DoT (2010) *Sea Level Change in Western Australia Application to Coastal*. Report by DoTôs Coastal Infrastructure, Coastal Engineering Group.

DoT (2012) Coastline movements Cape Naturaliste to Oyster Harbour Emu Point. Drawings

provided by DoT.

DoT (2000) *Emu Beach Erosion (Albany): Evaluation of Erosion Management Options*, Transport Report 408. GBA ï reference required item 108

Geological Survey of Western Australia (1989). *Albany Geological Map Sheet Part Sheets 2427 I, 2428 II, 2527 IV and 2528 III*.

GEMS (2007) *Oceanographic Studies Report and Dredging Program Simulation Studies.* Report prepared for Grange ResourcesôSouthdown Magnetite Project.

JKA (2014) *Beach Transects, Ellen Cove to Oyster Harbour, Middleton Beach, Albany*. John Kinnear & Associates Consulting Surveyors, DWG C604-B.

Kamphuis J. W., (2000) *Introduction to Coastal Engineering and Management.* Published by World Scientific Publishing Company.

PRWD (2013a) *Emu Point to Middleton Beach Coastal Adaptation and Protection Strategy.* Report prepared for the City of Albany, September 2013.

PRWD (2013b) *Emu Point to Middleton Beach Coastal Adaptation and Protection Strategy - Evaluation of Community Schemes*. Report prepared for the City of Albany, July 2013.

PRWD (2013c) *Emu Point to Middleton Beach Coastal Adaptation and Protection Strategy – Additional Studies and Data Collection: 2013 to 2015*. Report prepared for the City of Albany, September 2015.

Rogers MP (2003) *Emu Beach Management Strategy*. Report prepared for the City of Albany.

Rogers MP, Sanders BS & Hunt TS (2005) *Living on the Coast – But How Close is Safe?* Proceedings of the Coasts and Ports 2005 Conference, Adelaide, Australia.

Rogers MP (2015) *Middleton Beach Activity Centre Coastal Hazard Risk Management and Adaptation Plan*, MP Rogers and Associates, November 2015.

Sinclair Knight (1993) *Emu Point Coastal Protection Study*.

URS (2012a) *Stage A – Condition Assessment Report*. Report prepared for City or Albany.

URS (2012b) *Stage A – Coastal Processes Report*. Report prepared for City or Albany.

URS (2012c) *Stage A – Data Collection and Option Development*. Report prepared for City or Albany.

URS (2012d) *Stage B – Scheme Development*. Report prepared for City or Albany.

USACE (2006). *Coastal Engineering Manual*. Engineer Manual 1110-2-1100, U.S. Army

Corps of Engineers, Washington, D.C. (in 6 volumes).

WAPC (2013). *State Planning Policy No. 2.6 - State Coastal Planning Policy*. Western Australian

Planning Commission, Perth.

WAPC 2014. *Coastal hazard risk management and adaptation planning guidelines*. Western

Australian Planning Commission, Perth.

Maps

Summary:

Map 1 to Map 6 present the resulting coastal erosion hazard maps showing all required planning periods for the study area from Ellen Cove to the Oyster Harbour Boat Pens. **Maps 5A and 6A** present the *'with coastal protection structures'* scenario for the Emu Point area. **Maps 5B and 6B** present the *'without coastal protection structures'* scenario for the Emu Point area.

Map 7 to Map 12 present the resulting coastal inundation hazard maps showing all required planning periods for the study area from Ellen Cove to the Oyster Harbour Boat Pens.

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MAP 01

EMU POINT TO MIDDLETON BEACH COASTAL EROSION VULNERABILITY MAP

SCALE 1:4,000

PAGE SIZE A4

MAP 02

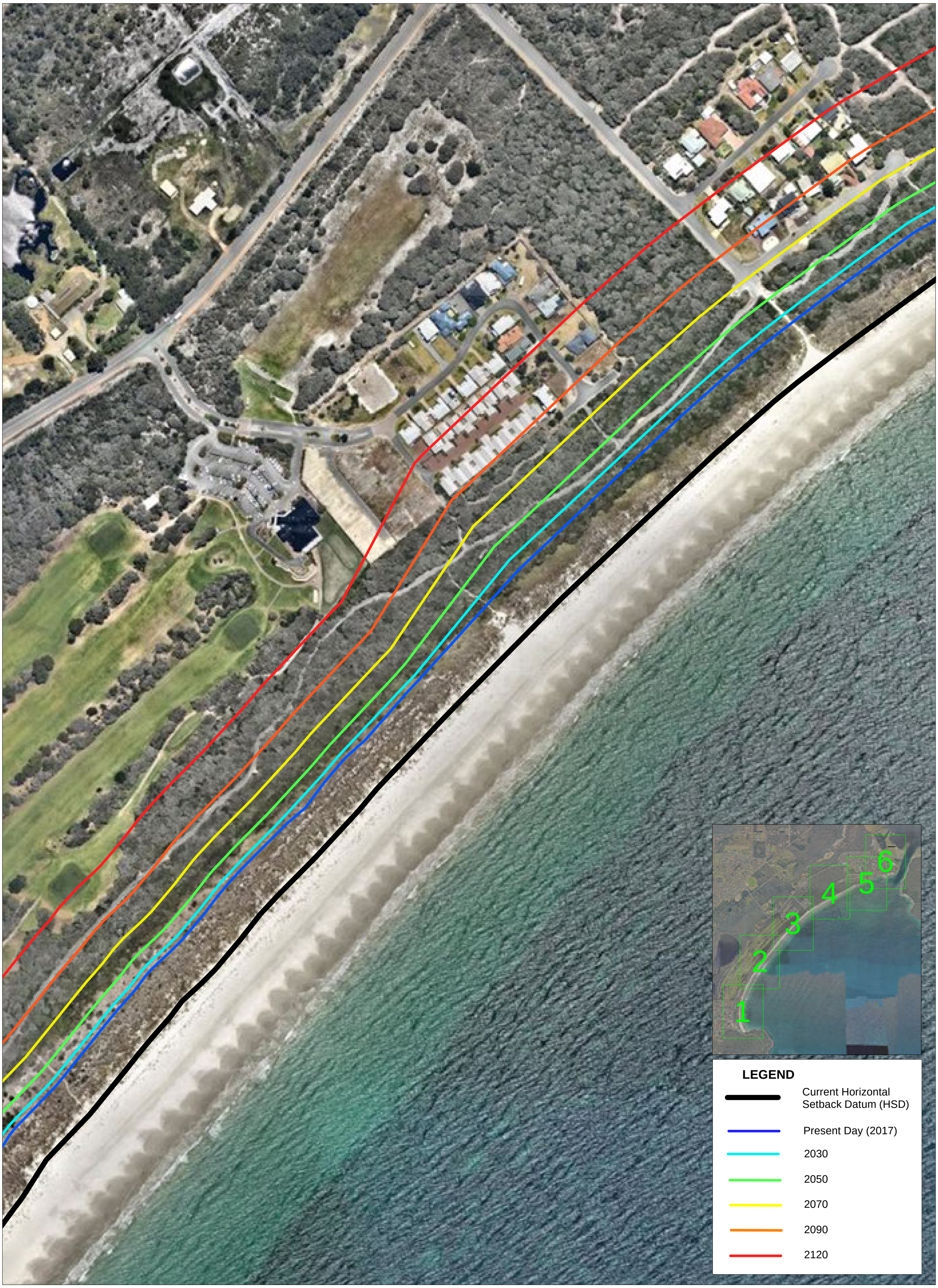
EMU POINT TO MIDDLETON BEACH
COASTAL EROSION VULNERABILITY MAP

NORTH

0 50 100m
Approx. Scale

SCALE 1:4,000

PAGE SIZE A4



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MAP 03

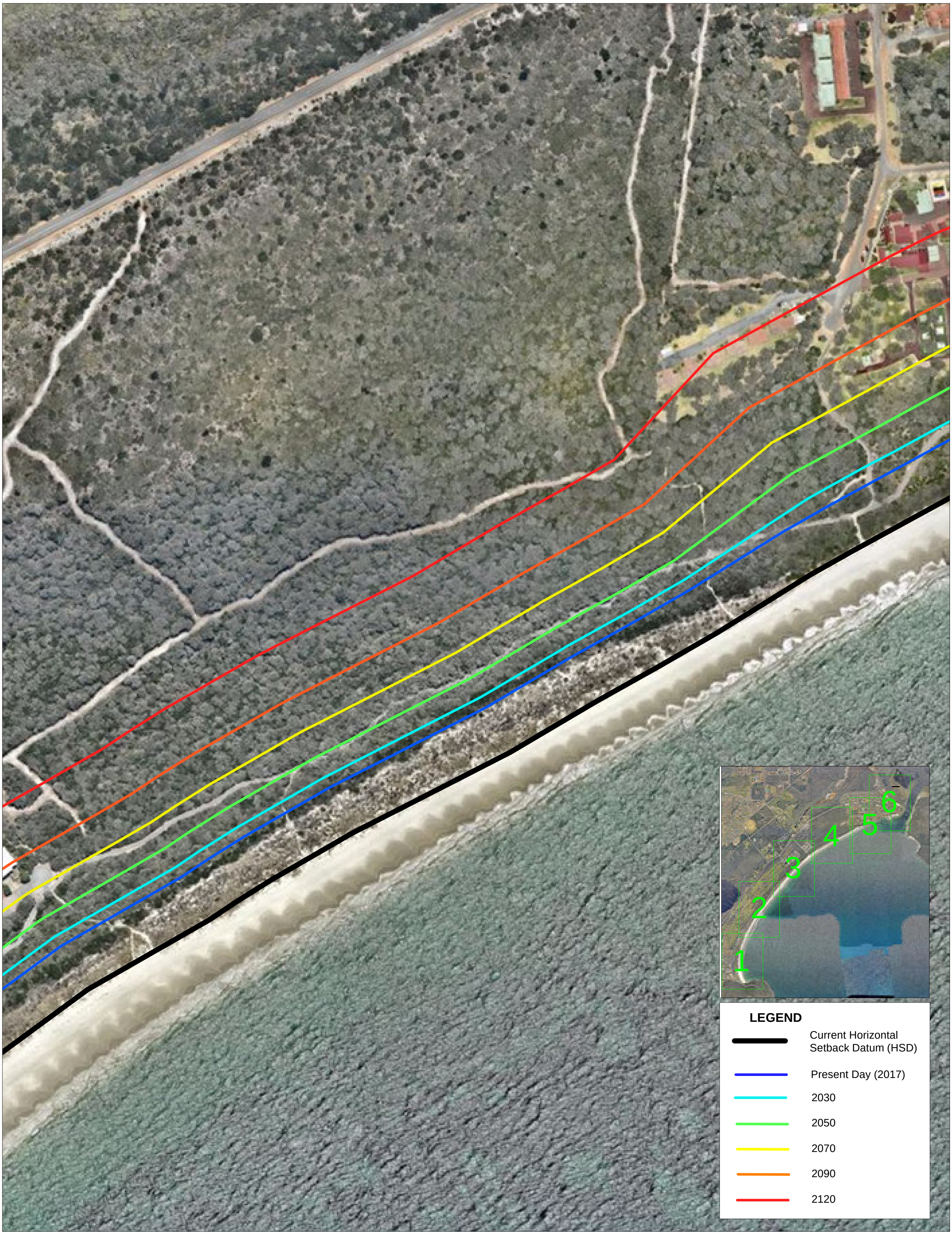
EMU POINT TO MIDDLETON BEACH
COASTAL EROSION VULNERABILITY MAP

NORTH

0 50 100m
Approx. Scale

SCALE 1:4,000

PAGE SIZE A4



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MAP 04

EMU POINT TO MIDDLETON BEACH
COASTAL EROSION VULNERABILITY MAP

NORTH

0 50 100m
Approx. Scale

SCALE 1:4,000

PAGE SIZE A4

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MAP 05

EMU POINT TO MIDDLETON BEACH
COASTAL EROSION VULNERABILITY MAP

NORTH

0 50 100m
Approx. Scale

SCALE 1:4,000

PAGE SIZE A4

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MAP 05B

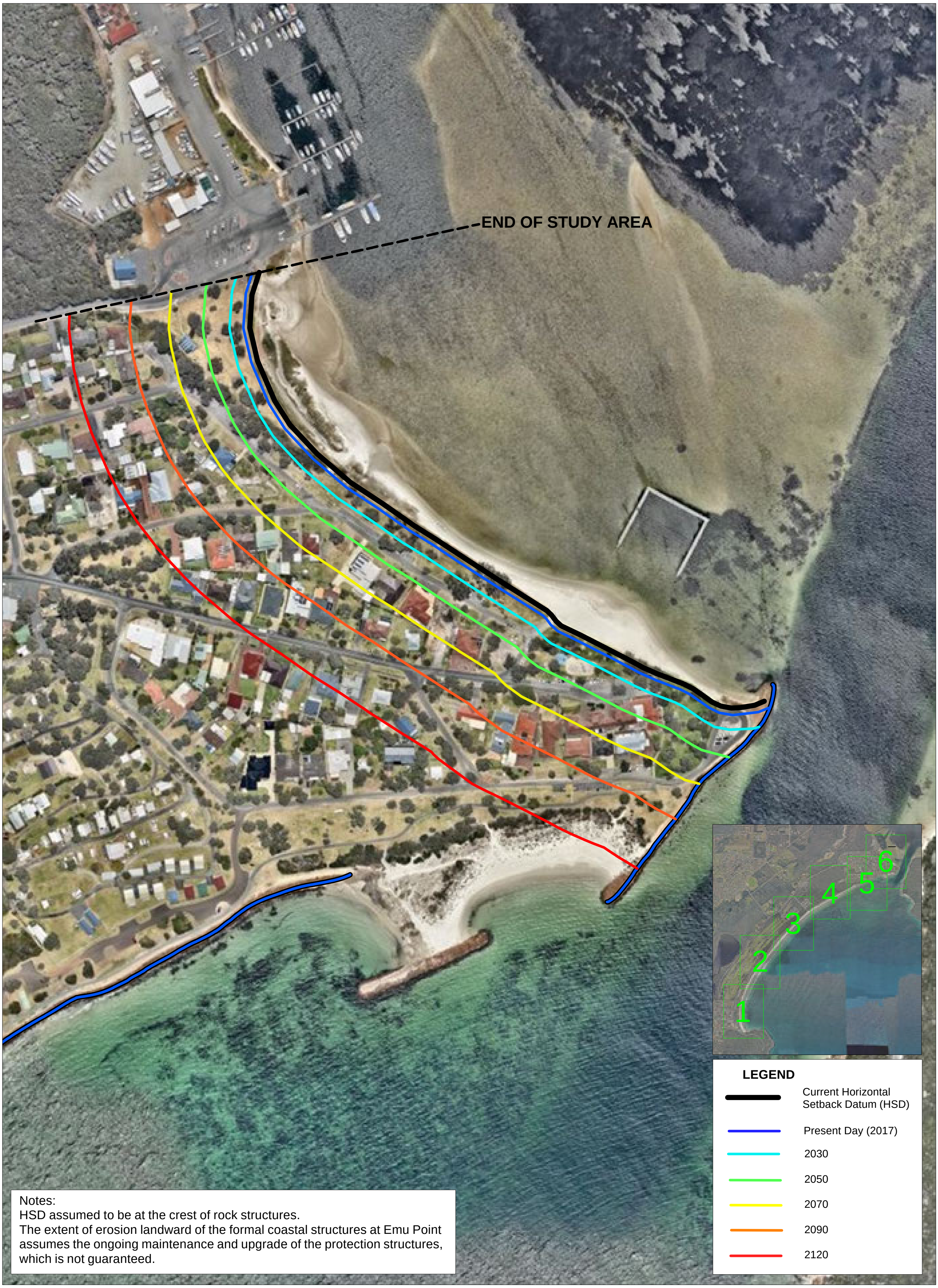
EMU POINT TO MIDDLETON BEACH
COASTAL EROSION VULNERABILITY MAP
(WITHOUT COASTAL PROTECTION STRUCTURES)

NORTH

0 50 100m
Approx. Scale

SCALE 1:4,000

PAGE SIZE A4



Notes:
HSD assumed to be at the crest of rock structures.
The extent of erosion landward of the formal coastal structures at Emu Point assumes the ongoing maintenance and upgrade of the protection structures, which is not guaranteed.

MAP 06A

EMU POINT TO OYSTER HARBOUR
COASTAL EROSION VULNERABILITY MAP
(WITH COASTAL PROTECTION STRUCTURES)

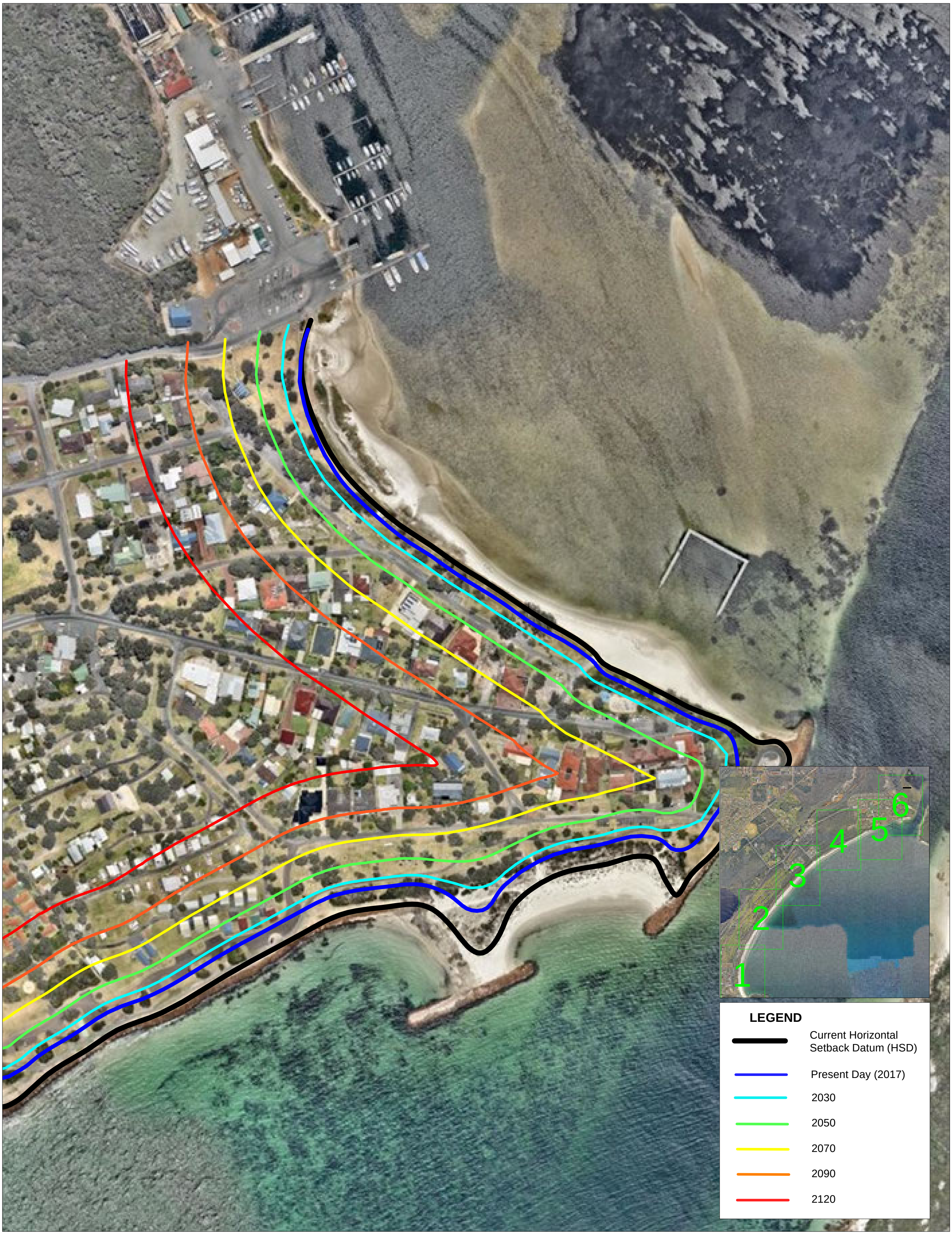
NORTH

0 50 100m
Approx. Scale

SCALE 1:4,000

PAGE SIZE A4

Disclaimer: While all reasonable care has been taken to ensure the information contained on this map is up to date and accurate, this map contains information from a number of sources - no warranty is given that the information contained on this map is free from error or omission. Any reliance placed on such information shall be the sole risk of the user. Please verify the accuracy of all information prior to using it. This map is not a design document.



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MAP 06B

EMU POINT TO MIDDLETON BEACH COASTAL EROSION VULNERABILITY MAP (WITHOUT COASTAL PROTECTION STRUCTURES)

NORTH

0 50 100m
Approx. Scale

SCALE 1:4,000

PAGE SIZE A4

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MAP 7

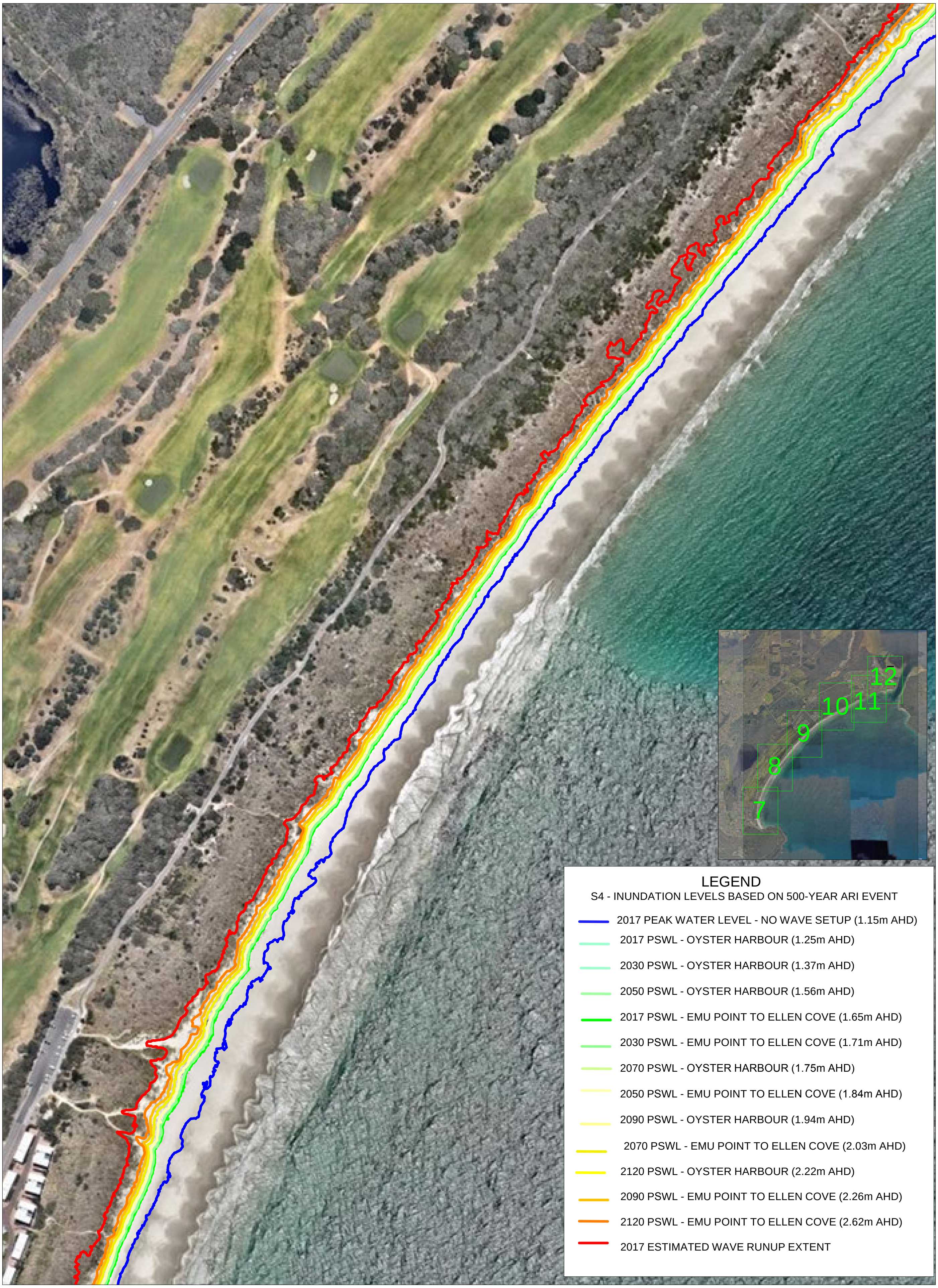
EMU POINT TO MIDDLETON BEACH COASTAL INUNDATION MAP

NORTH

0 50 100m
Approx. Scale

SCALE 1:4,000

PAGE SIZE A4



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MAP 8

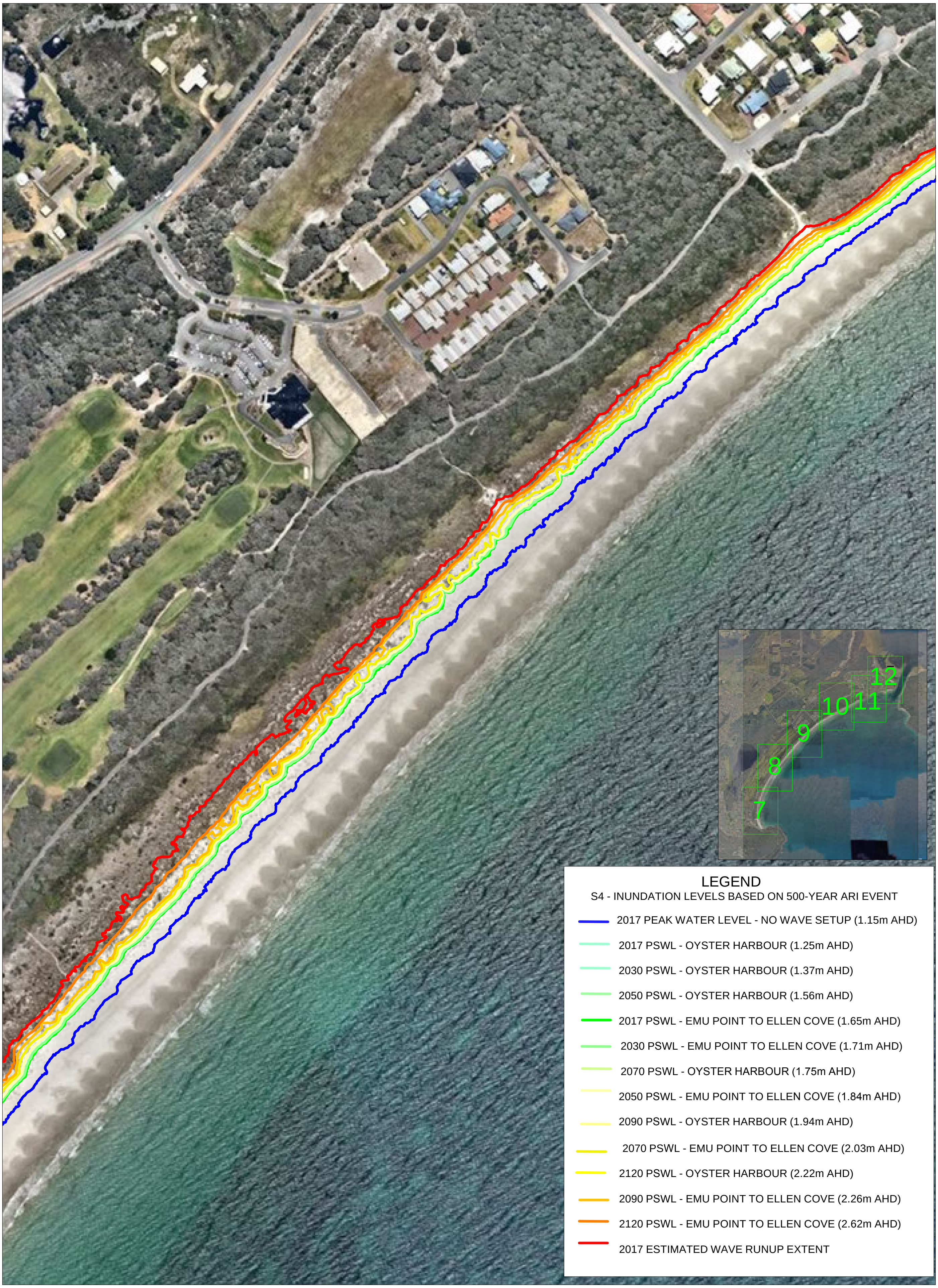
EMU POINT TO MIDDLETON BEACH COASTAL INUNDATION MAP

NORTH

0 50 100m
Approx. Scale

SCALE 1:4,000

PAGE SIZE A4



LEGEND

S4 - INUNDATION LEVELS BASED ON 500-YEAR ARI EVENT

- 2017 PEAK WATER LEVEL - NO WAVE SETUP (1.15m AHD)
- 2017 PSWL - OYSTER HARBOUR (1.25m AHD)
- 2030 PSWL - OYSTER HARBOUR (1.37m AHD)
- 2050 PSWL - OYSTER HARBOUR (1.56m AHD)
- 2017 PSWL - EMU POINT TO ELLEN COVE (1.65m AHD)
- 2030 PSWL - EMU POINT TO ELLEN COVE (1.71m AHD)
- 2070 PSWL - OYSTER HARBOUR (1.75m AHD)
- 2050 PSWL - EMU POINT TO ELLEN COVE (1.84m AHD)
- 2090 PSWL - OYSTER HARBOUR (1.94m AHD)
- 2070 PSWL - EMU POINT TO ELLEN COVE (2.03m AHD)
- 2120 PSWL - OYSTER HARBOUR (2.22m AHD)
- 2090 PSWL - EMU POINT TO ELLEN COVE (2.26m AHD)
- 2120 PSWL - EMU POINT TO ELLEN COVE (2.62m AHD)
- 2017 ESTIMATED WAVE RUNUP EXTENT

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MAP 9

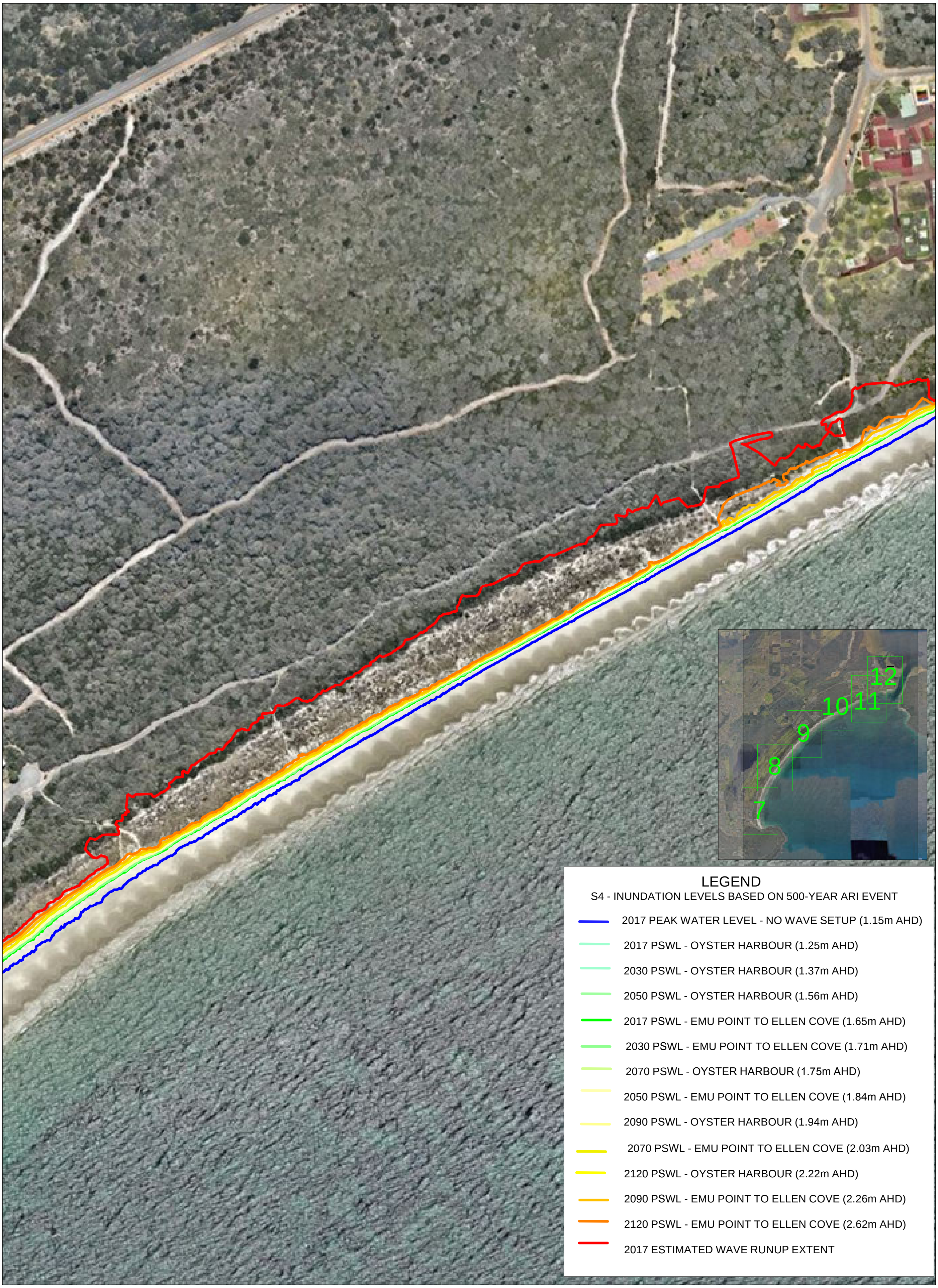
EMU POINT TO MIDDLETON BEACH COASTAL INUNDATION MAP

NORTH

0 50 100m
Approx. Scale

SCALE 1:4,000

PAGE SIZE A4



LEGEND

S4 - INUNDATION LEVELS BASED ON 500-YEAR ARI EVENT

2017 PEAK WATER LEVEL - NO WAVE SETUP (1.15m AHD)
2017 PSWL - OYSTER HARBOUR (1.25m AHD)
2030 PSWL - OYSTER HARBOUR (1.37m AHD)
2050 PSWL - OYSTER HARBOUR (1.56m AHD)
2017 PSWL - EMU POINT TO ELLEN COVE (1.65m AHD)
2030 PSWL - EMU POINT TO ELLEN COVE (1.71m AHD)
2070 PSWL - OYSTER HARBOUR (1.75m AHD)
2050 PSWL - EMU POINT TO ELLEN COVE (1.84m AHD)
2090 PSWL - OYSTER HARBOUR (1.94m AHD)
2070 PSWL - EMU POINT TO ELLEN COVE (2.03m AHD)
2120 PSWL - OYSTER HARBOUR (2.22m AHD)
2090 PSWL - EMU POINT TO ELLEN COVE (2.26m AHD)
2120 PSWL - EMU POINT TO ELLEN COVE (2.62m AHD)
2017 ESTIMATED WAVE RUNUP EXTENT

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MAP 10

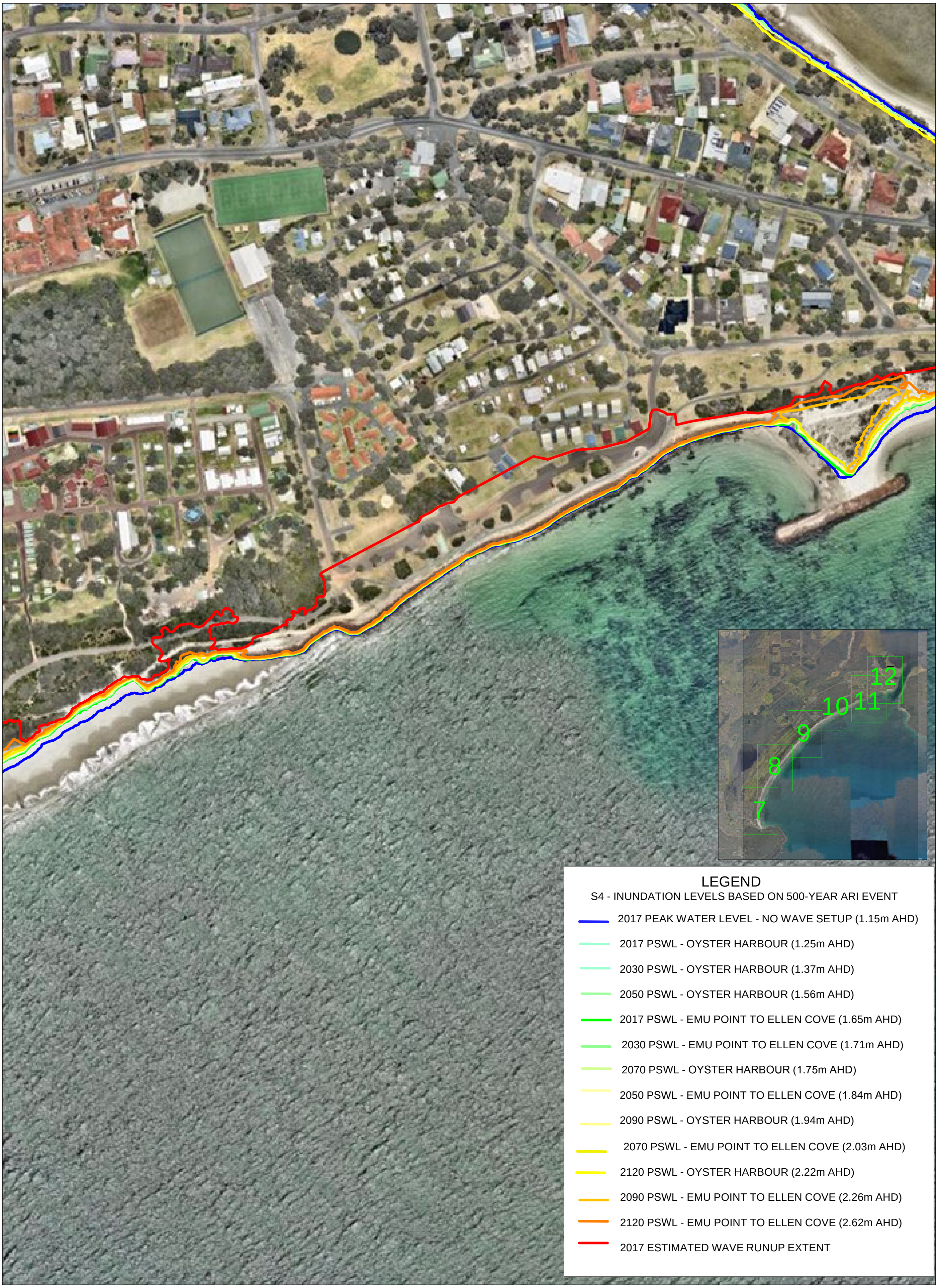
EMU POINT TO MIDDLETON BEACH
COASTAL INUNDATION MAP

NORTH

0 50 100m
Approx. Scale

SCALE 1:4,000

PAGE SIZE A4



LEGEND

S4 - INUNDATION LEVELS BASED ON 500-YEAR ARI EVENT

- 2017 PEAK WATER LEVEL - NO WAVE SETUP (1.15m AHD)
- 2017 PSWL - OYSTER HARBOUR (1.25m AHD)
- 2030 PSWL - OYSTER HARBOUR (1.37m AHD)
- 2050 PSWL - OYSTER HARBOUR (1.56m AHD)
- 2017 PSWL - EMU POINT TO ELLEN COVE (1.65m AHD)
- 2030 PSWL - EMU POINT TO ELLEN COVE (1.71m AHD)
- 2070 PSWL - OYSTER HARBOUR (1.75m AHD)
- 2050 PSWL - EMU POINT TO ELLEN COVE (1.84m AHD)
- 2090 PSWL - OYSTER HARBOUR (1.94m AHD)
- 2070 PSWL - EMU POINT TO ELLEN COVE (2.03m AHD)
- 2120 PSWL - OYSTER HARBOUR (2.22m AHD)
- 2090 PSWL - EMU POINT TO ELLEN COVE (2.26m AHD)
- 2120 PSWL - EMU POINT TO ELLEN COVE (2.62m AHD)
- 2017 ESTIMATED WAVE RUNUP EXTENT

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MAP 11

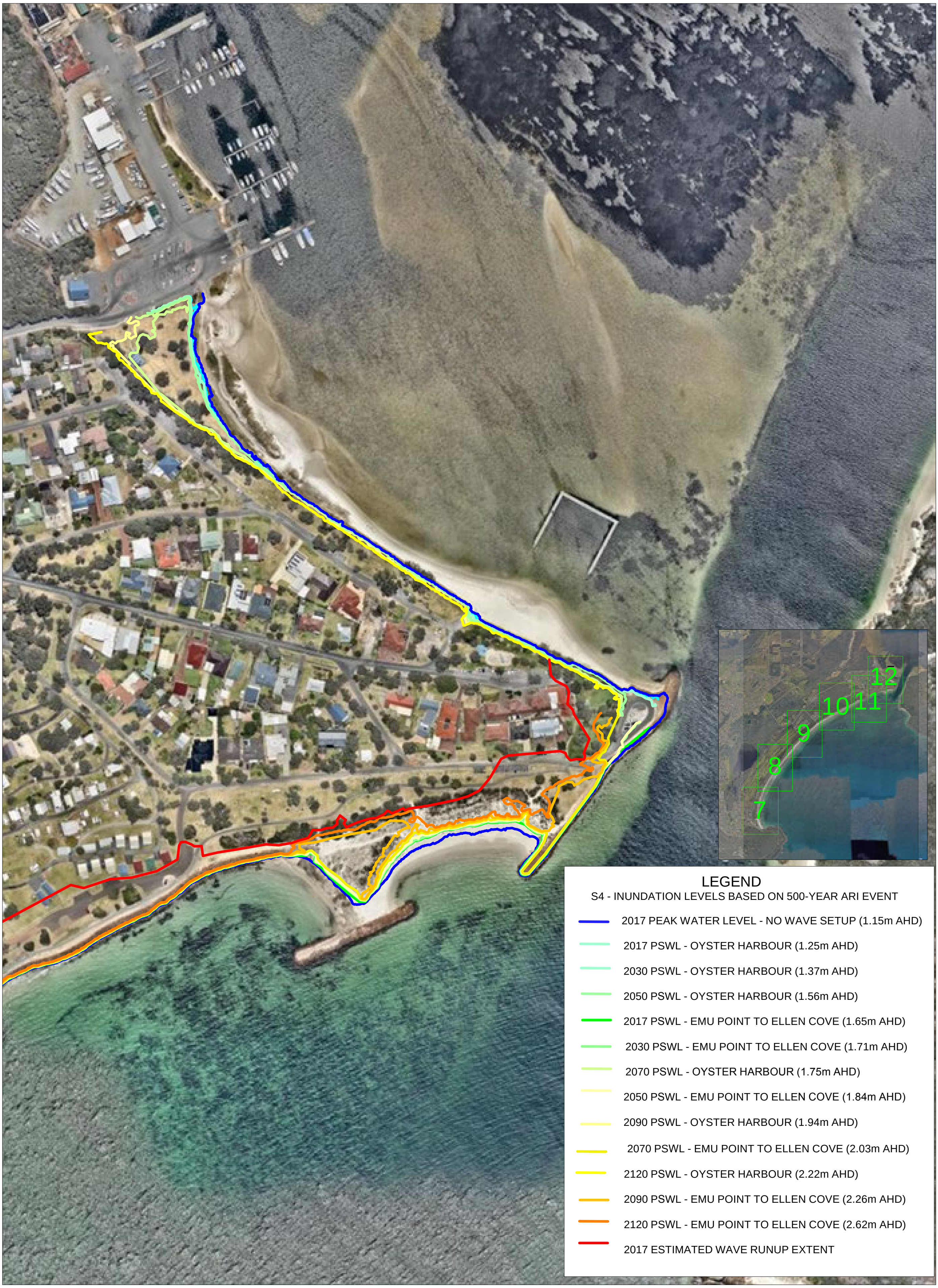
EMU POINT TO MIDDLETON BEACH COASTAL INUNDATION MAP

NORTH

0 50 100m
Approx. Scale

SCALE 1:4,000

PAGE SIZE A4



LEGEND

S4 - INUNDATION LEVELS BASED ON 500-YEAR ARI EVENT

- 2017 PEAK WATER LEVEL - NO WAVE SETUP (1.15m AHD)
- 2017 PSWL - OYSTER HARBOUR (1.25m AHD)
- 2030 PSWL - OYSTER HARBOUR (1.37m AHD)
- 2050 PSWL - OYSTER HARBOUR (1.56m AHD)
- 2017 PSWL - EMU POINT TO ELLEN COVE (1.65m AHD)
- 2030 PSWL - EMU POINT TO ELLEN COVE (1.71m AHD)
- 2070 PSWL - OYSTER HARBOUR (1.75m AHD)
- 2050 PSWL - EMU POINT TO ELLEN COVE (1.84m AHD)
- 2090 PSWL - OYSTER HARBOUR (1.94m AHD)
- 2070 PSWL - EMU POINT TO ELLEN COVE (2.03m AHD)
- 2120 PSWL - OYSTER HARBOUR (2.22m AHD)
- 2090 PSWL - EMU POINT TO ELLEN COVE (2.26m AHD)
- 2120 PSWL - EMU POINT TO ELLEN COVE (2.62m AHD)
- 2017 ESTIMATED WAVE RUNUP EXTENT

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MAP 12

EMU POINT TO MIDDLETON BEACH COASTAL INUNDATION MAP

NORTH

0 50 100m
Approx. Scale

SCALE 1:4,000

PAGE SIZE A4

Appendix A – Historical Photos

Figure A1-1a Photographs of erosion scarp (estimated to be approximately 4m in height) following August 1984 storm event. Also noted is the significant accumulation of seagrass wrack. (source: Briss family as reported in URS 2012)

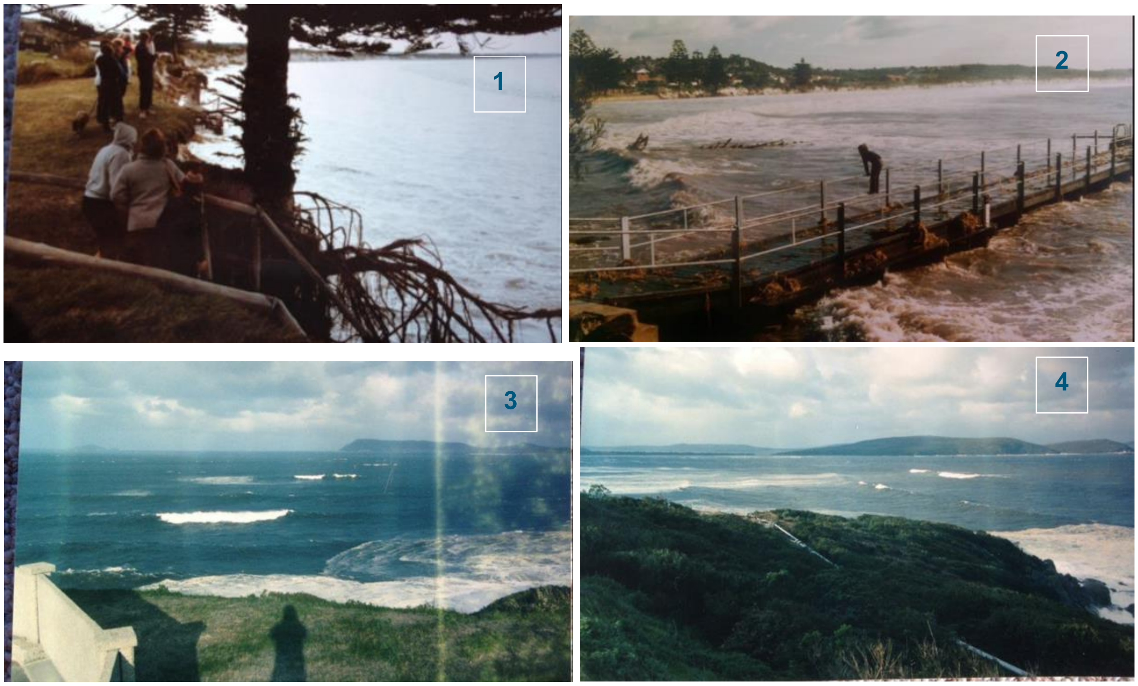


*Figure A1-1b Photographs taken during of 1984 storm **(1)** Ellen Cove, **(2)** Jetty; **(3)** from Woody head looking south, **(4)** from Woody Head looking towards Emu Point (showing Middleton Beach embayment). (source: Craig Marshall)*

Figure A1-2 Storm wave action in 1987 (source: DMH, 1992)

Figure A1-3 Photographs from 28th August 1992 showing the resulting erosion scarp after a storm event with the 10th largest nearshore waves in the 38-year wave hindcast (source: URS, 2012)

Figure A1-4 Photographs from 1995 showing erosion threatening houses along Emu Point (source: URS, 2015)

Figure A1-5 Photographs from 2012 showing the smaller erosion scarp (source: URS, 2012)

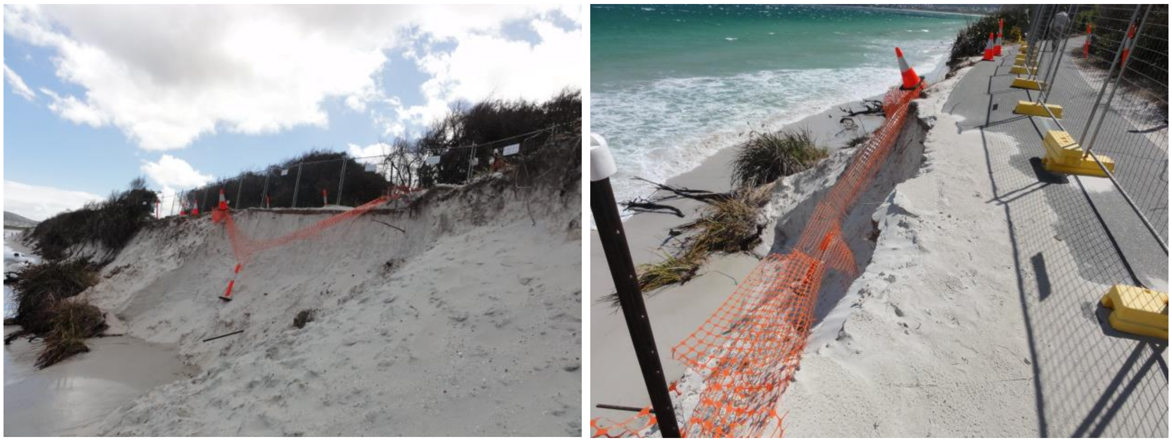


Figure A1-6 Photographs showing January 2012 erosion at the southern end of the geotextile seawall with erosion scarp and dual use path (both images are looking south) (Source: URS, 2012).

Figure A1-7 Photographs from April 2012 showing damage to the original 'brick wall' seawall at Oyster Harbour Beach (Source: URS, 2012).

Appendix B – Analysis of Morphological Data

B-1 Analysis of Shoreline Position

DoT (2012) determined a history of shoreline movements (inferred from the movement of the vegetation line) for Middleton Beach and Emu Point Beach using available aerial photography spanning the period from 1943 to 2011. **Figure B1-1** presents two images extracted from the DoT drawings, one for the western side of Emu Point and the other for central Middleton Beach. The accuracy of the position of these vegetation lines is believed to be in the order of plus/minus 5m, depending on the resolution of the aerial photographs and the rectification process.

Using the vegetation lines, MP Rogers (2015) determined the relative changes in the position of the shoreline at 100 to 200 m intervals across Middleton Beach up until 2014. **Figure B1-2** shows the beach chainages used in this assessment. The shoreline movements, relative to 1943, are presented in **Figure B1-2**. In this figure it is noted that the western most section of Middleton Beach is denoted as òManaged Section of Beachô This is in reference to the beach management activities undertaken by CoA for the section of beach in front of the seawall at Ellen Cove. Beach management practices in this area include removal of seagrass wrack and other vegetation as well as re-profiling and sand extraction (10,000m^3 in May 2014 for use as nourishment sand at Emu Point).

Figure B1-1 Analysis of aerial photography using vegetation lines to identify areas of erosion and accreation (source: DoT, 2012)

Figure B1-2 Chainage of shorenormal profiles used in interpretation of aerial photographs (source MP Rodger, 2015)

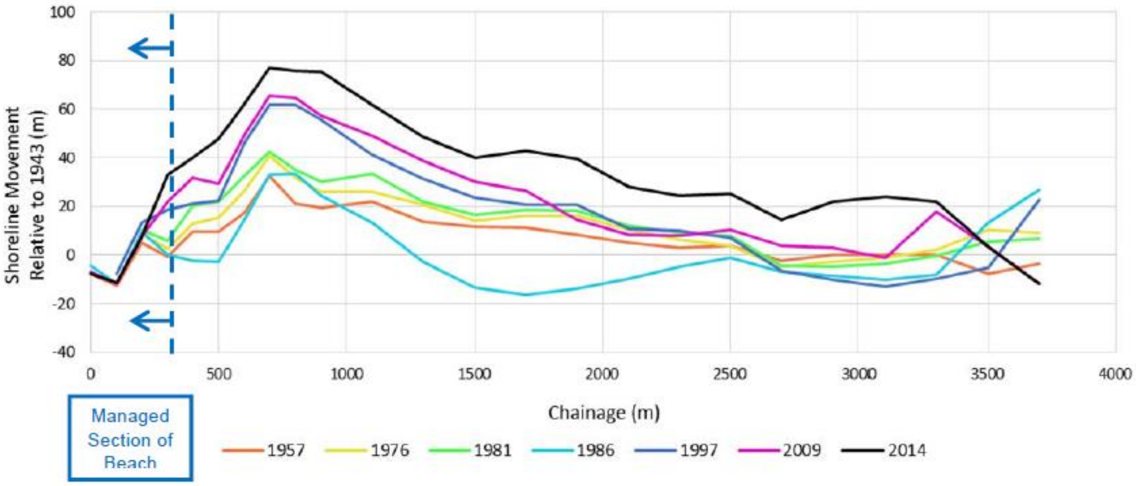


Figure B1-3 Shoreline movement relative to 1943 (+ive is a seaward movement (i.e. accretion), -ive is landward (i.e. erosion))

B-2 Hydrographic Surveys

As noted in **Section 3.3.3** there were 11 hydrographic surveys of the study area available for this study. Examples of the extents and depths in these surveys can be seen in **Figure B2-1**. The inshore area near Emu Point was covered by all of the 11 surveys, while only four of the surveys covered Middleton Beach to Ellen Cove (1976, 2011, 2014 and 2016), and only two (1976 and 1987) captured the deeper bathymetry of King George Sound.

These hydrographic surveys have been collected by a range of difference techniques (both single beam and multi-beam echo sounders) and range in either vertical accuracy. The accuracy of the older surveys was originally put into question due to data gaps and relative inaccuracy of survey technology available at the time. However, the trends observed during volumetric and cross sectional analyses suggest a high level of consistency between the datasets. This further supported by the fact that the observations from survey comparisons are consistent with the erosion observed on Emu Beach during this period. As such the surveys are considered fit for purpose.

All depths are presented relative to Lowest Astronomical Tide (LAT).

Volumetric Analysis

Changes in bathymetry between the various surveys were estimated using MapInfo Pro terrain modelling software. Areas of interest were identified where significant or consistent accretion or erosion had occurred, then the average change in seabed level and volume was analysed over the period of available surveys.

In all cases the extent of each area of interest was restricted to locations covered by multiple surveys, with the primary focus placed on areas with consistent, reliable survey data where obvious morphological change had occurred. The most significant area of interest was the Lockyer Shoal Area, which is defined as the inshore area southwest of Emu Point, delimited by the greater coverage extent of the 1976, 1987 and 2016 survey datasets. Within this area lie two other areas of interest referred to here as *Lockyer Shoal Survey Extent* and *Inner Shoal Area*. These areas are covered by all of the data sets except 1994, making them more suitable for a time series analysis of morphological change. As such it must be noted that the values calculated are not total volumes for morphological change over Lockyer Shoal, but rather representative values based on areas for which survey data is available.

Figure B2-1 below illustrates the extent and definition of these areas, with the difference in average depth and corresponding change in volume for each area tabulated in **Table B2-1** below.

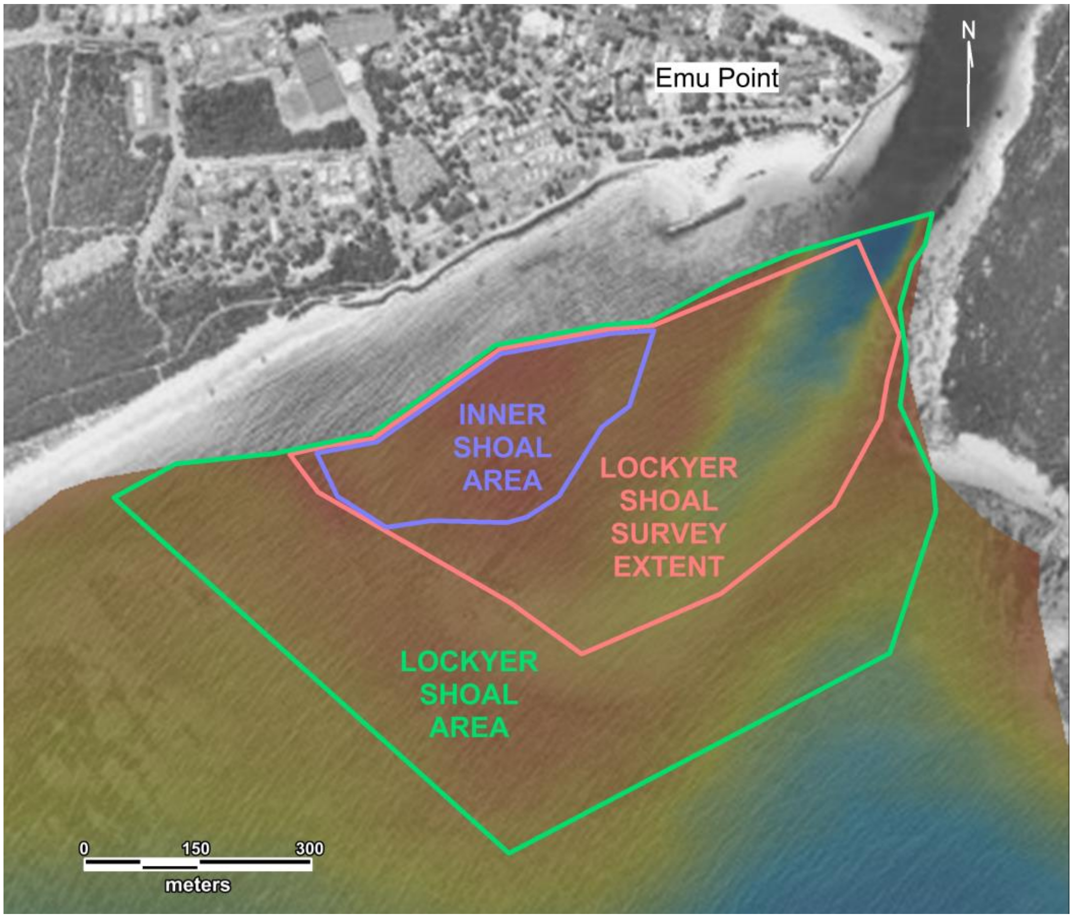


Figure B2-1 Control areas used in volumetric analysis

Table B2-1 Volumetric analysis of the Lockyer Shoal Area

Area/Parameter		1976-1987	1987-1999	1999-2016	1976-2016
Lockyer Shoal Area (492,500m^2)	Change in Avg. Depth	+0.20 m	-	-	-1.12 m
	Change in Volume	+99,000m^3	-	-	-550,000 m^3
Lockyer Shoal Survey Extent (231,100m^2)	Change in Avg. Depth	+0.43 m	-0.40m	-1.18m	-1.16m
	Change in Volume	+99,500 m^3	-93,000 m^3	-273,000 m^3	-267,000 m^3
Inner Shoal Area (63,500m^2)	Change in Avg. Depth	+0.71 m	-0.56m	-1.73m	-1.6m
	Change in Volume	+45,500 m^3	-35,000 m^3	-109,500 m^3	-99,500 m^3

Lockyer Shoal Area

A net erosion of approximately 550,000m^3 was observed over the Lockyer Shoal Area in the 40 year period between 1976 and 2016. This occurred as an increase in volume of ~100,000m^3 between 1976 and 1987, followed by a decrease of nearly 650,000m^3 between 1987 and 2016.

Lockyer Shoal Survey Extent

A net cut of approximately 267,000m^3 was observed for the *Lockyer Shoal Survey Extent* between 1976 and 2016, with an increase in volume similar to the larger Lockyer Shoal Area (~100,000 m^3) between 1976 and 1987, followed by a relatively stable period from 1989 to 1999. A significant decrease in volume (~370,000 m^3) occurred between 1999 and 2006, which was then followed by another period of stabilization from 2006 to 2016.

Inner Shoal Area

A similar but somewhat amplified trend was observed for the *Inner Shoal Area* (see **Figure B2-2**), with a greater relative increase and decrease in average volume for the periods from 1976 to 1987 and from 1998 to 2016, respectively. The periods of stabilization for this area also followed the *Lockyer Shoal Survey Extent* trend with the only significant difference being a reduction in relative volume between 1993 and 1999, which was expected as the adjacent Emu Beach experienced significant erosion during this period.

Figure B2-2 below illustrates the morphological changes of the *Lockyer Shoal Survey Extent* and *Inner Shoal Areas* over time.

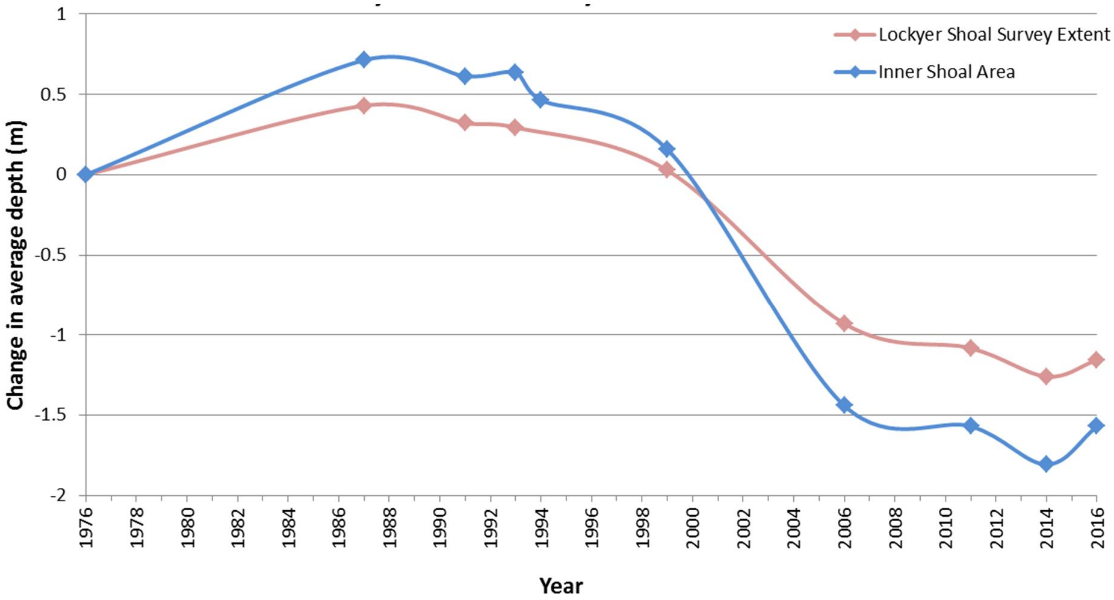


Figure B2-2 Change in average depth over time - Lockyer Shoal Survey Extent vs Inner Shoal Area

It is quite clear that a significant decrease in volume/seabed level occurred over the Lockyer Shoal Area, with a significant proportion of the volume coming from the *Inner Shoal Area*. In order to further analyse these morphological changes, a cross sectional analysis of the Lockyer Shoal Area was conducted.

Figure B2-3 shows the location of two cross sections that best illustrate the migration of Lockyer Shoal (óJ-shaped barô), with the 1976-2016 Isopach (depth difference map) layered into the image to highlight areas of net accretion (red) and erosion (blue).

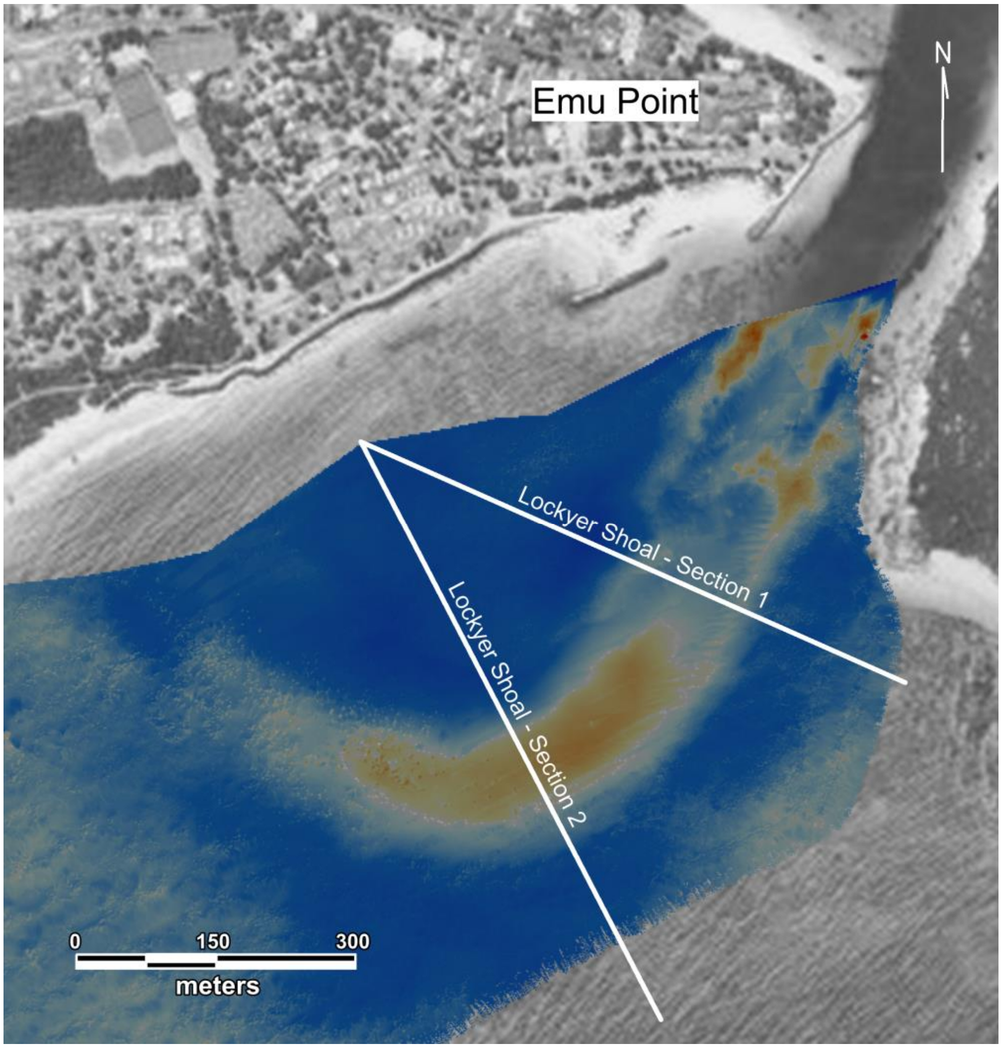


Figure B2-3 Lockyer Shoal volumetric analysis cross sections

Cross sectional plots were developed for all relevant data sets to best compare changes in volume and track the location of Lockyer Shoal (J-shaped bar) over time (see **Figure B2-4** and **Figure B2-5** below).

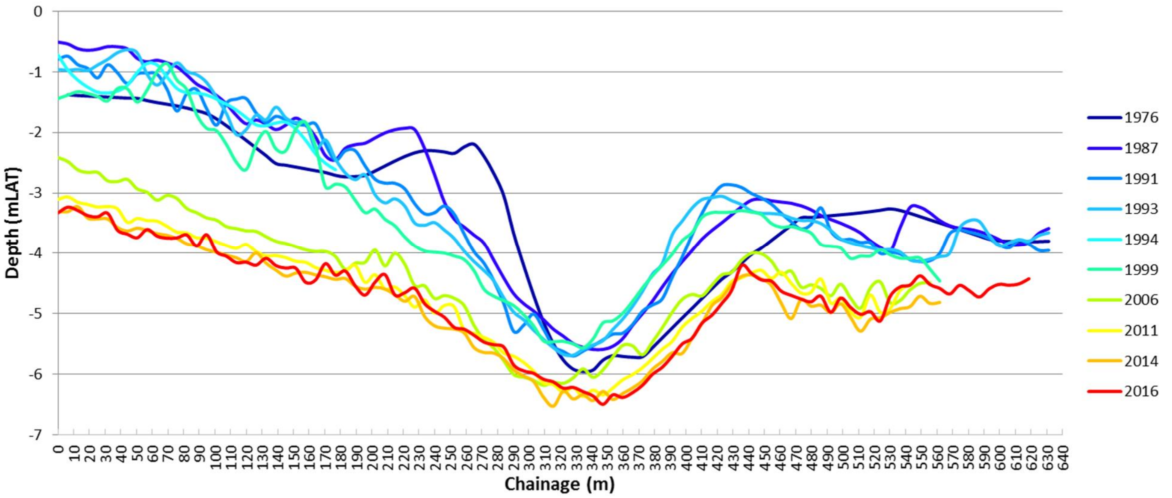


Figure B2-4 Lockyer Shoal - Section 1

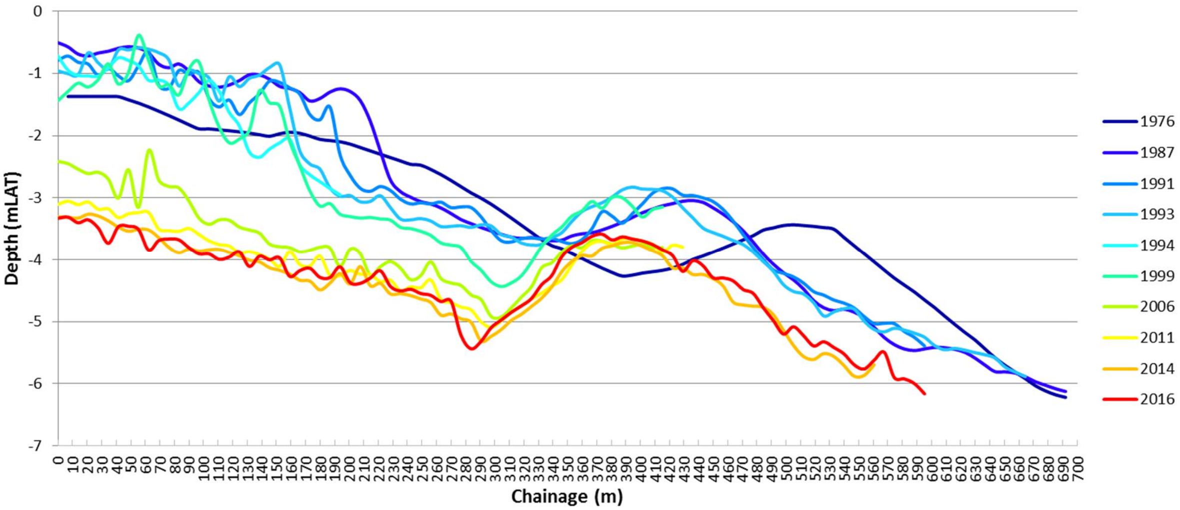


Figure B2-5 Lockyer Shoal - Section 2

The plots of these cross sections highlight the bulk loss of sediment from the Inner Shoal Area and demonstrate the evolution of two key features of the area; the outer Lockyer Shoal (J-shaped bar) and channel.

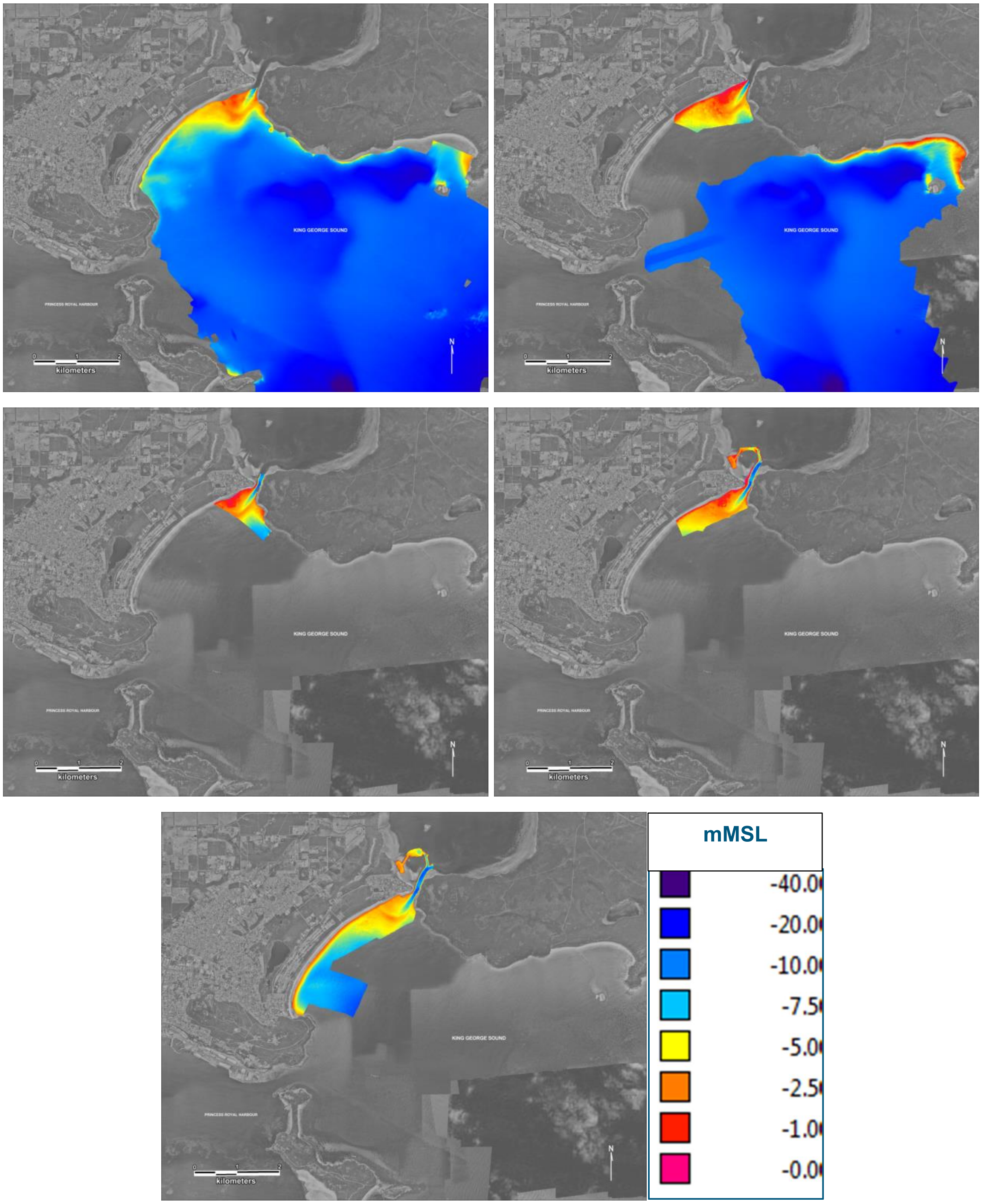
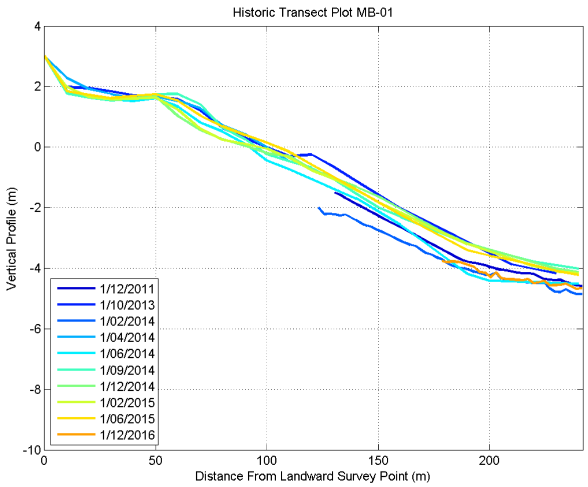
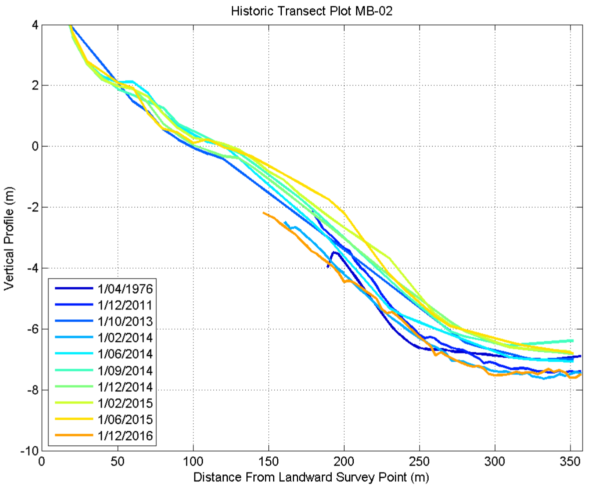


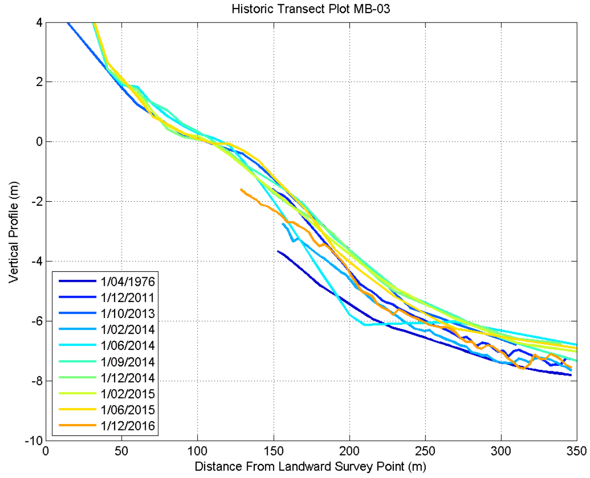
Figure B2-6 Example hydrographic survey extents and depths (top left: April 1976; top right: 1986; middle left: 1993; middle right: 1999; bottom: 2016)

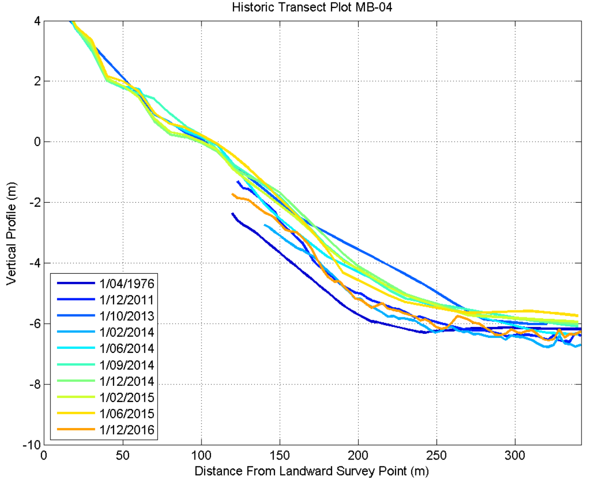
B-3 Morphological Change by Compartment

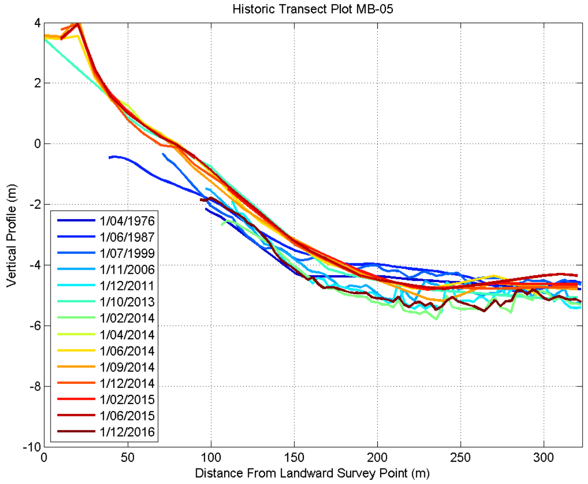
All beach transect plots are presented below.

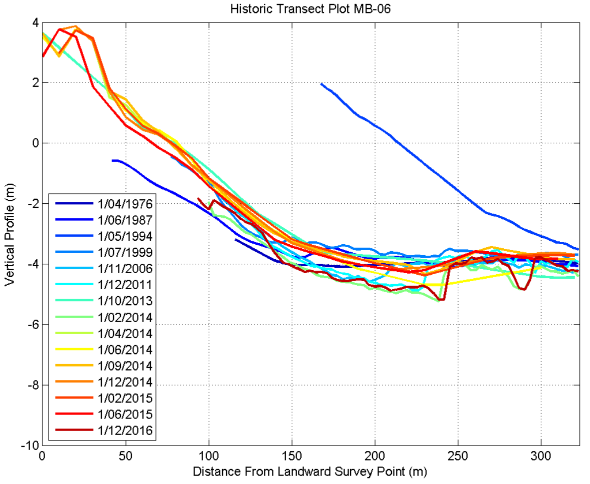


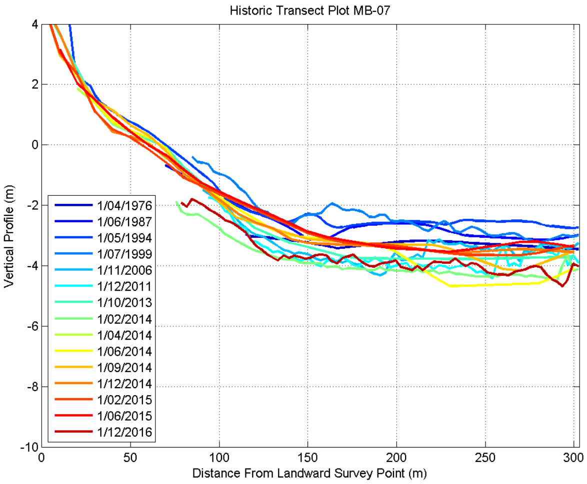


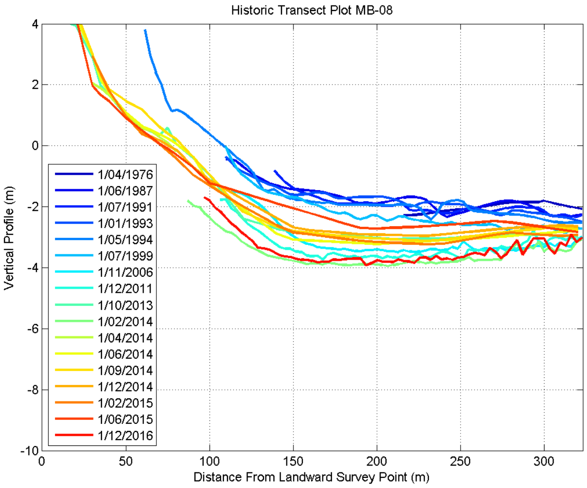


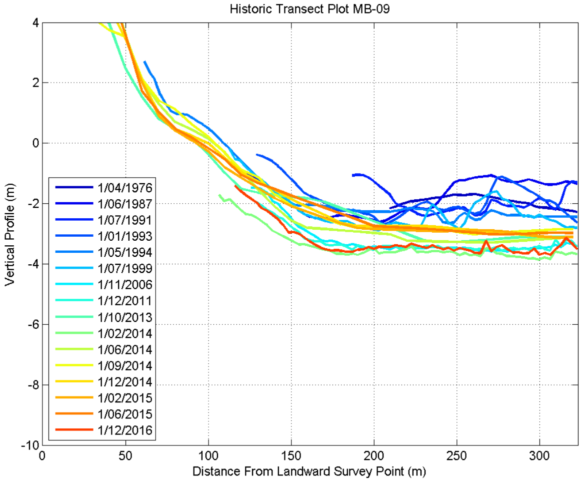


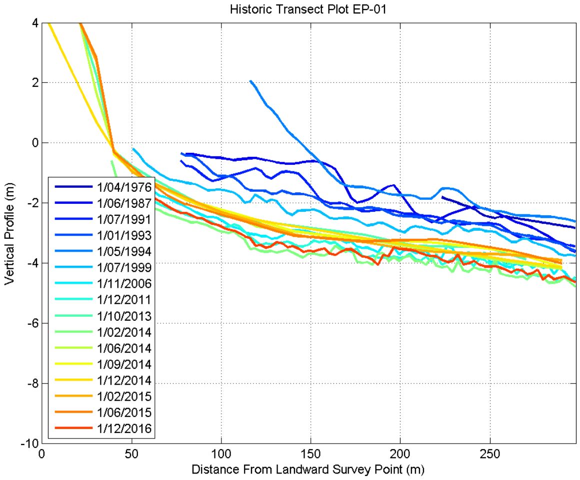


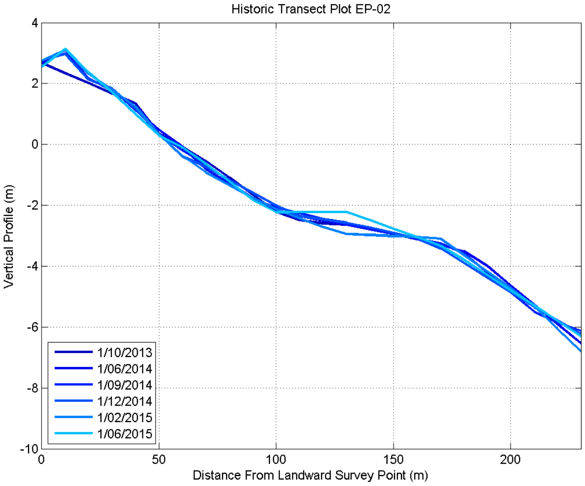


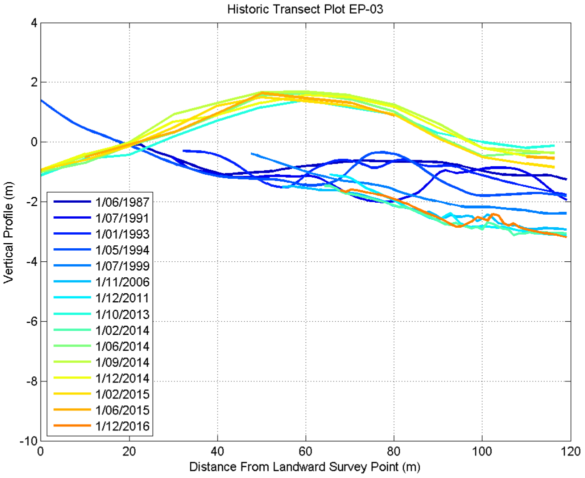

Historic Transect Plot MB-07


Historic Transect Plot MB-08


Historic Transect Plot MB-09


Historic Transect Plot EP-01


Historic Transect Plot EP-02


Historic Transect Plot EP-03

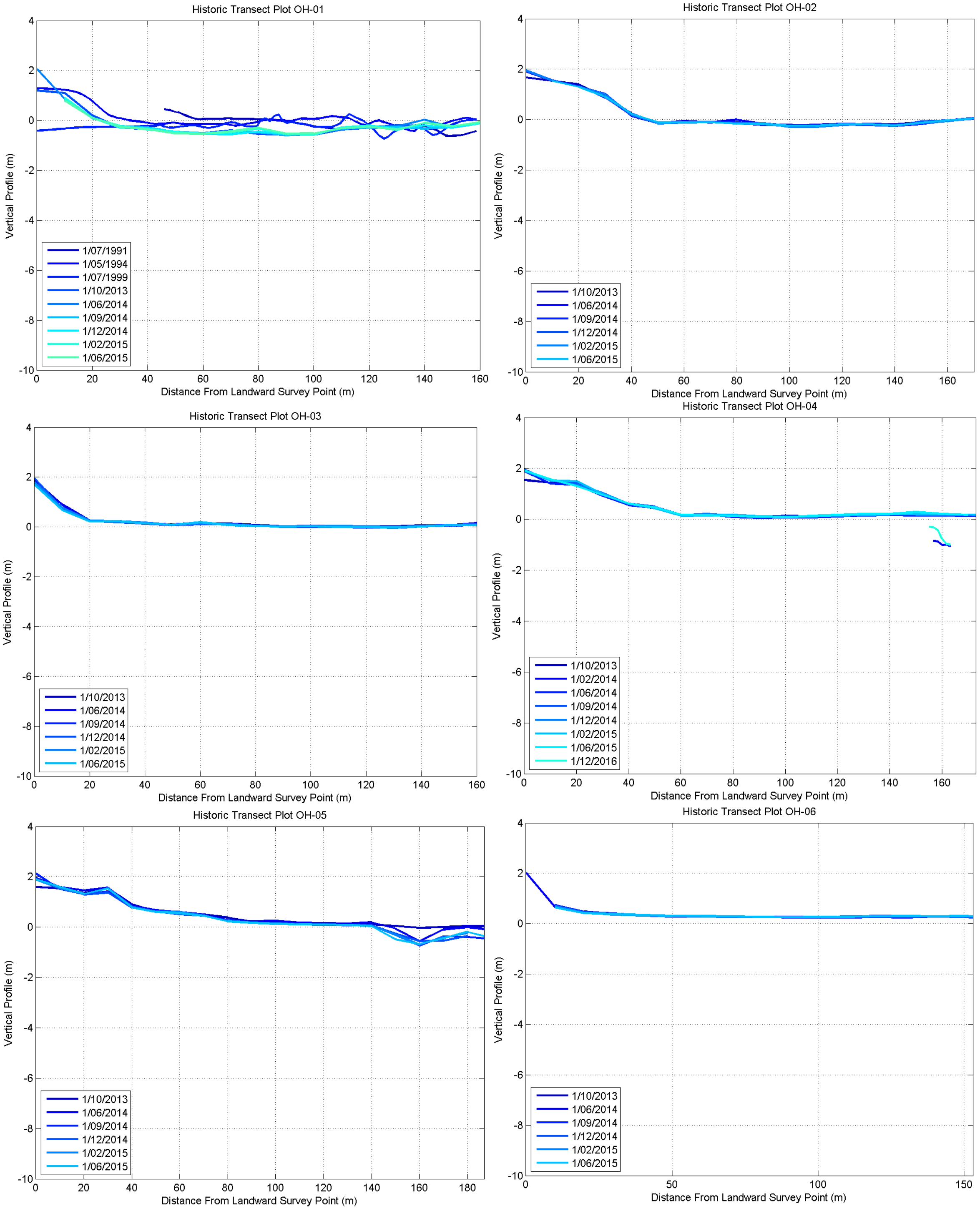


Figure A3-1. Historic bathymetric cross-section analysis

Appendix C – Metocean Analysis

C-1 Seasonal Wind analysis

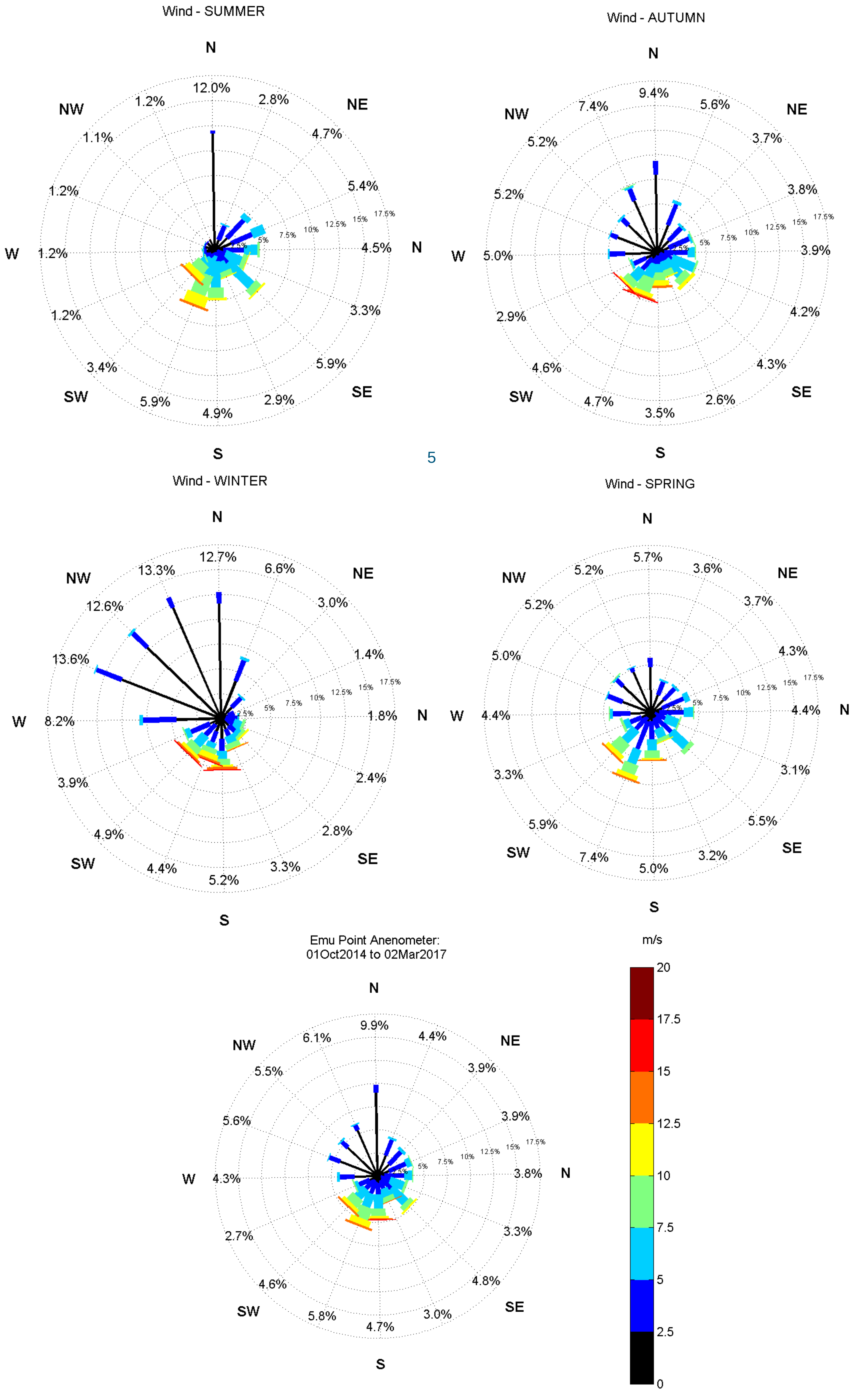
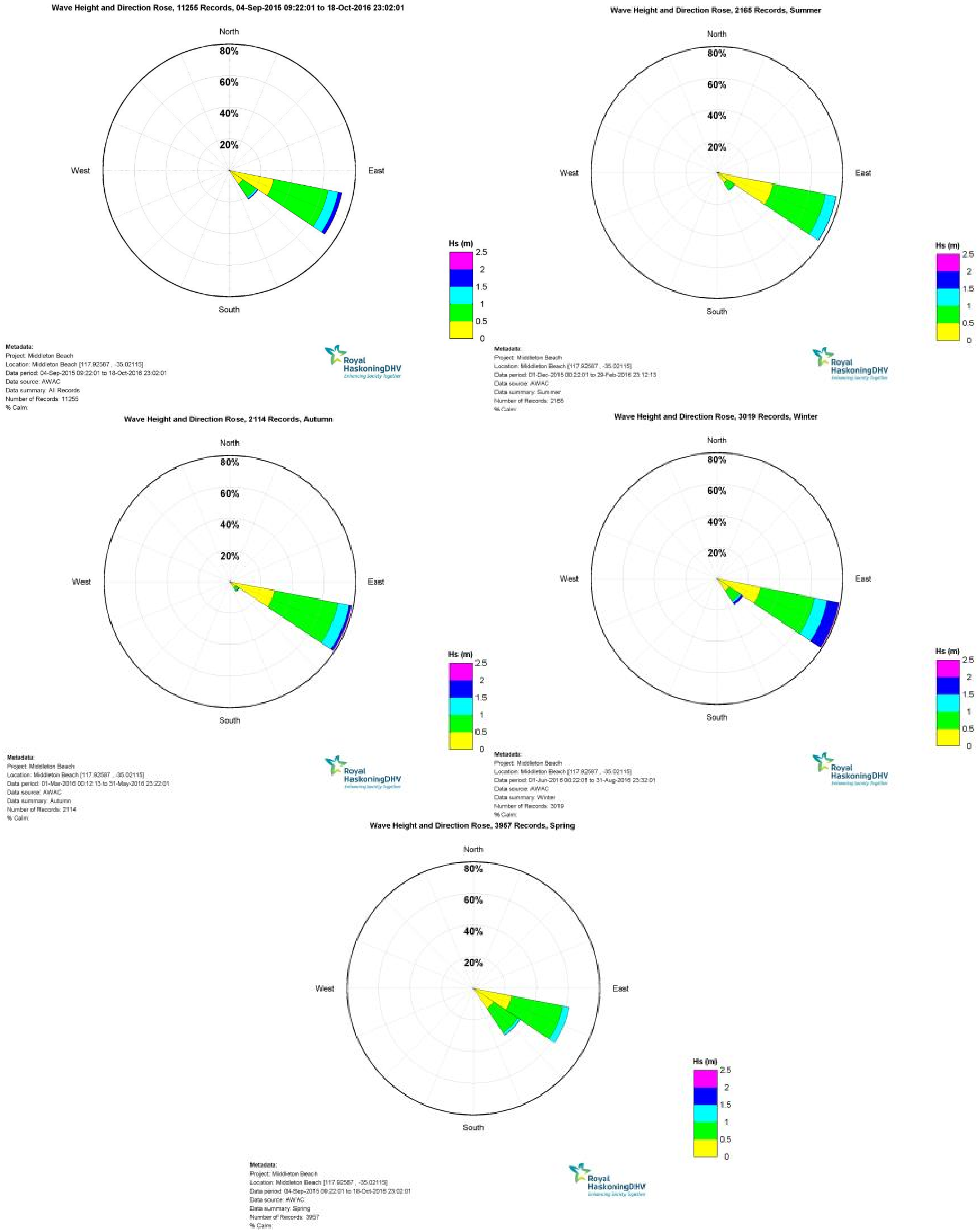


Figure C1-1 Total and seasonal wind roses based upon a 2.5year dataset recorded at the Emu Point anemometer from 01/10/2014 to 02/03/2017; Summer: Dec-Feb, Autumn: Mar-May, Winter: Jun-Aug, Spring: Sep-Nov.

C-2 AWAC Wave Analysis

RHDHV:



Metadata:
Project: Middleton Beach
Location: Middleton Beach [117.92587 , -35.02115]
Data period: 04-Sep-2015 09:22:01 to 18-Oct-2016 23:02:01
Data source: AWAC
Data summary: All Records
Number of Records: 11255
% Calm:

Metadata:
Project: Middleton Beach
Location: Middleton Beach [117.92587 , -35.02115]
Data period: 01-Dec-2015 00:22:01 to 29-Feb-2016 23:12:13
Data source: AWAC
Data summary: Summer
Number of Records: 2165
% Calm:

Metadata:
Project: Middleton Beach
Location: Middleton Beach [117.92587 , -35.02115]
Data period: 01-Mar-2016 00:12:13 to 31-May-2016 23:22:01
Data source: AWAC
Data summary: Autumn
Number of Records: 2114
% Calm:

Metadata:
Project: Middleton Beach
Location: Middleton Beach [117.92587 , -35.02115]
Data period: 01-Jun-2016 00:22:01 to 31-Aug-2016 23:32:01
Data source: AWAC
Data summary: Winter
Number of Records: 3019
% Calm:

Metadata:
Project: Middleton Beach
Location: Middleton Beach [117.92587 , -35.02115]
Data period: 04-Sep-2015 09:22:01 to 18-Oct-2016 23:02:01
Data source: AWAC
Data summary: Spring
Number of Records: 3967
% Calm:

Figure C2-1 Long Term Average (LTA) and seasonal wave roses from the RHDHV AWAC deployment in 7m water off Middleton Beach from September 2015 to October 2016.

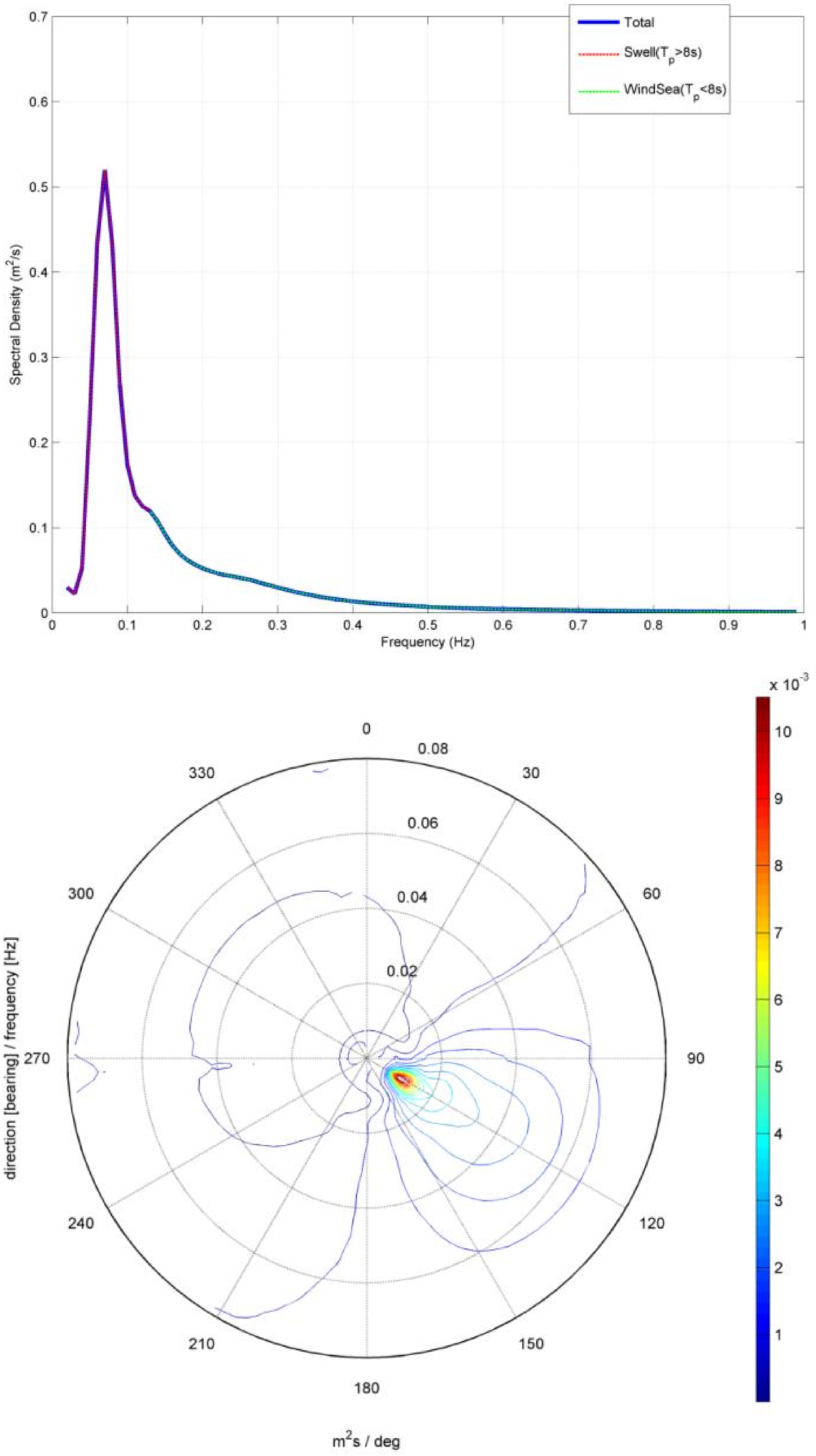
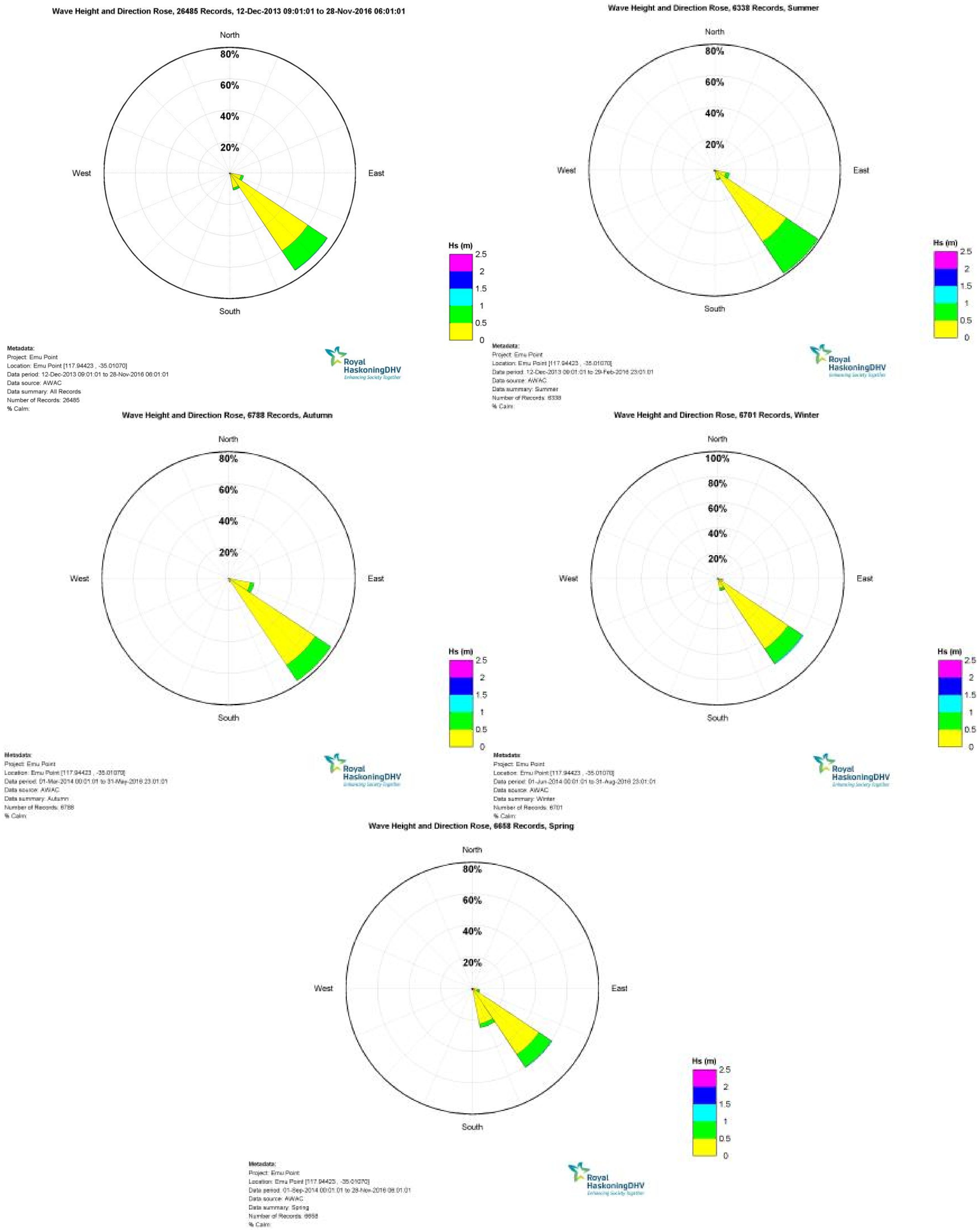


Figure C2-2 1D and 2D spectral analysis of the RHDHV AWAC deployment in 7m water off Middleton Beach from September 2015 to October 2016.

DoT


Wave Height and Direction Rose, 26485 Records, 12-Dec-2013 09:01:01 to 28-Nov-2016 06:01:01

Metadata:
Project: Emu Point
Location: Emu Point [117.94423 , -35.01070]
Data period: 12-Dec-2013 09:01:01 to 28-Nov-2016 06:01:01
Data source: AWAC
Data summary: All Records
Number of Records: 26485
% Calm:

Wave Height and Direction Rose, 6338 Records, Summer

Metadata:
Project: Emu Point
Location: Emu Point [117.94423 , -35.01070]
Data period: 12-Dec-2013 09:01:01 to 29-Feb-2016 23:01:01
Data source: AWAC
Data summary: Summer
Number of Records: 6338
% Calm:

Wave Height and Direction Rose, 6788 Records, Autumn

Metadata:
Project: Emu Point
Location: Emu Point [117.94423 , -35.01070]
Data period: 01-Mar-2014 00:01:01 to 31-May-2016 23:01:01
Data source: AWAC
Data summary: Autumn
Number of Records: 6788
% Calm:

Wave Height and Direction Rose, 6701 Records, Winter

Metadata:
Project: Emu Point
Location: Emu Point [117.94423 , -35.01070]
Data period: 01-Jun-2014 00:01:01 to 31-Aug-2016 23:01:01
Data source: AWAC
Data summary: Winter
Number of Records: 6701
% Calm:

Wave Height and Direction Rose, 6658 Records, Spring

Metadata:
Project: Emu Point
Location: Emu Point [117.94423 , -35.01070]
Data period: 01-Sep-2014 00:01:01 to 28-Nov-2016 06:01:01
Data source: AWAC
Data summary: Spring
Number of Records: 6658
% Calm:

Figure C2-3 Long Term Average (LTA) and seasonal wave roses from the DoT AWAC deployment in 7m water off Emu Point from December 2013 to November 2016.

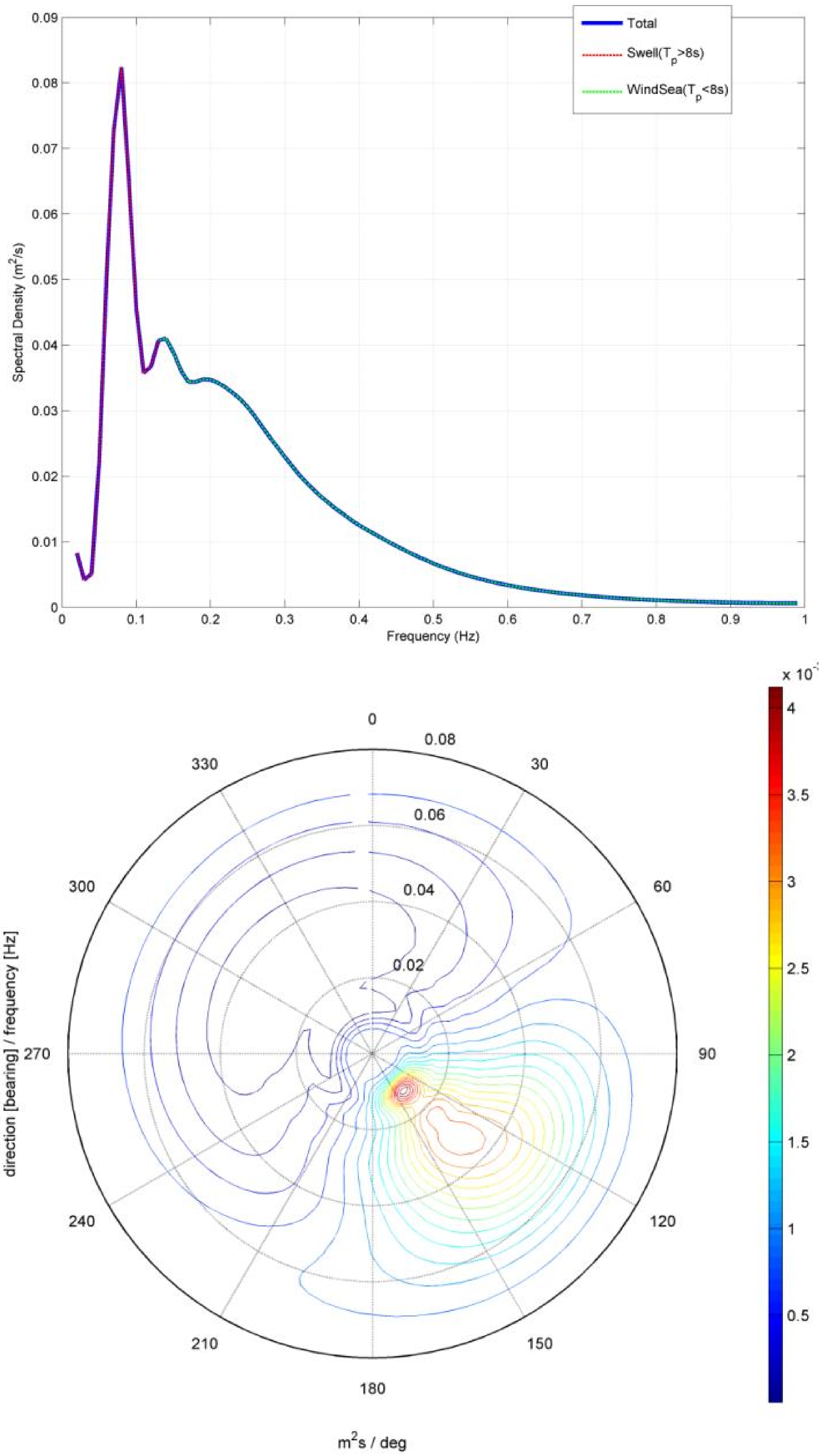


Figure C2-4 1D and 2D spectral analysis of the Do TAWAC deployment in 7m water off Emu Point from December 2013 to November 2016.

C-3 AWAC Current Analysis

RHDHV:

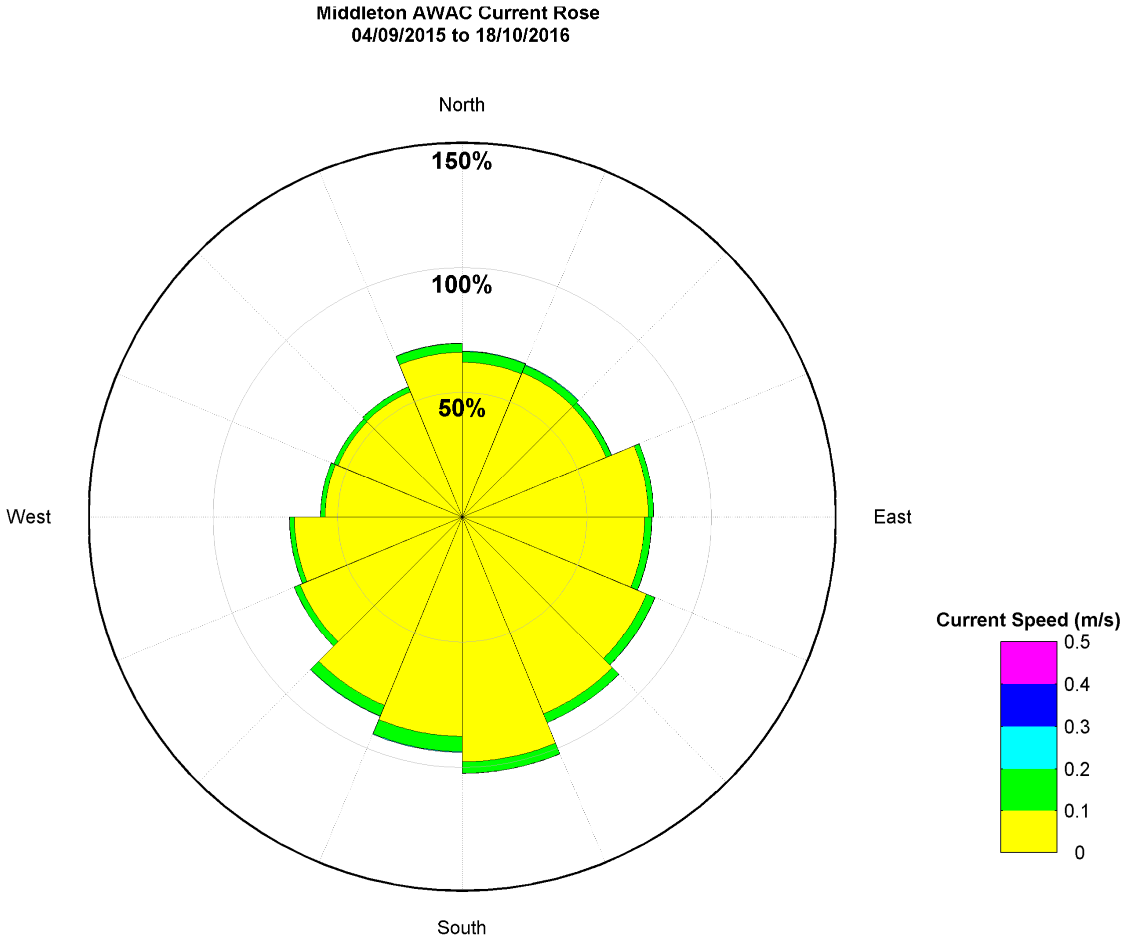


Figure C3-1 Long Term Average depth-averaged current rose from the RHDHV AWAC deployment in 7m water off Middleton Beach from September 2015 to October 2016.

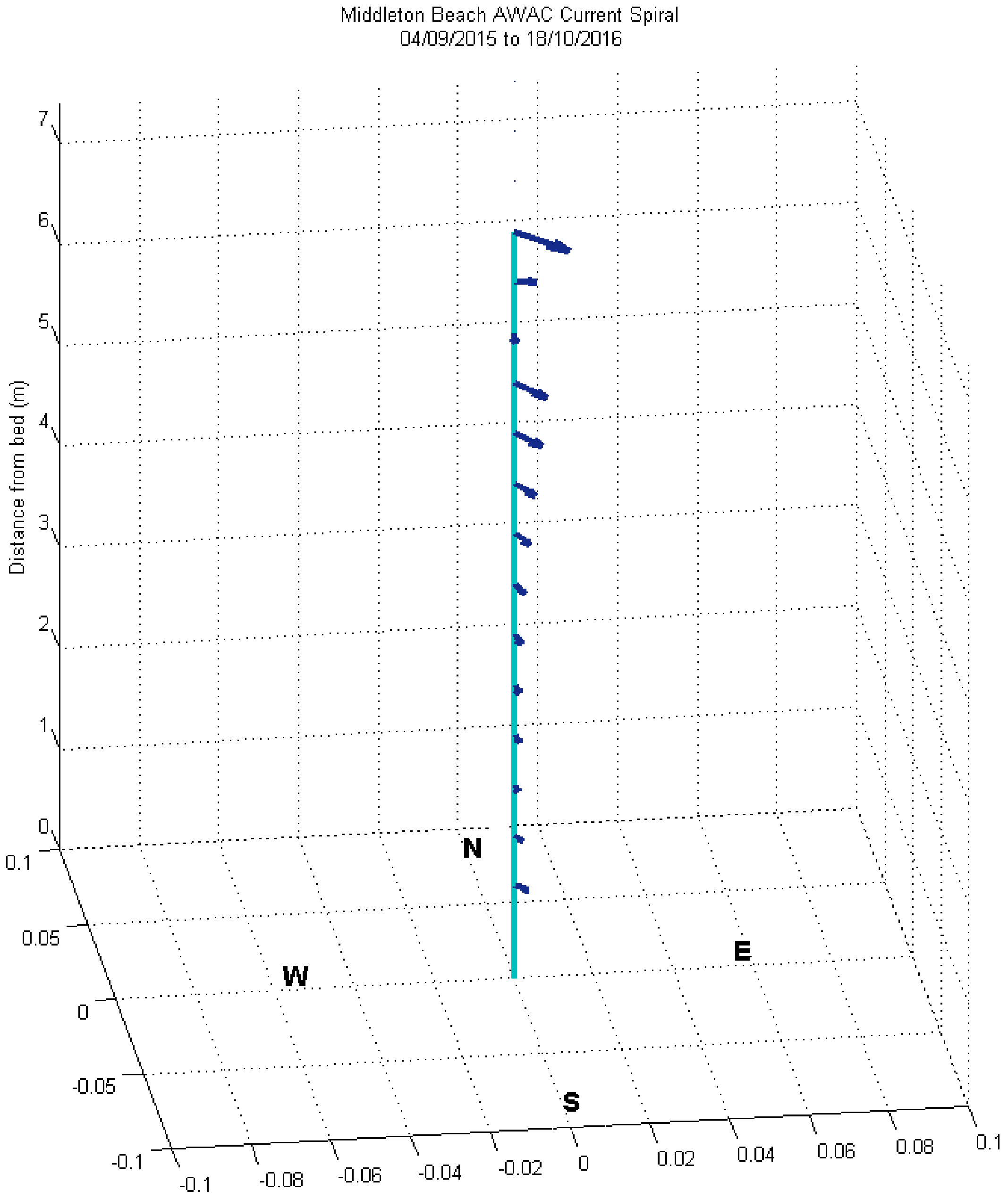


Figure C3-2 Current vector spiral for the RHDHV AWAC over the 13.5 month deployment period. The Vectors represent long term averaged current speed and direction at each of the AWACs recorded 'bins' through the water column.

DoT

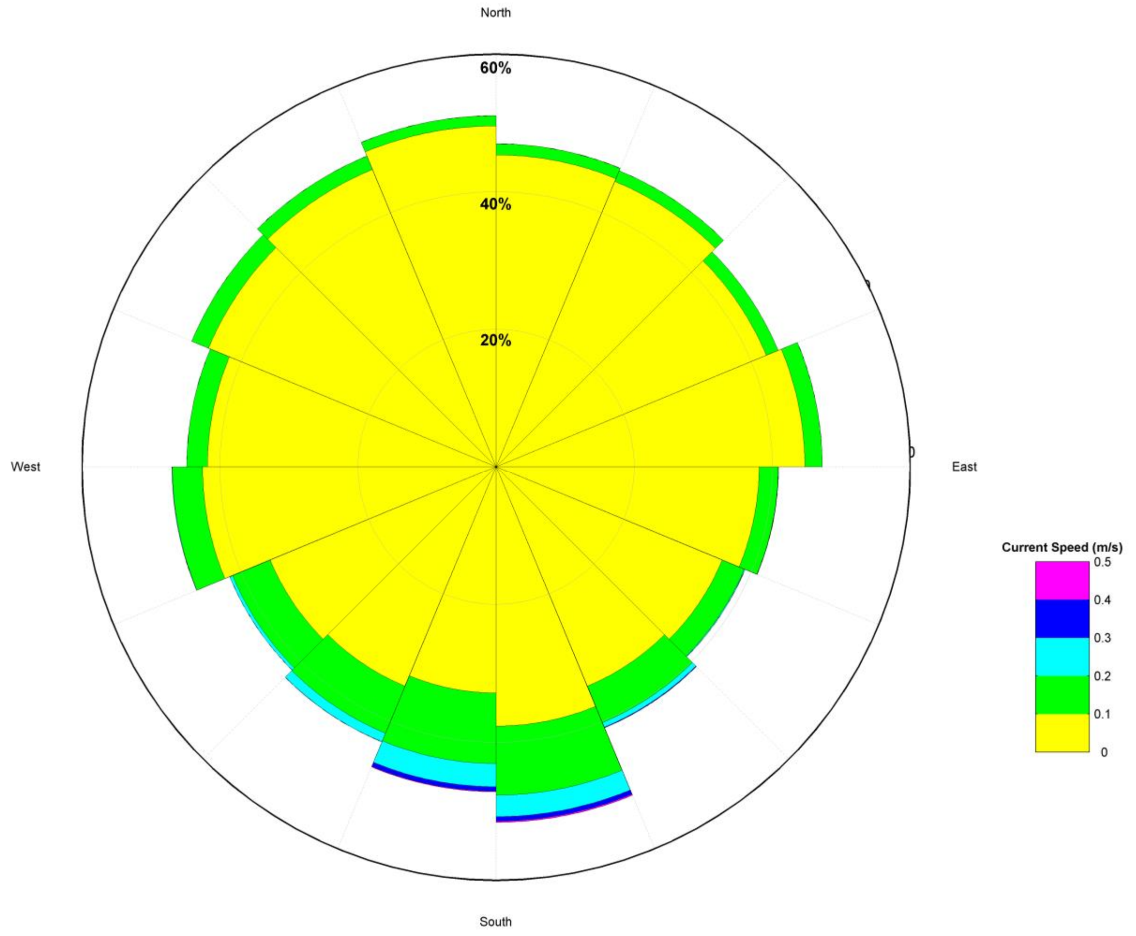


Figure C3-3 Long Term Average depth-averaged current rose from the DoT AWAC deployment in 7m water off Emu Point from December 2013.

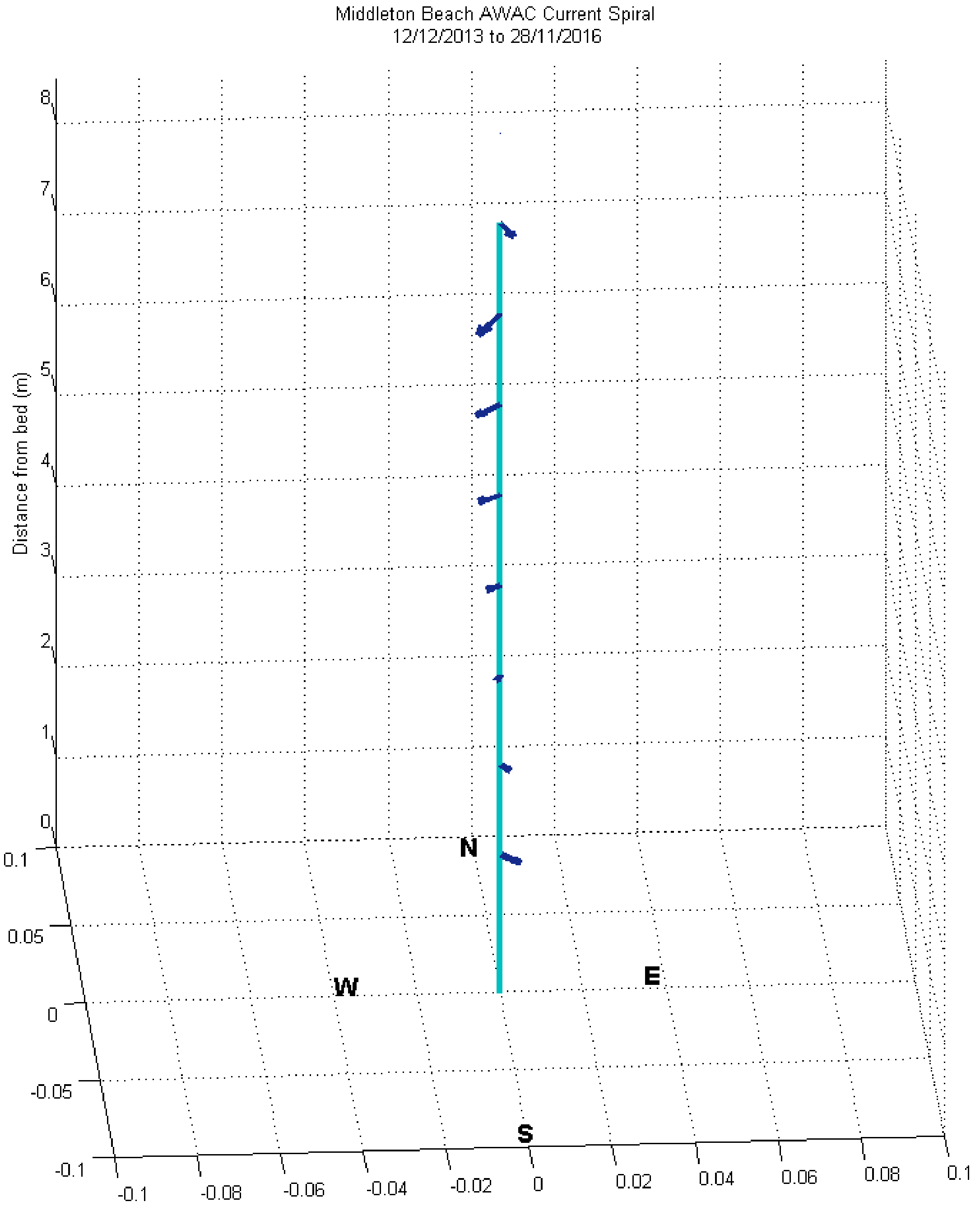


Figure C3-4 Current vector spiral for the DoT AWAC over the 4 year deployment period. The Vectors represent long term averaged current speed and direction at each of the AWACs recorded 'bins' through the water column.

C-4 AWAC Combined Analysis

RHDHV

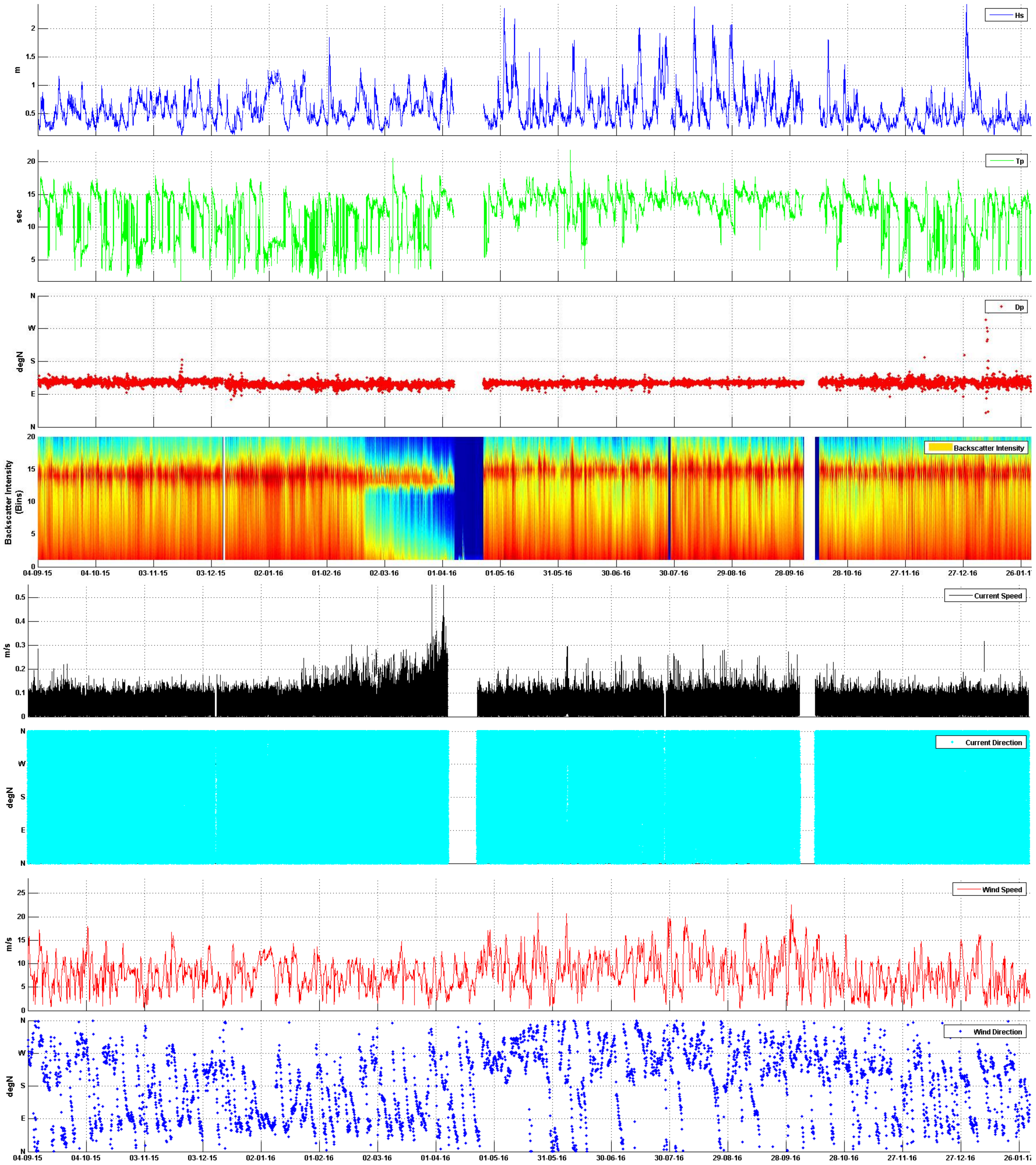


Figure C4-1 Combined metocean analysis of the RHDHV AWAC over the 13.5 month deployment period, plots are as follows; (from top); Hs, Tp, Dp, Cmag, Cdir (all bins), Wspd, Wdir.

DoT

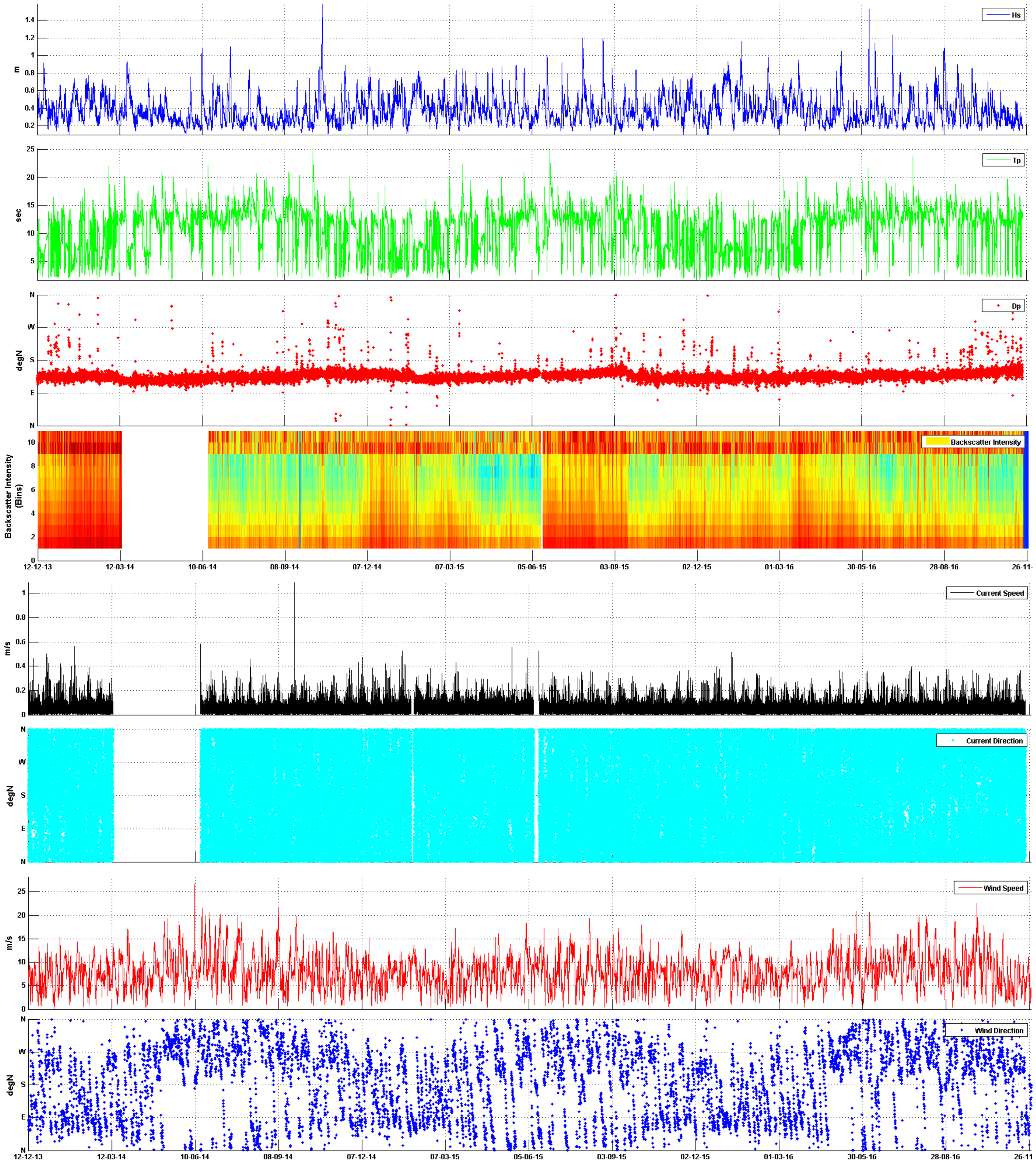


Figure C4-2 Combined metocean analysis of the DoT AWAC over the 4 year deployment period, plots are as follows; (from top); Hs, Tp, Dp, Cmag, Cdir (all bins), Wspd, Wdir.

C-4 38-year hindcast wave climate statistics

Rank	Start Date	End Date	Peak Date	Duration (days)	Peak Hs (m)	Mean Hs (m)	Peak Tp (sec)	Peak Dir (˚N)	Water Level LAT (m)
1	2/08/1984 18:00	6/08/1984 17:00	2/08/1984 23:00	3.96	3.15	1.86	12	151	NaN
2	25/02/1979 20:00	28/02/1979 23:30	26/02/1979 2:00	3.15	2.87	1.53	11.6	142	NaN
3	31/03/2005 7:00	2/04/2005 13:00	1/04/2005 13:30	2.25	2.85	1.74	9.2	141	1.19
4	19/07/1991 19:30	23/07/1991 9:30	20/07/1991 19:30	3.58	2.55	1.78	9.3	140	1.11
5	25/06/1988 10:30	25/06/1988 23:30	25/06/1988 14:00	0.54	2.31	1.55	6.2	149	1.06
6	13/06/1989 0:30	18/06/1989 8:00	14/06/1989 1:30	5.31	2.18	1.59	8.4	139	1.21
7	25/08/1993 12:00	26/08/1993 17:00	25/08/1993 19:30	1.21	2.16	1.48	5.1	154	0.78
8	22/09/1985 2:00	24/09/1985 22:00	22/09/1985 5:30	2.83	2.1	1.35	4.8	159	NaN
9	22/07/1986 20:30	26/07/1986 8:00	24/07/1986 17:00	3.48	2.06	1.4	11.3	142	NaN
10	28/08/1992 2:30	29/08/1992 4:00	28/08/1992 5:30	1.06	2.06	1.37	5.8	148	1.13
11	27/09/2003 23:00	2/10/2003 14:30	29/09/2003 23:00	4.65	2	1.54	9.3	136	0.98
12	17/01/1985 16:30	18/01/1985 23:30	18/01/1985 4:00	1.29	1.99	1.42	8.1	137	NaN
13	1/08/1992 17:30	4/08/1992 5:00	3/08/1992 5:30	2.48	1.98	1.54	10.2	139	0.91
14	19/03/1993 2:00	20/03/1993 23:30	19/03/1993 20:00	1.9	1.95	1.4	10.9	139	0.79
15	19/11/2008 22:00	22/11/2008 11:00	21/11/2008 8:30	2.54	1.89	1.47	12.4	136	0.96
16	23/05/1979 14:00	25/05/1979 6:30	23/05/1979 17:30	1.69	1.81	1.27	16.6	143	NaN
17	1/05/1988 3:30	5/05/1988 14:30	2/05/1988 17:30	4.46	1.79	1.36	9.4	143	1.29
18	10/05/1987 22:00	14/05/1987 1:30	12/05/1987 13:00	3.15	1.78	1.46	12.3	143	1.01
19	16/03/1992 10:00	18/03/1992 10:00	17/03/1992 14:00	2	1.77	1.35	8.5	133	0.86
20	22/12/1995 1:30	26-Dec-95	23/12/1995 9:00	3.94	1.77	1.45	9.7	137	1.23
21	9/03/2000 19:00	13-Mar-00	10/03/2000 19:30	3.21	1.75	1.32	7.7	139	1.01
22	31/05/2012 17:00	2/06/2012 22:00	1/06/2012 8:00	2.21	1.74	1.31	5.6	140	1.24
23	10/07/2006 13:00	12/07/2006 17:00	11/07/2006 10:00	2.17	1.74	1.41	11.3	141	1.17
24	18/10/2014 13:30	20/10/2014 11:00	19/10/2014 15:00	1.9	1.74	1.4	9.7	138	0.82
25	29/03/1999 17:30	31/03/1999 6:30	29/03/1999 23:30	1.54	1.74	1.44	5.8	136	0.93
26	14/01/2000 13:00	16/01/2000 9:30	15/01/2000 17:00	1.85	1.72	1.37	8.4	140	1.01
27	16/04/1998 2:30	18-Apr-98	17/04/1998 17:30	1.9	1.71	1.35	16.8	137	1.09
28	20/03/1999 18:30	21/03/1999 23:30	20/03/1999 23:30	1.21	1.69	1.37	5.6	143	0.97
29	16/11/1983 9:00	18/11/1983 7:30	17-Nov-83	1.94	1.68	1.31	8.5	134	NaN
30	31-Aug-92	31/08/1992 8:30	31/08/1992 3:30	0.35	1.68	1.43	5.7	143	0.92
31	8/09/1982 6:30	9/09/1982 12:30	8/09/1982 15:30	1.25	1.67	1.37	18.2	144	NaN
32	12/12/2011 11:30	14/12/2011 20:00	13/12/2011 8:00	2.35	1.66	1.31	15.9	138	1.17
33	25/07/1985 23:00	26/07/1985 11:00	26/07/1985 7:30	0.5	1.65	1.3	5.3	139	NaN

Rank	Start Date	End Date	Peak Date	Duration (days)	Peak Hs (m)	Mean Hs (m)	Peak Tp (sec)	Peak Dir (˚N)	Water Level LAT (m)
34	3/01/2007 23:00	6/01/2007 10:30	5/01/2007 8:30	2.48	1.65	1.31	10.3	141	1.21
35	28/03/1997 4:30	30/03/1997 14:00	29/03/1997 7:30	2.4	1.63	1.26	5.8	136	0.88
36	15/03/1991 13:00	16/03/1991 6:00	16/03/1991 2:00	0.71	1.63	1.26	5.5	140	0.99
37	5/03/1990 21:00	6/03/1990 10:30	6/03/1990 5:00	0.56	1.63	1.37	6.3	132	0.91
38	18/07/2008 20:30	19/07/2008 4:30	18/07/2008 23:00	0.33	1.63	1.33	4.3	159	1.01
39	19/05/1997 4:00	19/05/1997 18:30	19/05/1997 7:30	0.6	1.63	1.24	4.6	153	1.26
40	21/01/2000 13:00	25/01/2000 14:00	23/01/2000 8:00	4.04	1.62	1.23	8.4	134	1.12
41	30/04/1993 10:30	5/05/1993 3:00	3/05/1993 11:00	4.69	1.61	1.29	14.7	140	1
42	8/07/1997 22:00	9/07/1997 20:00	9/07/1997 5:00	0.92	1.61	1.32	5.3	144	0.8
43	11/07/2014 5:30	11/07/2014 13:30	11/07/2014 8:30	0.33	1.6	1.46	10.4	139	1.23
44	19/02/1997 18:00	21/02/1997 3:30	20/02/1997 1:30	1.4	1.6	1.24	5.8	130	1.01
45	21/01/1982 10:00	22/01/1982 8:00	22/01/1982 2:00	0.92	1.6	1.27	5.7	136	NaN
46	14/03/1999 14:00	16/03/1999 20:30	15/03/1999 8:30	2.27	1.6	1.22	12.1	137	1.17
47	27/10/2008 15:30	29/10/2008 12:00	27/10/2008 17:30	1.85	1.6	1.33	5.3	140	1.15
48	9-Jun-93	10/06/1993 0:30	9/06/1993 15:30	1.02	1.59	1.36	5.7	140	1.04
49	24/04/1980 1:30	25/04/1980 8:30	24/04/1980 12:30	1.29	1.59	1.33	18.2	144	NaN
50	5/10/1992 20:30	7/10/1992 8:30	6/10/1992 13:30	1.5	1.58	1.26	5.5	141	0.65
51	28/07/1985 19:30	29/07/1985 22:30	29/07/1985 3:30	1.13	1.58	1.31	18.2	144	NaN
52	10/03/1988 2:00	12/03/1988 1:30	10/03/1988 13:30	1.98	1.57	1.21	5.7	137	0.77
53	13/02/2009 0:30	15/02/2009 5:30	13/02/2009 22:30	2.21	1.57	1.27	5.6	138	1.04
54	13/05/2001 10:00	13/05/2001 21:00	13/05/2001 13:30	0.46	1.56	1.25	4.5	150	1.27
55	20/12/2008 1:00	20/12/2008 6:30	20/12/2008 5:00	0.23	1.56	1.33	8.6	136	0.85
56	8/10/2011 9:30	9/10/2011 5:00	8/10/2011 16:30	0.81	1.56	1.26	5.7	136	0.91
57	15/03/2013 5:30	17/03/2013 1:30	15/03/2013 23:00	1.83	1.56	1.39	14.8	136	1
58	20/04/2008 11:30	21/04/2008 4:00	20/04/2008 16:00	0.69	1.53	1.31	5.2	134	1.28
59	22/08/2003 12:00	22/08/2003 21:00	22/08/2003 16:30	0.38	1.53	1.27	8.5	148	1.05
60	21/12/1986 3:30	22/12/1986 10:30	22/12/1986 2:30	1.29	1.52	1.13	13.8	138	NaN
61	28/08/1998 17:00	29/08/1998 9:30	29/08/1998 5:00	0.69	1.52	1.3	6.2	129	0.71
62	10/09/1997 10:00	11/09/1997 2:30	10/09/1997 14:30	0.69	1.5	1.32	9.1	134	0.7
63	5/10/1990 9:30	6/10/1990 17:30	6/10/1990 2:30	1.33	1.5	1.27	12.6	137	0.88

Appendix D – Seagrasses of Middleton Bay (Geoff Bastyan)

Middleton Bay Seagrass Dynamics and Observed Physical Processes

A discussion paper to Royal Haskoning DHV for the Emu Point Coastal Adaption Study

G Bastyan & Associates
(April 2017)

Summary

- Historical observations showed that the outer Lockyer Shoal was formed over considerable time by seagrass accumulating >4 m of sediment.
- Average leaf length of *Posidonia coriacea* varies 600 mm in winter to more than 1000 mm in summer. This canopy is able to reduce the effects of both swell and currents.
- Annual leaf production has been identified as 2 leaves/year
- The time for a leaf to reach maximum length in summer was 133 days and leaf retention time was greater than 186 days. This coincides well with the spring and autumn senescence periods.
- Shoot production was generally regular and spread over most of the year
- With the knowledge that *P. coriacea* produces 2 leaves annually, rhizome examination reveals the rate of sediment accretion.
- All sites examined north of Griffith Street showed accretion of $\geq$250 mm between December 2015 and 2016
- The main study site showed a further 300 mm accretion from a swell event in late March 2017
- The main study site also showed that prior to 2015 the site was very stable for some 12 years
- This site has also shown a total accretion of 450 mm in the past 14 months
- The outer Lockyer Shoal has revealed steady accretion for the past 7 years (for the total rhizome excavated)
- Near shore Griffith Street suffered a 250 mm scouring in late March 2017. In 2014 this site supported a dense population of 50 mm seedlings, the main study site nearby suggests that there was a period of low sediment movement and thus swells, and therefore favouring recruitment.
- Swell direction (open ocean) appears to be driving sediment movement

Background

Oceanic swells along the south coast prevail from the south-west, these swells then refract around Bald Head into King George Sound. They are attenuated by a reduction in water depth and are focused towards Middleton Bay (GEMS 2006). Infrequently, storm systems give rise to swells from a more southerly direction that enter King George Sound less impeded and result in increased beach erosion.
In 1921 a storm reportedly eroded Emu Point beach back as far as the current Emu

Point Beach Café. Subsequently, recovery of the system occurred over some 60 years. In August 1984 a severe storm removed almost all seagrass along Middleton Beach, including the protective Lockyer Shoals. This storm event also removed 2 Norfolk Pine trees from Ellen Cove.
Aerial photographs compiled by the Department of Transport show that the small Aarea of seagrass that survived this storm event (on Lockyer Shoal and near-shore Emu Point) was steadily eroded over time. By 2001, only traces of these once dense meadows remained. The only obvious signs of seagrass re-colonization by this time was an area adjacent to Griffiths Street.

Following the 1987 erosion of Emu Point and adjacent beaches, the Department of Transport (formerly Marine & Harbours) constructed a revetment wall and two groynes between 1989 and 1991. A further breakwater was constructed in 1995 (Draft Transport Report, May 2000). Severe erosion occurred in early 1999 and was attributed to higher than predicted sea levels. Remnant seagrass meadows were in decline throughout this period and this loss would have contributed to the erosion.

It appears the high energy along the rock revetment has prevented sediment being deposited. Bathymetric data collected by the Department of Transport has shown that the inshore area of Lockyer Shoal has deepened by some 2-3 metres. Much of this sand appears to have been transported down Middleton Beach.

The dominant seagrass in Middleton Bay is *Posidonia coriacea*, a species that is high-energy tolerant and has a rhizome (underground stem) that grows vertically rather than horizontally. This species traps sand and thus causes a gradual reduction in water depth. *P. coriacea* grows in water depths between 1 and 30 metres, and it's distribution ranges from Shark Bay to South Australia. Leaf widths range from 2.5-7 mm. Seeds tend to settle in sand wave depressions, thus forming rows of plants.

The formation of Lockyer Shoals is believed to be largely due to this species: in the months following the 1984 storm, the author dived on Lockyer Shoals and recorded rhizome descending for some 4 metres in remnant seagrass 'columns'.

Historical Imagery

Images from 1943 and 1957 show a strongly developed channel that, on exiting from Oyster Harbour turns sharply to the west. This channel was surrounded on all sides by dense and apparently relatively shallow seagrass beds. By 1957 some seagrass erosion was evident on the southern side. The outer Lockyer Shoal to the south east was always relatively devoid of seagrass but surrounded by dense meadows. This area of the shoal (pre 1984 storm) used to break the swells (boaters from Oyster Harbour heading south had to deviate around this shoal.
1971 (23/2/71, image No. 5208, Landgate) shows the original extent of dense seagrass and in particular the dense meadows of Lockyer Shoals and Emu Point.
The 1989 image (26/3/89, image No. 5001-5039, Landgate) reveals that by 5 years post storm all seagrass was effectively gone other than remnants near Emu Point.
By 2001, the Emu Point area had lost all of the remnant seagrass, however regrowth was occurring particularly near Griffith St, and the 2007 image shows a dense meadow. This meadow (polygon 2 on the 2014 image) had undergone some erosion between these two dates.

The 2014 image shows considerable colonization in the former channel area by plants 1-2 metres in diameter (Polygon 6). This could be the result of the increase in water depth in this region as recorded by the Department of Transport. The resulting increase in cross sectional area may reflect in a decrease in localised currents and velocity, thus allowing recruitment years ago. Interestingly this area did not show evidence of recent recruitment. Since large-scale seagrass regrowth has occurred historically, potentially the channel could reform in a similar manner to pre 1984. The revetment and associated groynes can be seen to be causing turbulent water, hence the increased depth at the toe and the absence of seagrass re-colonization near by.

The southern boundary of seagrass distribution as seen in both 1971 and 2014 was almost identical. Presumably the current flow and larger swell at Ellen Cove does not permit seedling establishment here. In addition, much of the seagrass wrack that is shed in autumn tends to concentrate in Ellen Cove; as this breaks down a significant decline in light reaching the bottom occurs and this may also contribute to the absence of seagrass here.

The above mentioned images have been provided separately from this report

Observations on Circulation

Unfortunately little data on circulation and currents exists. The following are notes based on observations and many hours diving whilst undertaking seagrass research.

Generally I have noted that the circulation often runs down the bay and an outflow occurs off 'surfers'. During large swells the resultant rips carry 700 m or more offshore (Plate 1). The acoustic shark buoy can be seen centre right between the 2 swells. This buoy is 500 m from both the beach and southern shore, the rip to the north of it runs east of it and a second between the camera and buoy.
This is most likely why the southern seagrass extent ceases to the north.

Another observation during the Grange Resources study was that I was asked to retrieve a sub-surface drogue that had gone missing. A fresh easterly wind was blowing (15-18 knots) for several days, the drogue was released near Gull Rock on the northern coastline. The owners were concerned that it would be washed up on the beach near Emu Point; I said it would run south down the beach. We recovered it some 1.5 km off Ellen Cove.

Swells

The open ocean swell direction is significantly more important than swell height. When the direction deviates from the normal SW to southerly or with a touch of east in it, the impact across Middleton Bay is elevated. Under normal situations, the largest waves are experienced at 'surfers', wave height dramatically drops in close proximity to the north and south. When swells deviate to southerly the north shoreline is awash and Emu Point experiences the impact. This then exacerbates the long shore drift southwards and sets up significant rips at 'surfers'(eg. March 29). This will be discussed further with sediment accretion.

Plate 1. Rips generated by an unusual swell event on 29 March 2017-04-23

Seagrass Growth

Middleton Bay is essentially homogeneous with *Posidonia coriacea,* a species that is high-energy tolerant and has a rhizome (underground stem) that grows vertically rather than horizontally.
Leaf length ranges from 600 mm in winter to more than 1000 mm in summer. Due to it’s vertical growth habit and high branching rate, this species forms extremely dense shoots. The formation of evenly spaced rows (Plate 2) is due to seeds settling in sand wave depressions and that this species only branches on one side that is determined by wave direction. The plant is anchored by strong roots at least 500 mm long.

Leaves grow basally from a point termed a ligule; when the leaf is shed it does so at this point. Each leaf forms a scar that is the node formed on the rhizome. It grows vertically by extending the inter-node. Where sediment accretion is minimal the nodal lengths are small and often around 1-2 mm in length. This results in the extremely tight bunching of shoots. Nodal length increases dramatically if sediment accretion is high. Lengths of 100-150 mm have been recorded.

Thus by examining the rhizome, the rates and patterns of sediment accretion can be mapped as long as the annual leaf production rate is known.

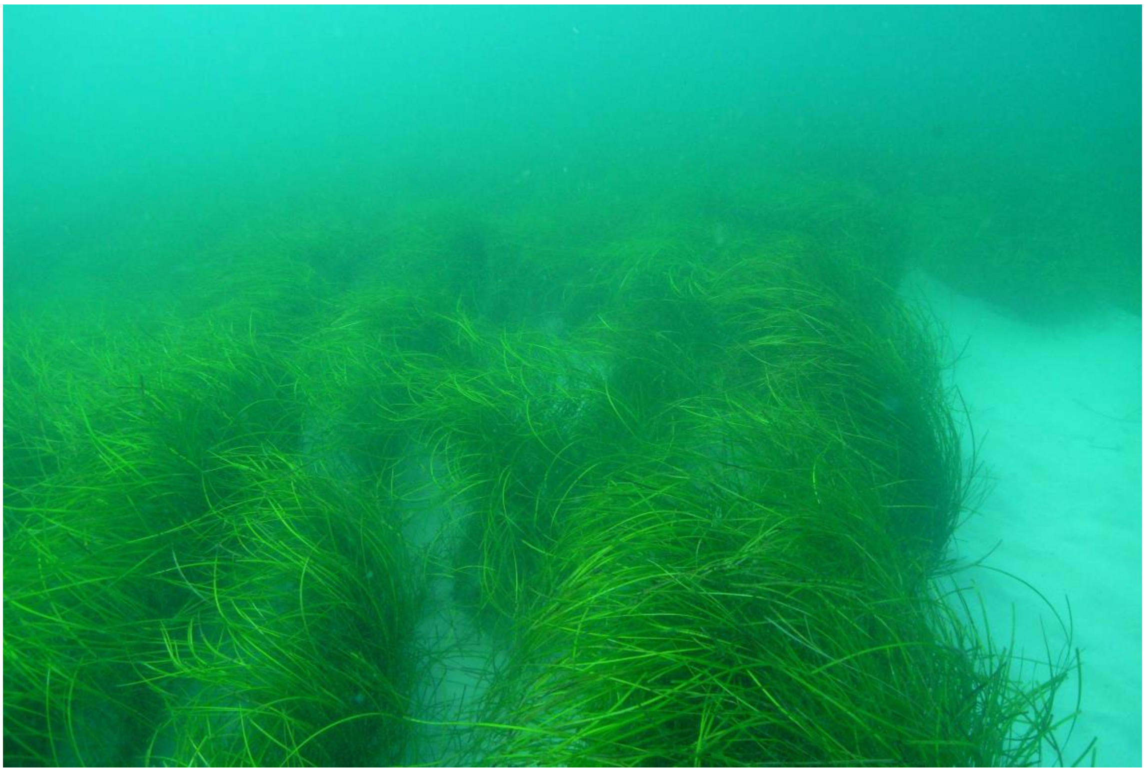


Plate 2. Mature *P. coriacea* meadow typically forms distinct rows

Plate 3 shows the rhizome structure and how changes in sediment accretion are evident. This sample has had most of the leaf sheaths stripped to reveal the nodes. The robust anchoring roots can be seen and as nodes are produced and buried more roots develop. This explains why this species tolerates such habitats and to dislodge these plants most of the roots have to be exposed.

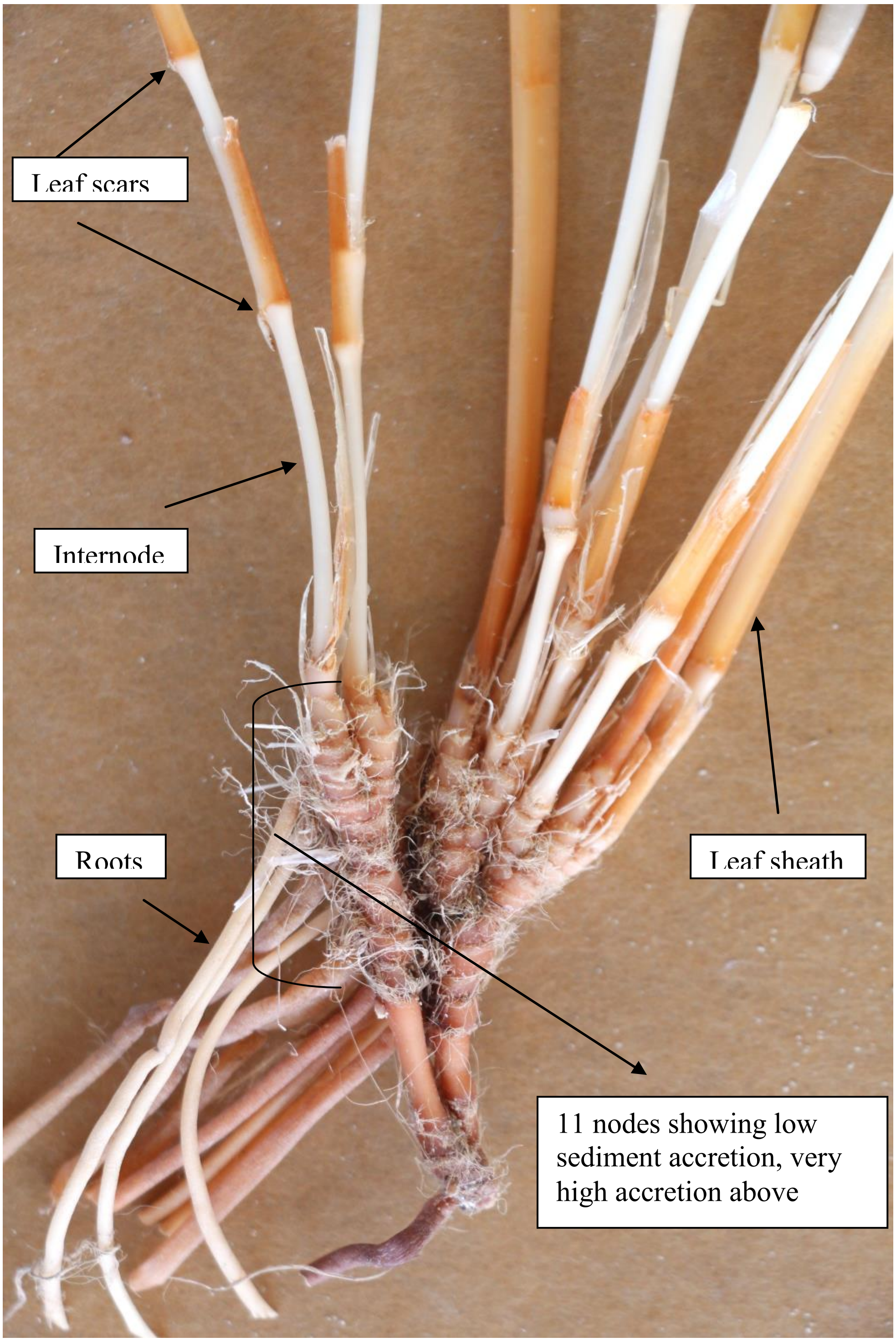


Plate 3. *P. coriacea* rhizome structure

Seagrass Leaf Production

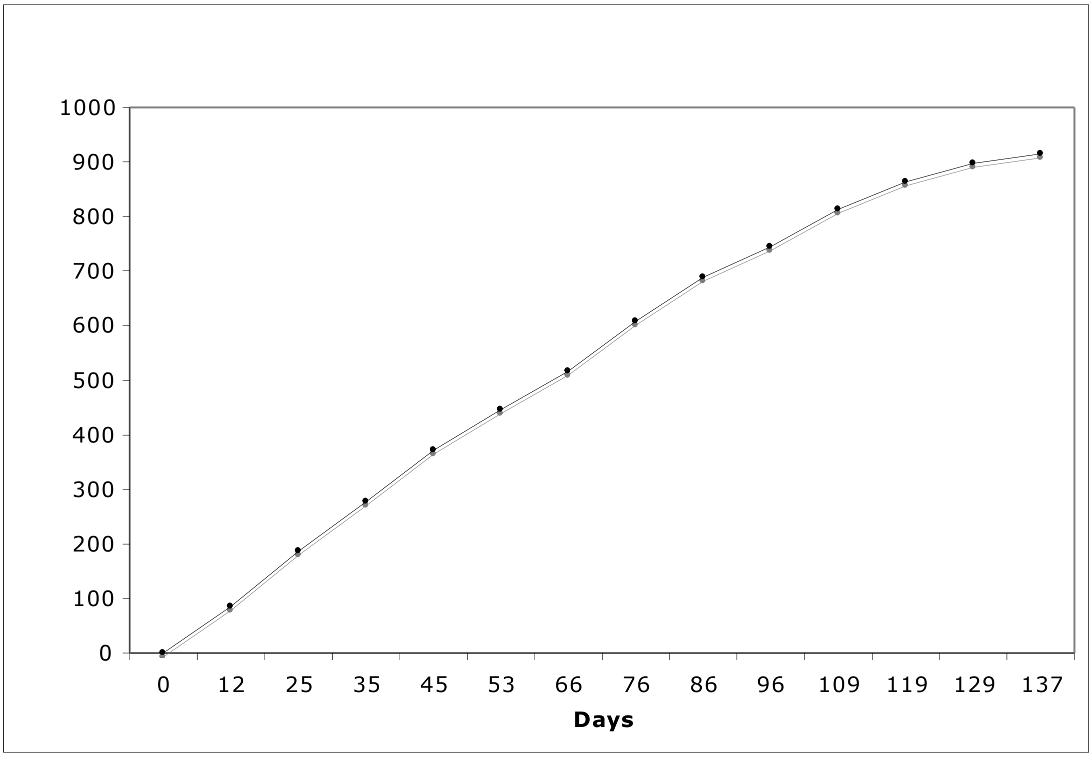
In order to age seagrass rhizome, we need to determine leaf retention times and the number of leaves produced annually. Studies by the author on *P. australis* have shown that 12 leaves are produced annually, and there are 2 branching events; usually twice in spring and once prior to winter (unpublished data).

Methods

Leaves are punched some 5 mm above the ligule using a needle. The scar becomes necrotic without damaging the leaf. This scar then moves up the leaf as it grows (by adding cells at the ligule). To determine true growth rates this needs to be repeated several times, preferably 10-14 day intervals. The punched shoots are harvested and the leaf length and growth is measured and expressed as mm/day. Punch scars are clearly visible even after more than 2 months.

Punching was undertaken seasonally to determine annual variation, with a sample number of 60-80 shoots). In order to establish a growth curve, an intensive study was done on 5 occasions through December/January 2017, over 53 days (Figure 1).

Figure 1. Growth rate of *P. coriacea* leaves (mean total length 919.6 mm). Growth was linear to 75% of final length (690 mm) where it steadily reduced).



A total of 77 shoots were used where all 5 punch marks were clearly visible. Leaves were pooled into 3 groups; leaves that showed a steady decline in growth rate in each successive period (waning), leaves that showed mean growth for earlier tag periods followed by a slowing, and emergents. These leaves appeared between tag dates. The new leaves (emergents) had the same growth rates of about 9 mm/day compared to mature leaves. A slowing in growth occurred when a leaf reached 75% of it's final length.

Using established growth rates, the age of each leaf (prior to the first tag) was calculated, this was then added to the known growth over the following 53 days. Data from leaves with a slowing in rate completed the calculation.

Thus it took a leaf 133 days to reach maximum length. A total of 35 leaves showed zero growth but were viable with no signs of necrosis, so adding 53 days we have a leaf retention time of greater than 186 days.

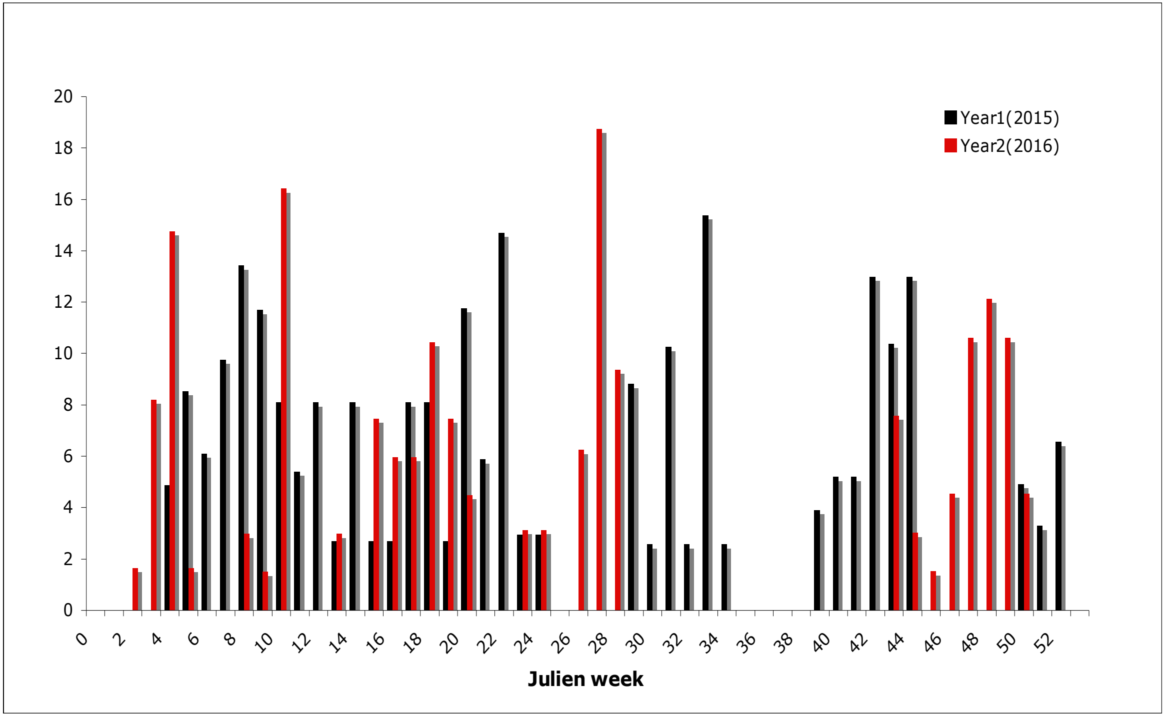
A leaf age of 6 months fits perfectly with the early October and the late March leaf senescence periods. Thus it is concluded that *P. coriacea* produces only 2 leaves per year and thus 2 nodes.

Branching patterns

Throughout the past 2 years, emergent leaves consistently appeared over all tag intervals; these can be identified as the first leaf of a new branch/shoot. After an emergent has appeared, the date of appearance is calculated using it's growth rate. The dates were placed into Julien weeks (Figure 2) and the frequency of emergents expressed as a % of the total number of shoots tagged in each interval.
Emergents were not recorded for most of June in both years, the absence in August (weeks 36-39) was because sampling was not undertaken.

While data suggest some seasonality (as expected), the production of new shoots (ie. branching) was relatively consistent over much of the year. Initial (and on-going) measurements involving mapping leaf scar/branching ratios will clarify this further. This revelation explains why despite extremely low leaf turn-over, this species establishes relatively quickly.

Figure 2. Seasonal branching patterns expressed as % of shoots that produced an emergent leaf for each tag period. Data are for 2015 and 2016 and plotted against Julien week.



Sediment Accretion

Seagrasses play an important role in determining how water flow (both swells and currents) impact on sediment movement. Measurements across dense meadows off Griffith St indicate that swell is dampened by 15% (Jeff Hanson, UWA pers. comm.) Other studies suggest that near-sediment current velocity is reduced by 80% one metre into a meadow.

P. coriacea works to trap sediment and grows vertically to do so (Plate 4). Robust roots that extend down some 50 cm anchor the plant. My recent studies show that this species can cope with some 30 cm accretion in a single year. Some months after the 1984 storm event I recorded rhizomes extending down some 4 m on Lockyer Shoal. As this seagrass accretes sediment, the resultant reduction in water depth (and the formation of banks) can significantly alter water dynamics. Unfortunately little information exists on these dynamics.

Plate 4. This small plant (~70 cm) has trapped some 20 cm of sand

Evidence of accretion

At 4 sites (Figure 3) sediment was removed using a dredge operating off a 3" water pump. A sliver of seagrass was removed for rhizome mapping. A high amount of branching at a constant level indicates years of sediment stability.

Repetitive non-destructive excavations at 3 sites (MB, LS_O and LS_I, Figure 3) all showed identical levels of accretion of 250-300 mm over the past 2 years.

Plate 3 is from the main study site (MB) just north of Griffith Street (Figure 3). The 11 densely grouped nodes flagged reveal that this site was very stable for 5 years (2 nodes/year). There are 4 nodes above this dense section of rhizome, indicating that within the past year (December 2015-December 2016) 175 mm of sediment accreted. The most recent internode length averaged 150 mm and the 2 prior 25 mm. Prior to December 2015 some 45 mm accreted. It was noted in field notes, and supported by light logger data that there was at least 2 swell events that deviated from the normal SW direction.

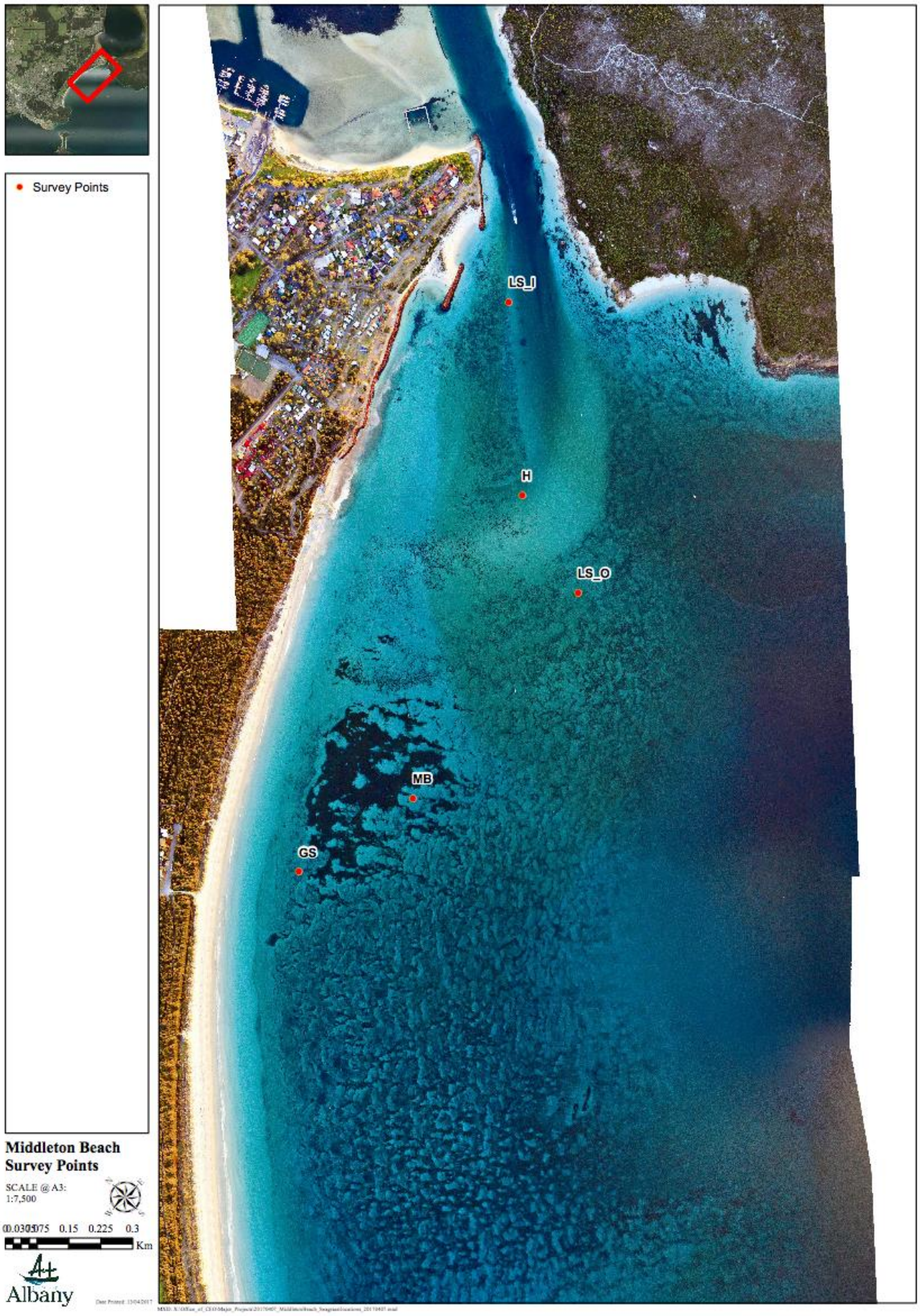


Figure 3. Locations of excavated seagrass rhizome

Plate 5. A young plant from site MB showing recent 200 mm accretion. Note the long anchoring roots and the finer feeding roots

Plate 5 is of a young plant that shows rapid vertical extension (2 leaf scars only) above the dense multiple branching rhizome.

Node length of rhizome samples from the 4 sites were measured and plotted as accumulative node length (Figure 4). This shows the rate of sediment accretion at these sites. All sites show a dramatic increase over the past year (2 nodes).
MB and the inner Lockyer Shoal site were seen to be stable for many years (~10,) while the Historical channel has been constantly accreting over the past 5 or 6 years. Rhizome at this site was collected down to 60 cm with no sign of dense, short

internode rhizomes. The outer Lockyer Shoal was seen to also be accreting at a steady rate.

I believe that the channel shows accretion as there has been relatively little seagrass seaward to stabilise the sediment, and the outer Lockyer Shoal accretes as the sand is gradually moving shoreward from deeper water

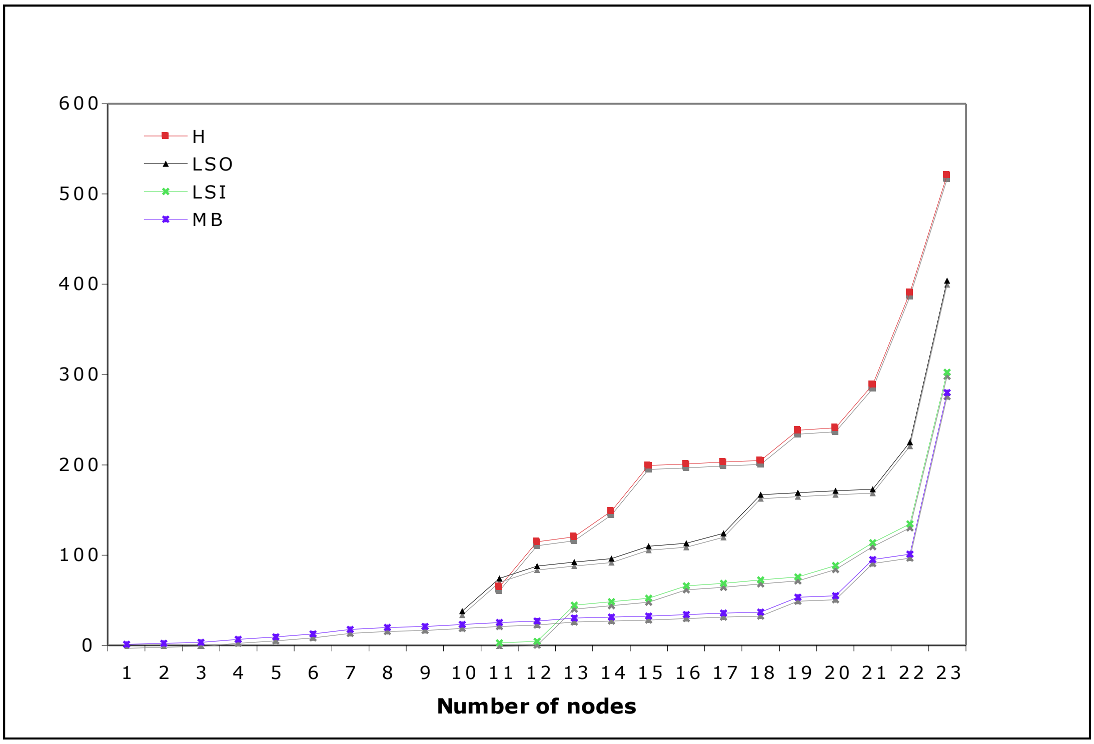


Figure 4. Accumulative rhizome length collected from the Historical channel (H), study site (MB), outer Lockyer Shoal (LS_O) and inner Lockyer Shoal (LS_I).

Plates 6 and 7 show the continuous accretion that has been occurring at the Historical channel and outer Lockyer Shoal sites.

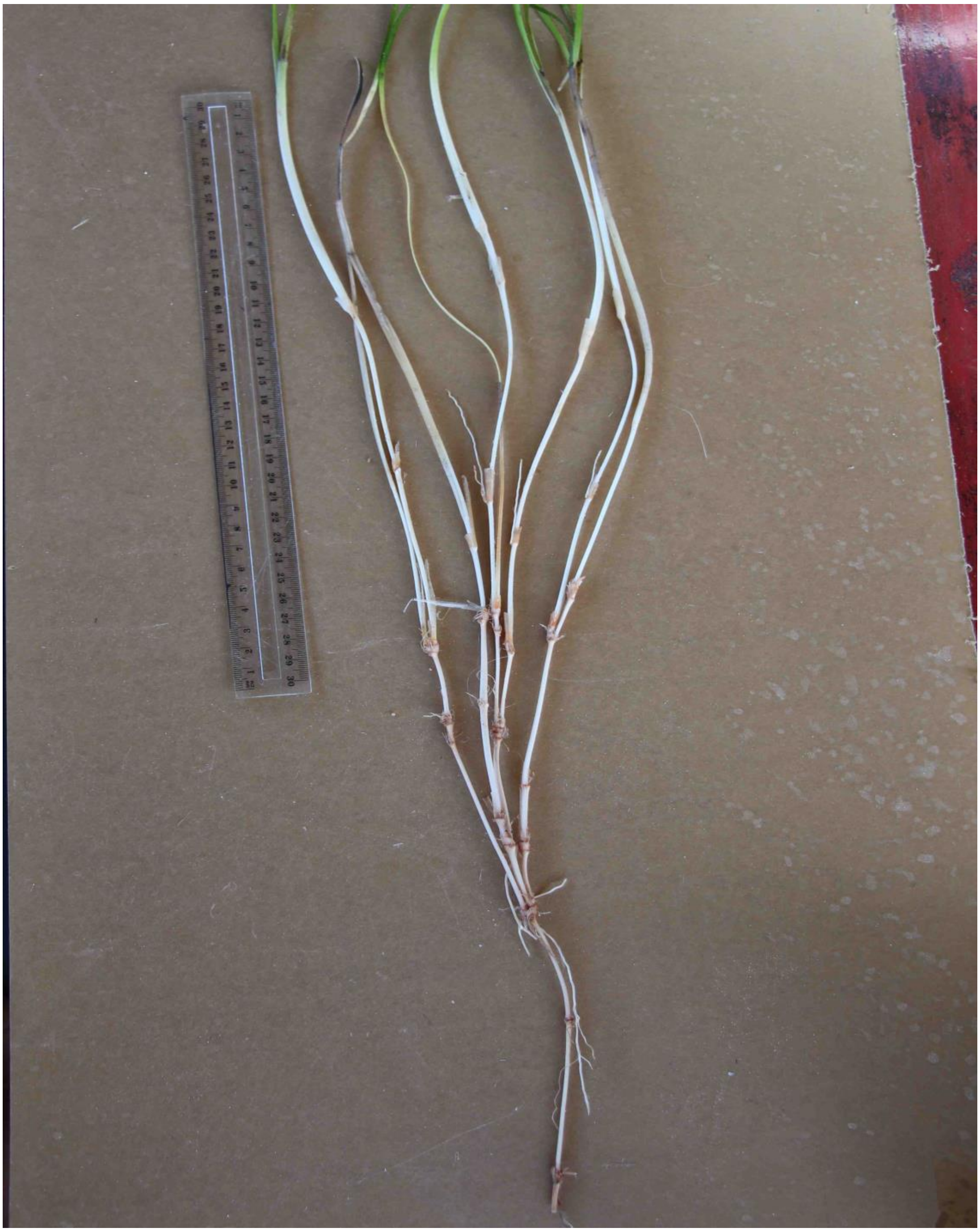


Plate 6. Sample from the Historical channel showing very long internodes lengths.

Plate 7. Sample from the outer Lockyer Shoal also showing long internodes lengths.

The swell event that occurred in late March 2017 deposited some 30 cm of sand at the MB site. It is not know how widespread this was. This accretion was confirmed on 3 fronts. First, the light logger was completely buried (Plate 8). Second, in this photo the top 4 cm of a star-picket can be seen above the buried logger. This was 500 mm above the sediment when the site was set up 14 months ago. Finally, the surrounding seagrass was covered 30 cm above the green leaf bases. It is not known if such a instant accretion will kill these plants, so they will be monitored.

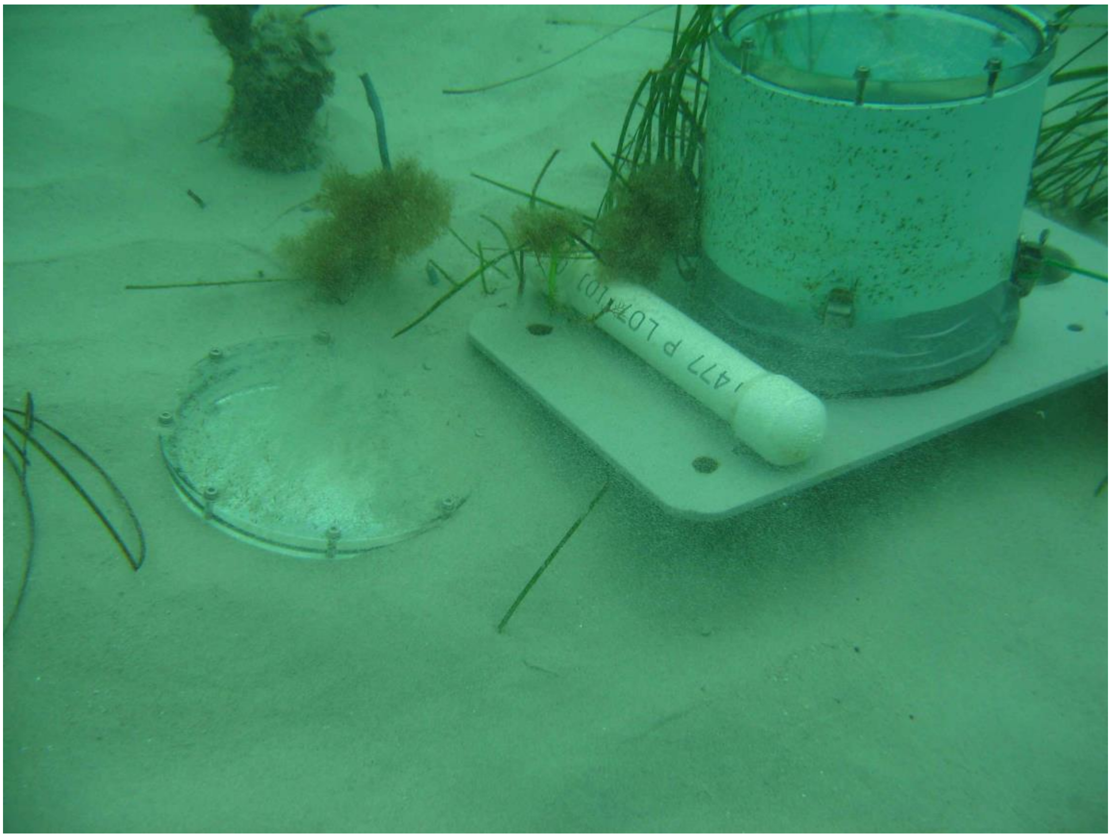


Plate 8. 21 cm high logger buried 29 March 2017.

An inspection was also made of a site off Griffith Street (GS in Figure 3). The seagrass here was predominantly small seedlings around 5 cm in size in 2014 when mapped. These formed a narrow band along Middleton Bay inshore of the denser meadows. It can be inferred that these seedlings were able to establish as the rhizome studies indicate that sediment accretion was low more than 2 years ago, and therefore swell conditions more optimal for survival.

Many of these young plants were lost due to the March 2017 swell event, and the survivors indicated erosion of some 250 mm (Plate 9). Most of these survivors were holding on with about 100 mm of root exposed. Scouring is expected with larger swell events, usually sand is transported off shore where it forms a bank. This was evident down at ‘surfers’, but not here. Presumably the sediment was transported southwards.

Plate 9. A young plant indicating 250 mm of scouring near shore off Griffith Street.

Timeline of seagrass response to storm events

Seagrass meadows are subjected to substantial physical forces in near shore ocean conditions. Historical photographs show both consolidation and loss over time.

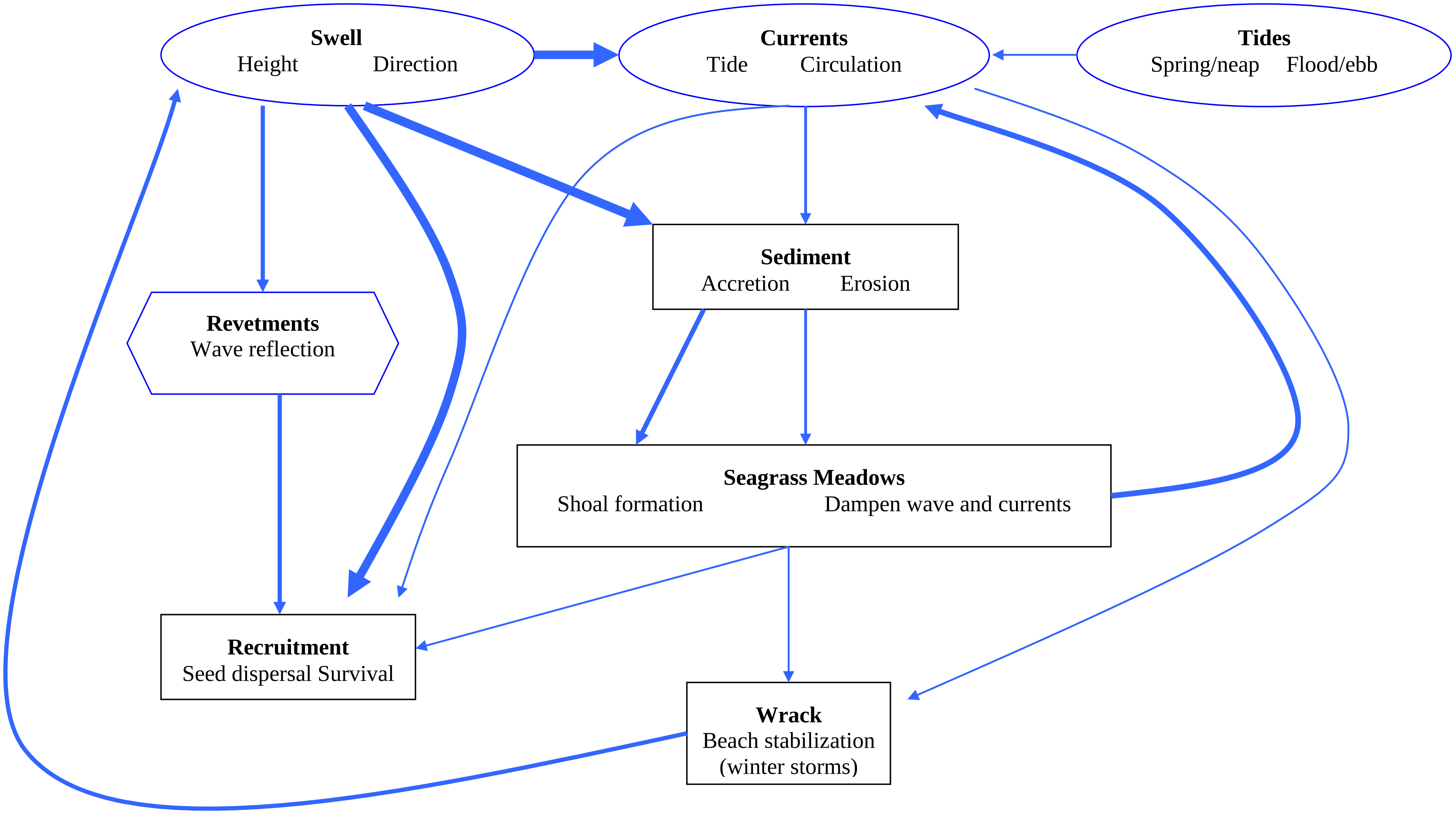
Assuming that the 1920 storm (where Emu Point eroded to the site of the present Café) also removed all seagrass as in 1984, we saw a presumably near complete recovery by 1984 (within 64 years). Seagrass mapping in 2014 showed a substantial recovery within 30 years.

Following such a severe storm event, re-colonisation is dependant upon so many factors:

- The seed bank has been severely depleted
- Absence of seagrass leads to higher sediment level currents and swell energy is more dominant (seed lost or recruits eroded).
- Success of seed settlement is dependant on conditions for a few short weeks around early December (burial/washed ashore/displaced offshore)
- The lack of established plants offers little for sediment stabilisation and recruitment
- Spatial growth is slow for this species so recruitment is a priority
- Following establishment, adverse conditions are critical to survival
- As re-colonisation occurs, protective habitat is afforded and the seed bank increases. This permits a rapid increase in seagrass coverage.

Thus recovery following a major storm event is dependant on numerous factors; the initial response is slow but then follows an exponential curve (subject to following abnormal events).

Since the established seagrass trap sediment which in turn leads to the formation of shoals, the impact of swell events are dampened offshore. In turn, this affects localised water flow and thus beach stabilisation. Given that it has taken 30 years for the seagrass to recover to the present state, it is most probable that it requires another 30 years to reach the state that existed prior to 1984. The seagrass of Middleton Bay has been shown to cope with an accretion of some 300 mm in a single year. The event/s that lead to this sediment movement need to be better understood. While some localised damage may have occurred, overall such events aid shoal formation and thus beach protection.


Swell
Height
Direction
Currents
Tide
Circulation
Tides
Spring/neap
Flood/ebb
Sediment
Accretion
Erosion
Revetments
Wave reflection
Seagrass Meadows
Shoal formation
Dampen wave and currents
Recruitment
Seed dispersal Survival
Wrack
Beach stabilization
(winter storms)