WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

Ashburton Salt Project

Marine, Coastal and Surface Water Existing Environment

K+S Salt Australia Pty Ltd

27 May 2021

Document Status

Version	Doc type	Reviewed by	Approved by	Date issued
R03v01	Draft	GXC	AMC	30 September 2020
R03v02	Report	ABM	ABM	11 December 2020
R03v03	Report	JMP	ABM	19 April 2021
R03v04	Final	JMP	ABM	27 May 2021

Project Details

Project Name	Marine, Coastal and Surface Water Existing Environment
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Document Number	5196-20_R03_v04_Marine_Coastal_&_Surface_Water_Existing_Environment.docx

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Environment ISO 14001 SAI GLOBAL
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CONTENTS

LIST OF TABLES

LIST OF FIGURES

5196-

1 INTRODUCTION

K+S Salt Australia (K+S) is proposing to build and operate a solar salt evaporation facility (the Ashburton Salt Project) approximately 40 km south west of Onslow. The facility will be constructed on existing salt flat areas that are located inshore from the coast. The Project will require a range of infrastructure to be constructed including a seawater intake and hypersaline wastewater (bitterns) outfall structures, as well as a jetty and berthing pocket to allow for export of the salt product. The location of the proposed project is presented in Figure 1-1 and Figure 1-2.

K+S commissioned Water Technology to undertake a range of modelling studies which assessed coastal processes, water quality, nutrient pathways and surface water. This report focuses on the description of the existing marine, coastal and surface water environment.

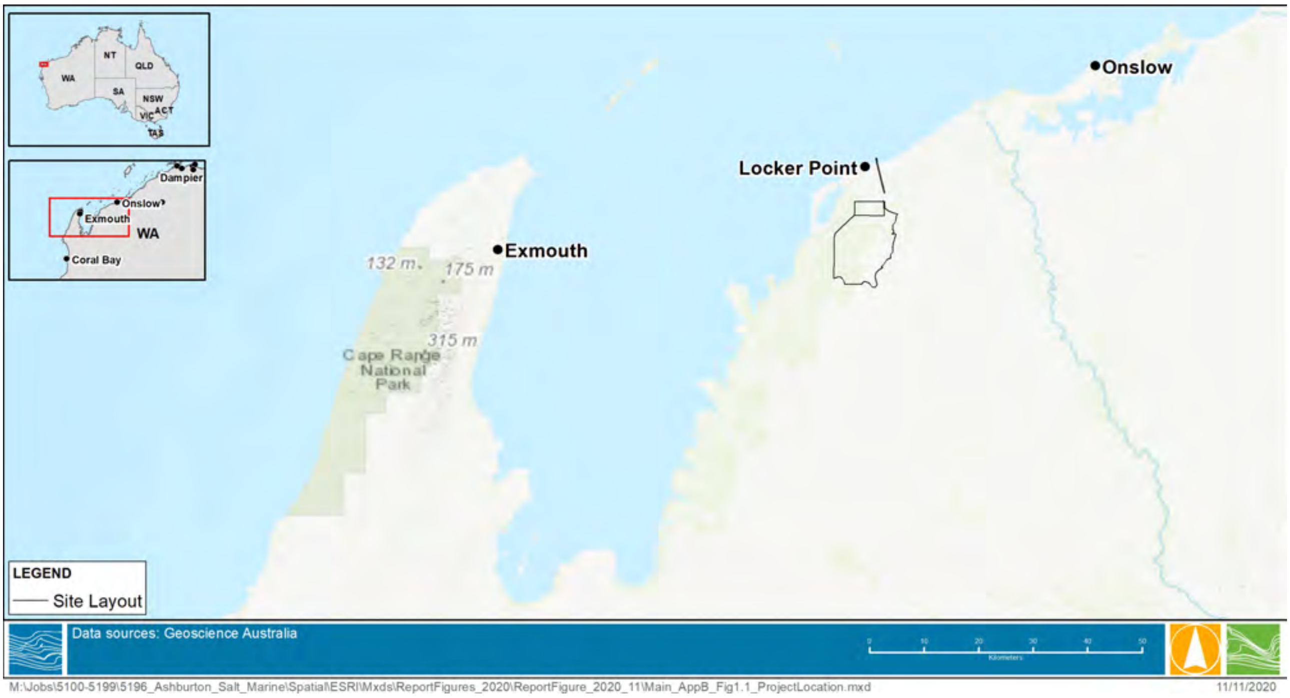


FIGURE 1-1 PROJECT LOCATION

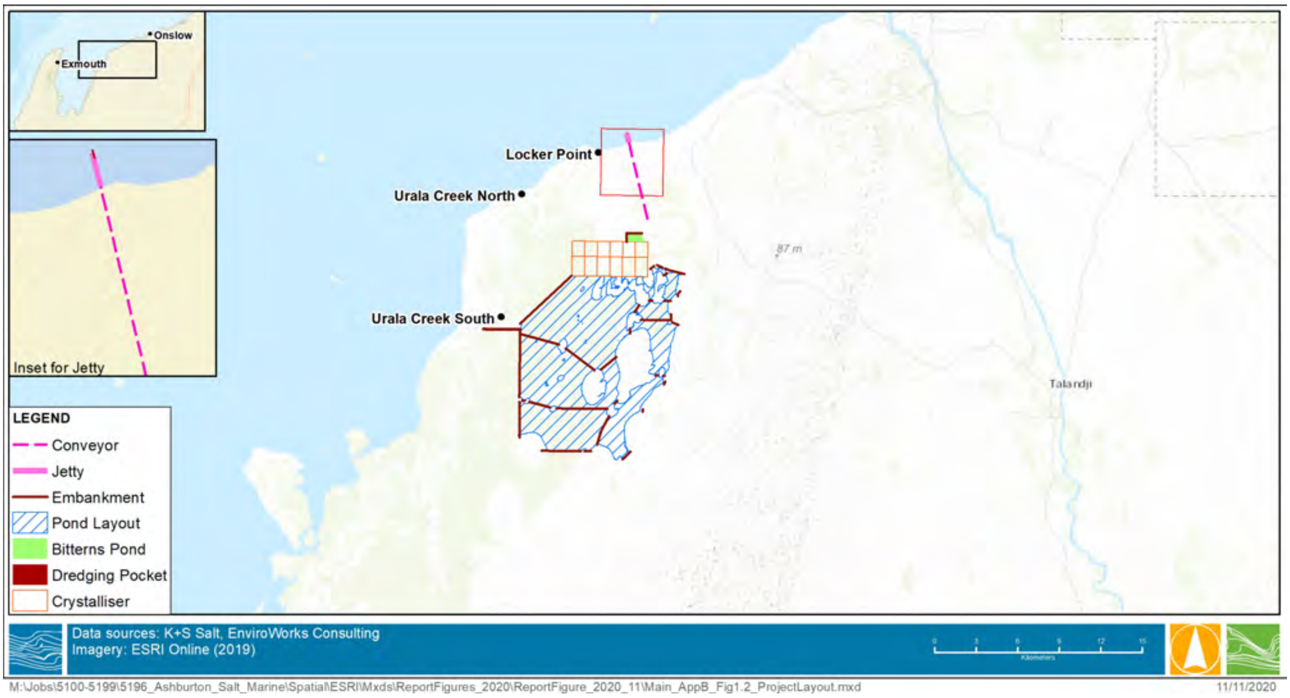


FIGURE 1-2 PROPOSED PROJECT LAYOUT (JULY 2020)

2 COASTAL GEOMORPHOLOGY

The geomorphology of the study area can be examined at a range of scales, including;

- The regional context of the North West Shelf;
- The shallower inshore waters of the Pilbara Shelf and Exmouth Gulf protected by the Murion and Serrurier Islands;
- The tidal creeks such as Urala Creek North and South; and
- The intertidal and supratidal coastal plain along Turbridgi Coast..

Each component has its own characteristics which are linked via their physical conditions, hydrology, sediment transport and water quality dynamics. This section broadly describes the geomorphic characterisation of the study area at these different scales.

2.1 North West Shelf and Pilbara System

The Northwest marine region, as defined by Department of Environment, Water, Heritage and the Arts (DEWHA 2007), extends from Joseph Bonaparte Gulf in the north to Shark Bay in the south. DEWHA (2007) provides a brief summary of the geological history and geomorphology of this area. Key points are summarised below:

- 300 million years ago, tectonic plate movements formed the Westralia Basin;
- The Westralia Basin was filled with thick sediments, plateaux and mid-slope terraces developed forming the North West Shelf and Kimberley;
- 135 million years ago, a rifting event separated India and Asia, resulting in a narrow continental shelf south of the present-day North-West Cape and the creation of the Indian Ocean;
- As the Eurasian Plate moved north, it converged with the Eurasian Plate, resulting in an uplift of the Australian Plate in the northwest of the Australian continent; and
- The southern half of the North West Shelf is characterised as a “distally-steepened ramp” – where the shelf slopes outwards away from the continent.

The features of the North West Shelf are presented in Figure 2-1, including the Plate Boundary along the Indonesian Archipelago, the Exmouth Plateau offshore of the Pilbara and the shallower waters along the Australian continent.

The Northwest marine region was further classified into three systems, as follows:

- The Kimberley system, north of Broome which is tidally dominated;
- The Ningaloo-Leeuwin system, south of the North West Cape, with a narrow shelf and slope dominated by seasonal wind forcing; and
- The Pilbara system - where the project lies. The Pilbara system is considered a transitional zone where the continental shelf and slope extends offshore.

Within the Pilbara system, DEWHA (2007) has broken the offshore zone into six (6) sub-systems, largely based on depth. These are presented in Figure 2-2, with a summary relating to the geomorphology provided in Table 2-1.

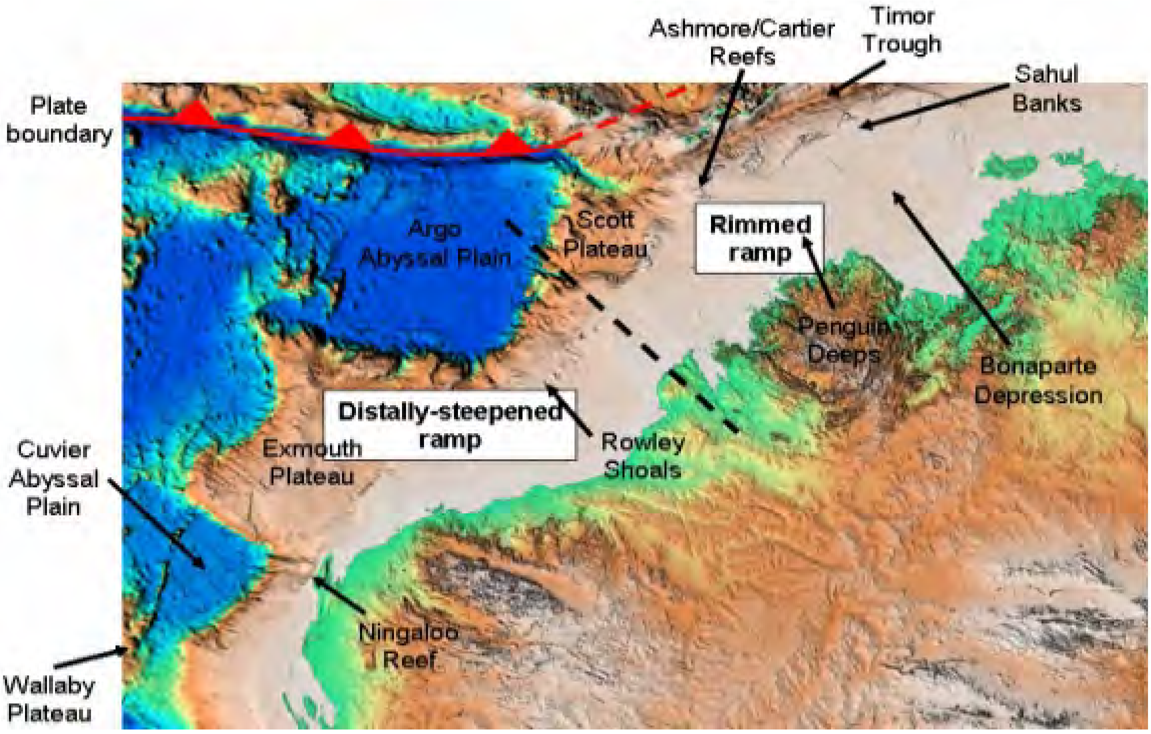


FIGURE 2-1 GEOMORPHOLOGY OF THE NORTH WEST SHELF (DEWHA, 2007)

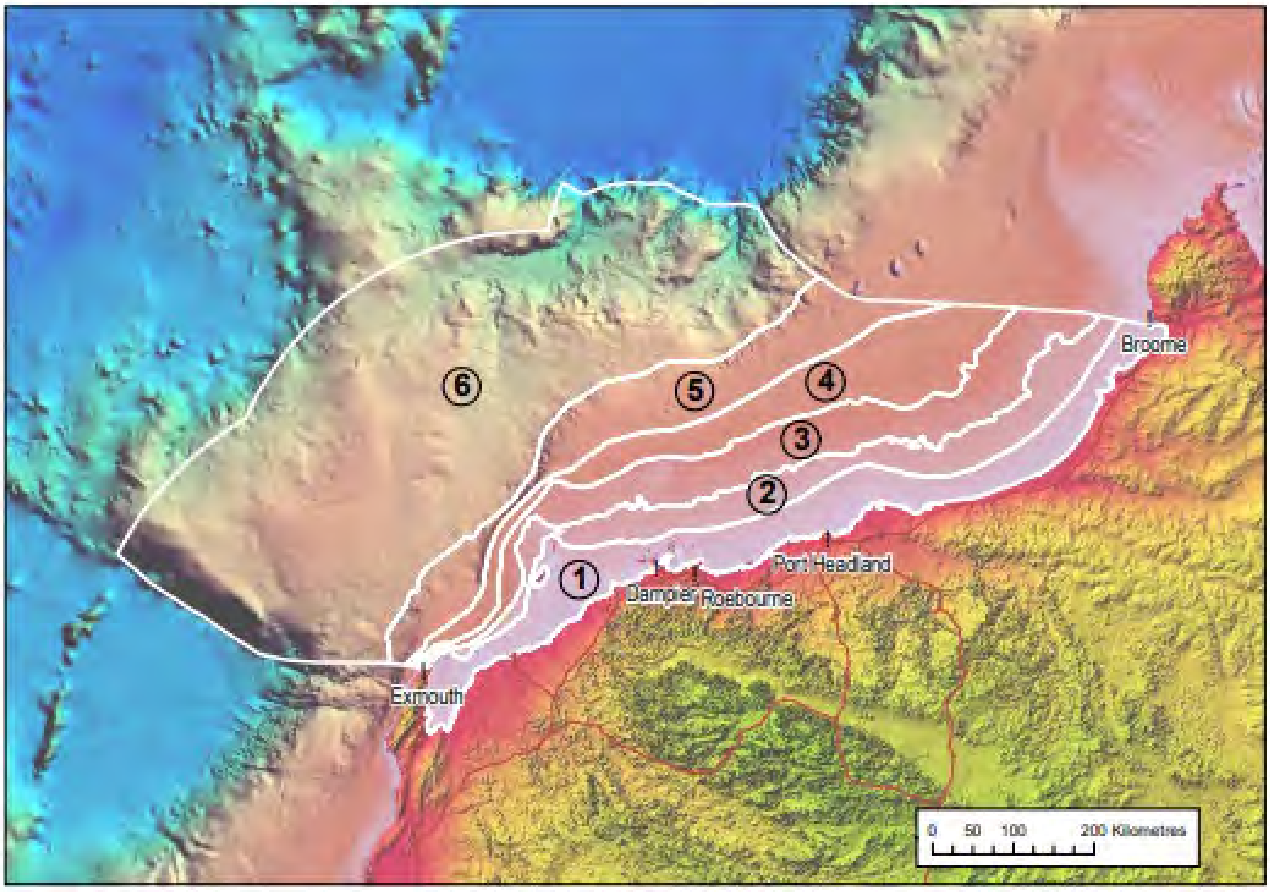


FIGURE 2-2 SUB-SYSTEMS OF THE PILBARA (DEWHA, 2007)

TABLE 2-1 SUB-SYSTEMS OF THE PILBARA (DEWHA, 2007)

Zone (Depth)	Features
1. Coastal (0 – 30 m)	Coastal waters to offshore Islands and Exmouth Gulf. Seafloor virtually flat, with slight slope seaward. Turbid waters with wind driven waves and tides the main physical mechanism. Seagrasses and algal mats occur, algae and coral are dominant on shallow sandbars, platforms reefs and ridges.
2. Inner Shelf (30-60 m)	Flat and featureless, overlain with sparse sandy substrates. Water column stratified and wind driven surface waves dominant mixing process.
3. Mid Shelf (60-100 m)	Sediments comprise sands and gravels on hard cemented bed.
4. Outer Shelf (100-200 m)	A gradient change at 120 m has been identified as a possible ancient coastline. Sub-sea canyons from previous terrestrial flow paths are notably absent from the region. Sediments comprise sands and gravels, transitioning to muds with distance offshore.
5. Slope (200-1000 m)	Another shelf break occurs between 200 and 500 m depth and the smooth seafloor is believed to comprise pelagic derived sediments. Between 500 m and 1,000 m, the seafloor is considered to be comprised of sandy mud.
6. Exmouth Plateau (>1,000 m)	Exmouth Plateau has a relatively uneven seafloor compared with the shelf zone and may include pinnacles. In contrast to the shelf the Exmouth Plateau has canyons and gully's incising the northern escarpment of the Plateaux.

2.2 Exmouth Gulf

On a regional scale, the site is within the primary compartment as defined by Eliot, et al (2012) from Giralia, at the southern end of Exmouth Gulf, to Locker Point at the northern end of the development. Within this compartment, it is expected that coastal sediment movement is mostly constrained. A general summary of regional geomorphology is provided in Table 2-2 with the inner shelf morphology and the tidal flat zones. A schematic of the tidal flat zones is provided by Eliot (2012), presented in Figure 2-3, and the locations noted in Table 2-2 are further shown in Figure 2-5.

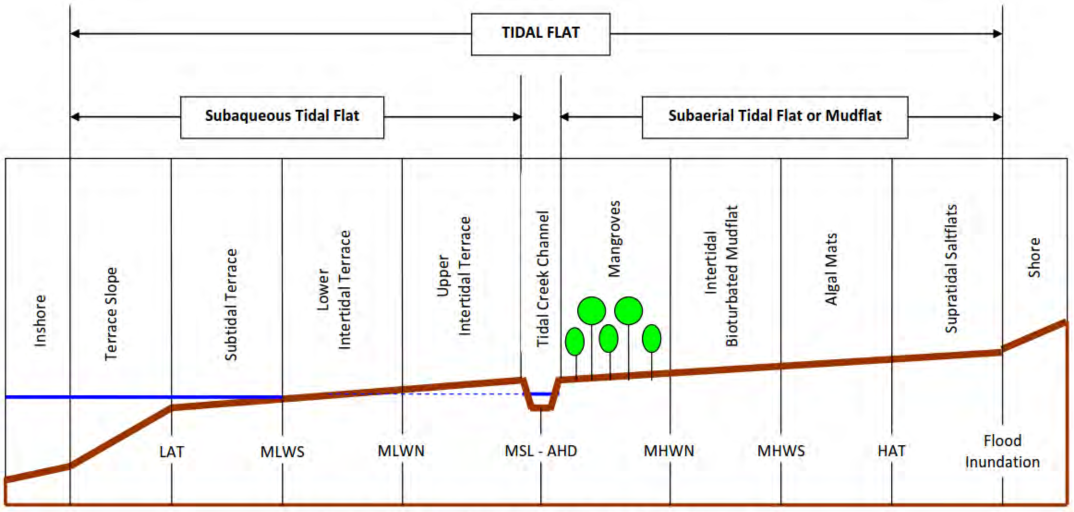
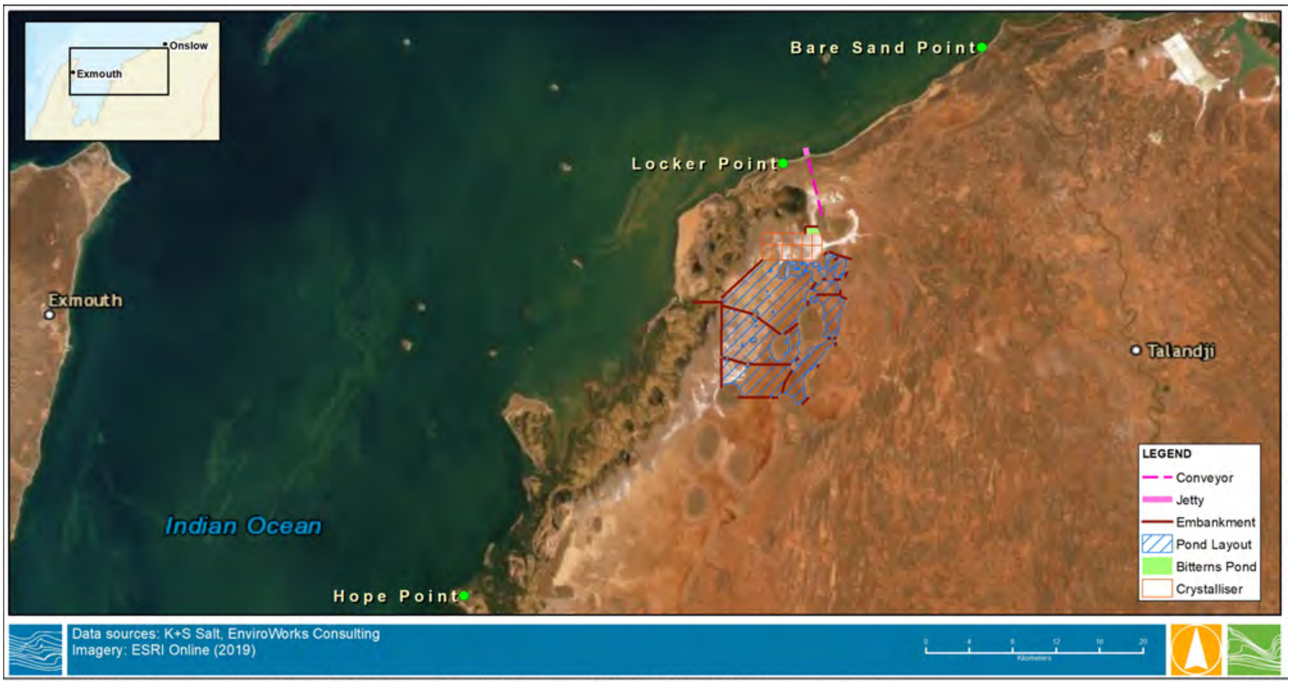


Figure 4-12: Nomenclature Applied to Tidal Flat Environments

Approximate tidal limits are indicated with reference to Australian Height Datum (AHD = 0.0m); Highest Astronomical Tide (HAT); Mean High Water Spring Tide (MHWS); Mean High Water Neap Tide (MHWN); Mean Low Water Neap Tide (MLWN); Mean Low Water Spring Tide (MLWS) and Lowest Astronomical Tide (LAT). Actual tidal heights will vary geographically as well as between environments subject to diurnal and semi-diurnal tides.The full sequence of units is not necessarily present at all mudflat locations. The slope of the surface is commonly less than 2°.

FIGURE 2-3 NOMENCLATURE OF THE TIDAL FLAT ENVIRONMENT (ELIOT, 2012)



Data sources: K+S Salt, EnviroWorks Consulting
Imagery: ESRI Online (2019)

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FIGURE 2-4 COASTAL MORPHOLOGY ZONE LOCATIONS

TABLE 2-2 SUMMARY OF COASTAL MORPHOLOGY RELEVANT TO THE PROPOSED FACILITY (FROM ELIOT ET AL, 2013)

Zone	Morphology
1. Hope Point to Locker Point	
Inner-shelf morphology	The coast is the northern part of the eastern shore of Exmouth Gulf, and is open to the NW to NNE. The inner shelf is narrow but substantially sheltered. At approximately 20km from shore, the water depth deepens from 1 0m in the S of the compartment and deepens to 20m in the NW. There are numerous islands and reefs in the compartment, including Tent Island, Simpson Island, Hope Island, the Rivoli Islands, Brown Island, rocky islets and Fly Island as well as Exmouth, Beryl and Pearl Reefs
Subtidal Shoreface	The subtidal shoreface is moderately wide, with water depths <5m approximately 10km from shore. Less than 25% of reef or rock outcrop is apparent in the inshore waters. A broad subtidal terrace is cut by numerous tidal channels that are linked to tidal creeks draining the seaward margin of an extensive mudflat extending along the coast.
Intertidal Shore	The highly-irregular NNW facing shore is the dissected margin of an outwash plain. There are more than five tidal creeks per 10km along the shore. In some places the tidal creeks are separated by remnants of an older land surface which form discrete points, such as Hope Point. The shore is vegetated with mangroves. With increasing distance north, the coast is affected by sediment moved south from the Ashburton River. Chenier spits, a cuspate foreland with mobile sand sheets and large tidal creeks have formed in the vicinity of Tubridgi Point.
Backshore	In the southern part of the compartment the backshore is comprised of broad bare mudflats up to 7xkm wide seaward of an extensive, low-lying outwash plain north of the Yannarie River mouth on the landward edge of the mudflats. Residual mounds of an older land surface, including weakly cemented dune sediments, are common on the saltflats. To the north and landward of Tubridgi Point, Chinty Creek drains across a floodplain into an inherited basin drained by tidal creeks, including Urala Creek.

Zone	Morphology
2. Locker Point to Bare Sand Point	
Inner-shelf morphology	At a broad scale, the coast between Locker Point and Coolgra Point faces NNW and is in the lee of a remnant barrier chain along a formerly embayed coast. The inner-shelf is of moderate width. Water depth is <10m at approximately 15 km from shore; 20m approximately 30km from shore; and 50m approximately 3km from shore. Eight islands are located in State Waters; the larger being Serrurier, Bessieres and Flat Islands
Subtidal Shoreface	The water depth is <5m for approximately 2-4 km from shore. A number of reefs are also apparent, and the inshore substrate is on 25-50% reef or pavement and unconsolidated sediment. The curve of the embayed shoreline is broken by three small cuspate forelands, each associated with rock outcrops close to shore. A rock platform extends approximately 4.5km eastwards from Locker Point to the first foreland.
Intertidal Shore	Away from the mouth of Urala Creek the sandy, shallowly arcuate shore faces NW. The coast is on an interfluve between Chinty Creek and the Ashburton River. The two eastern forelands are associated with isolated outcrops at the shore and in the inshore waters. Between the forelands the sandy beach is perched on a rock platform
Backshore	The compartment includes a prograded barrier with a high frontal dune ridge seaward of older washover features. Landward of Locker Point the dunes impound a floodplain basin into which Urala Creek, a tidal creek, flows. In the central part of the compartment they overlie an older outwash plain of the Ashburton River with numerous paleochannels, crevasses and residual mounds. Further east the dunes include mobile sand sheets and impound a basin that drains directly into the ocean. The basin abuts an old shoreline with lithified dunes, marine sediments and evidence of extreme high water-level events

2.3 Project Area and Onslow Plain

The intertidal and backshore morphology of the Project area is consistent with the typical eastern Exmouth Gulf shoreline, which consists of four key elements (trending from the Exmouth Gulf shoreline inland):

- Coastal fringe consisting typically of creeks with mangroves, dunes and beaches;
- Salt flats (also known as Onslow Plain), within which most of the proposed development is located. Within this sits a number of remnant mainland islands;
- Dunefield - a relict longitudinal dunefield sits inland of the salt flats, with low-lying swales running parallel between the dunes that act as drainage channels; and
- Outwash plains consisting of alluvial and colluvial sediments, due to floodplain flow from the Ashburton and Yannarie Rivers.

The regional geomorphology of the compartment has little protection from the prevailing south and south-west moderate wave climate. Combining this with the low-lying unconsolidated shoreline, its overall classification is “moderately susceptible to change”, and a “moderately unstable landform” on a regional scale according to Eliot, et al (2012). This gives the overall tertiary compartment a moderate vulnerability to geomorphic change.

The coastline of the study site can be broken into four different sections, as shown in Figure 2-5. These sections consist of:

- Shoreline Section 1 - The southern-most section between Toms Creek and North Creek, consisting predominantly of mangroves and intertidal flats;
- Shoreline Section 2 - Further north, between North Creek and Urala Creek South, a sandy beach, dune and vegetation system fronting a mangrove swamp;
- Shoreline Section 3 - North of Urala Creek South sits Tubridgi Point, along which the shoreline tracks north before bending around the point to the northeast, with this section ending at Urala Creek North. This sandy shoreline has an extensive dune system, and is partially backed by a sand sheet; and

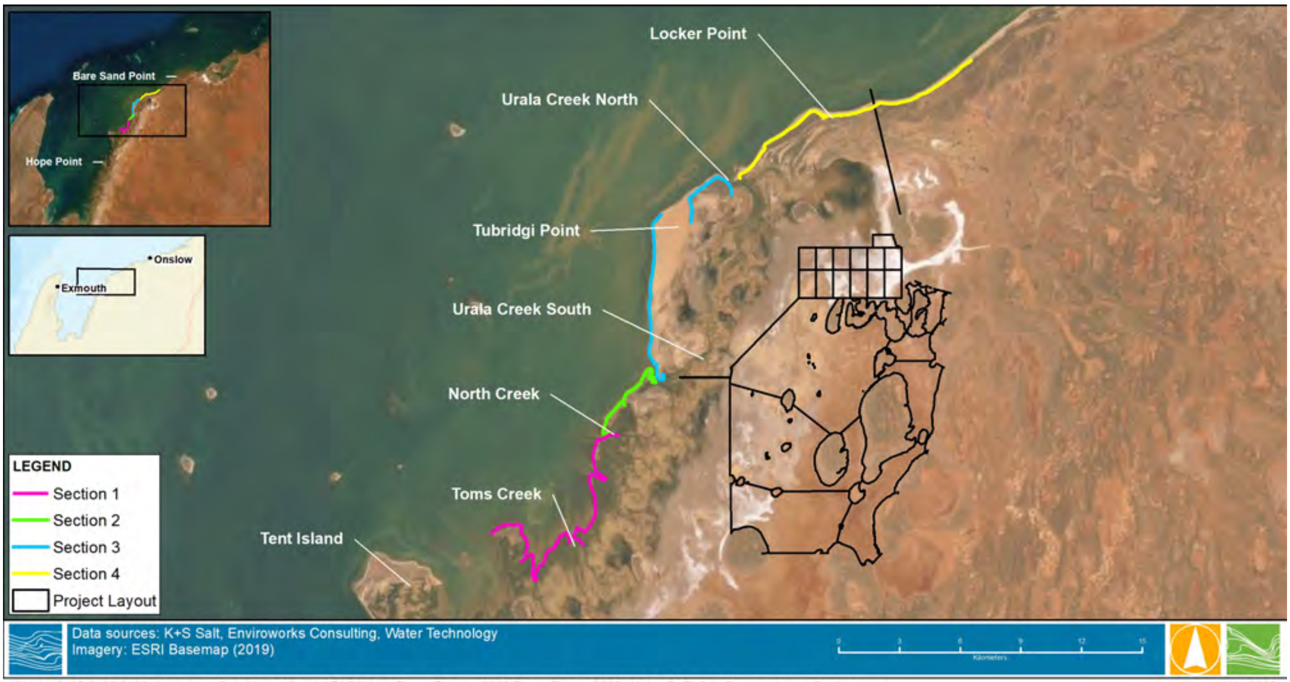
- Shoreline Section 4 - North-east of Urala Creek North river mouth sits another section of sandy beaches with dune and vegetation behind, extending to Locker Point in the north.

2.4 Sediment Characteristics

Sediments within Exmouth Gulf are typically dominated by sand; however, muds and silts are also present, especially in the mangrove and depositional areas near the project site. Sediment sampling undertaken by Brunskill, et al (2001) suggests offshore sediments are typically at least 80% sand, in the range of 62 – 2,000µm.

Sediment at the project site is highly variable, especially along the coastal fringe. Blandford et. al. (2005) previously reported on sediment samples within the coastal fringe zone at Hope Island. The Blandford et. al. (2005) samples were taken approximately 20 km south of the project, at a location which exhibits mangroves and tidal flats, similar to Section 1 of the project site. The Blandford et. al. (2005) study found that sediment layers of the coastal fringe were “an upper 300mm layer of fine to medium grained sand, overlying 200 mm of marine silt and then 300 mm of sandy silt containing shell fragments”, suggesting a muddy sand subject to tidal and current movements.

Dunes and beach deposits were found by Blandford et. al. (2005) to consist of more coarse-grained sand containing abundant shell fragments. This agrees with samples taken by Water Technology on the 12th and 13th of September 2017 from the three locations shown in Figure 2-7. All three samples are classified as fine sand; the median grain diameter at the outfall location approaches the medium sand classification. Table 2-3 presents the median particle size at each location. Figure 2-6 shows the sediment composition at Locker Point (left) and the Urala Creek South location (right). Shell fragments dominate the sediment at the beach fronting the ocean, as compared to finer sediment found inside the creek.



Data sources: K+S Salt, Enviroworks Consulting, Water Technology
Imagery: ESRI Basemap (2019)

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FIGURE 2-5 GEOMORPHOLOGY SECTIONS

FIGURE 2-6 SEDIMENT CHARACTERISTICS AT THE PROPOSED OUTFALL LOCATION (LEFT) AND URALA CREEK SOUTH (RIGHT)

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FIGURE 2-7 SEDIMENT SAMPLE LOCATIONS

Further inland, the majority of the development footprint sits in the supratidal salt flats. The soil in this region was extensively studied by Blandford et al (2005), with multiple soil samples taken approximately 10 – 30 km south of the site. The sediments in this area are subject to the drivers of wind and storm tides, along with deposition during flood events and have therefore been worked into a complex arrangement. The primary materials present include sand, mud and silt, with each varying depending on the primary driver at the local site.

TABLE 2-3 SOIL PARTICLE SIZE ANALYSIS RESULTS

Location	Median particle size(mm)	Soil Classification
Outfall (or jetty location)	0.213	Fine sand
Uralla Creek South	0.154	Fine sand
Uralla Creek North	0.158	Find sand

2.5 Sediment Transport Processes – Sandy Beaches

The Western Australia State Planning Policy 2.6 (SPP2.6) “Coastal Planning” nomenclature for coastline indicates that Sections 2 to 4, the most northern sections shown in Figure 2-5, can all be defined as “sandy coasts” (WAPC, 2013).

Section 1, the southern-most section between Toms Creek and North Creek, can be defined as “coastal lowland”, as part of the Yannarie River outwash plains (WAPC, 2013).

To estimate historical shoreline movement trends, available aerial imagery from 2001 was compared to aerial imagery from 2017 by tracing vegetation lines at the rear of the beaches. Due to the remote nature of the study site, there is limited availability of historical aerial imagery. This method is not applicable to the coastal lowland coastline due to the extensive mangrove presence.

Section 1 – Toms Creek to North Creek

This section does not exhibit a ‘shoreline’ as such, as it consists of a series of creeks and tidal flats bounded by mangroves. The extent of these mangroves may vary over time but will be less variable than the sandy shoreline due to the dense vegetation bounding the creeks. This area is provided in SPP2.6 specifically as a coastal lowland outwash plain.

Section 2 – North Creek to Urala Creek South

Section 2 shows an overall pattern of an accreting shoreline, with the vegetation line moving towards the ocean between 2001 and 2017, as shown in Figure 2-8 (left). The areas of maximum accretion are at the far northern (Southern Urala Creek) and far southern end (North Creek) of the section near the creek mouths, with up to 45 m (2.8m/year) of accretion. The Urala Creek South river mouth appears especially mobile on the southern side, with the sand spit appearing to grow and deflect to the north-east between images.

Section 3 – Urala Creek South to Urala Creek North

Between the Urala Creek mouths, the overall pattern is that of a stable shoreline, with some minor localised erosion and accretion between 2001 and 2017, as shown in Figure 2-8 (right). The area of local maximum erosion is along the western beach face, with up to 17m (1.1m/year) of vegetation line retreat. The vegetation line is also setback on the eastern side of the extensive sandplain system on Tubrigdi Point – this appears to not be due to erosion, but instead due to vegetation being enveloped by the moving sandplain.

Section 4 – Urala Creek North to Locker Point

In this section, the overall pattern is that of a stable shoreline, with the vegetation line showing areas of minor accretion and erosion between 2001 and 2017, as shown in Figure 2-9. The areas of maximum accretion are at the far northern end near Locker Point, with up to 30m (1.9m/year) of accretion. The area with maximum erosion is along the western shore, with up to 15m (0.9m/year) of erosion.

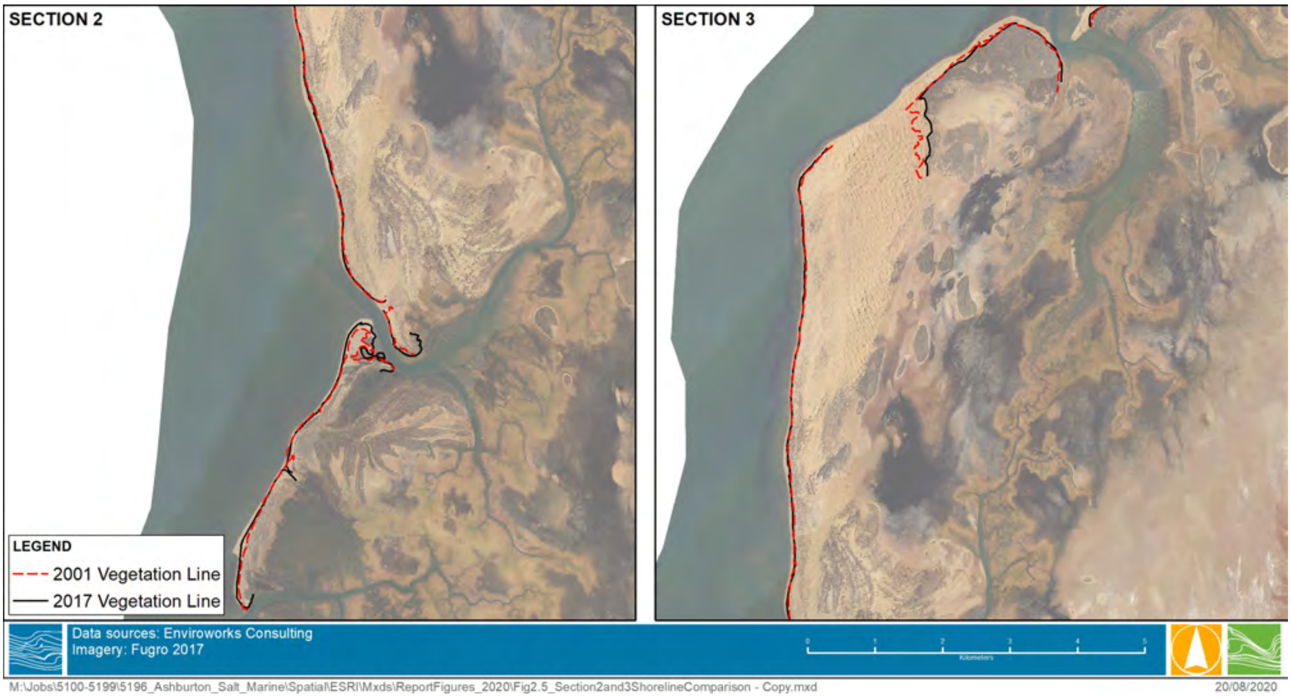

FIGURE 2-8 SECTION 2 AND 3 SHORELINE COMPARISON (2001 – 2017)

FIGURE 2-9 SECTION 4 SHORELINE COMPARISON (2001 – 2017)

2.6 Sediment Transport Processes – Urala Creek South

2.6.1 Historical Shoreline Movement

To analyse changes in the planform and bank location of Urala Creek South over a long timeframe, aerial and satellite imagery was analysed between 2001 and 2017. Bank and bend lines have been mapped and are presented in Figure 2-11.

In general, Urala Creek South shows a meandering planform, comprising a single main channel with dendritic smaller tidal creeks joining the main channel along its length. Analysis of historical aerial imagery captured between 2001 and 2017 indicates that downstream and upstream of the proposed intake location, there has been very little change in bank alignment over the period analysed. However, there has been change at the creek mouth, with accretion on the western bank.

2.6.2 Fluvial morphology

Fluvial morphology in Urala Creek South is tide dominated, while being occasionally affected by storms and extreme events. As noted above, the creek comprises a main channel which shows very minimal change in bank alignment since 2001. Mangrove habitats stabilise the riverbank and sediments with dense vegetation. The oscillatory tidal flow appears to have attained a dynamic equilibrium within the body of the creek, showing no clear trend of bed level/shoreline change.

Within a channel bend, flow is directed preferentially towards the outside bank which generates a vertical component of velocity resulting in scour of the bank, and typically deeper water on the outside bend. (Figure 2-10).

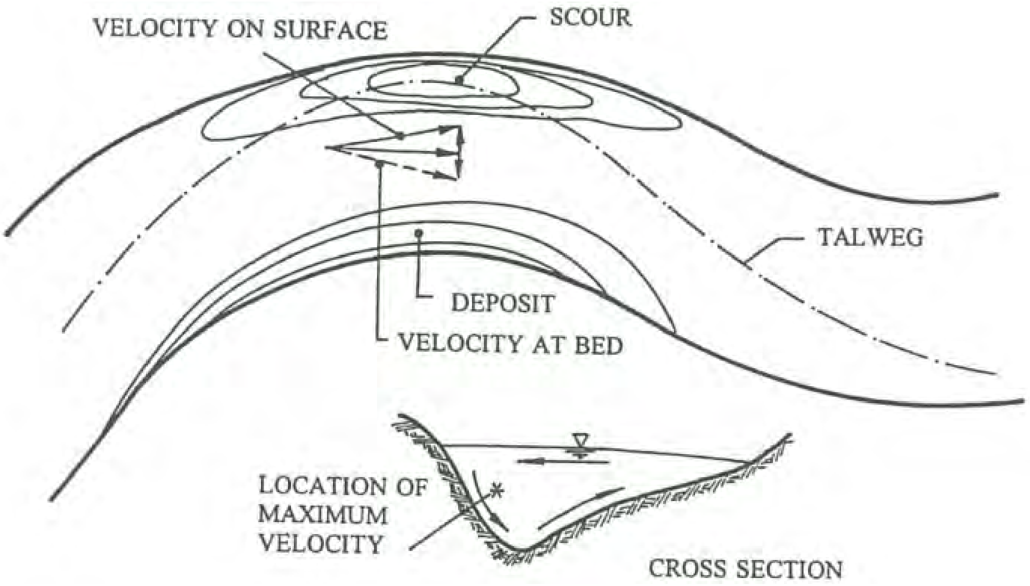

FIGURE 2-10 VERTICAL VELOCITY COMPONENTS OPERATING AROUND A CHANNEL BEND (RAUDKIVI, 1998)

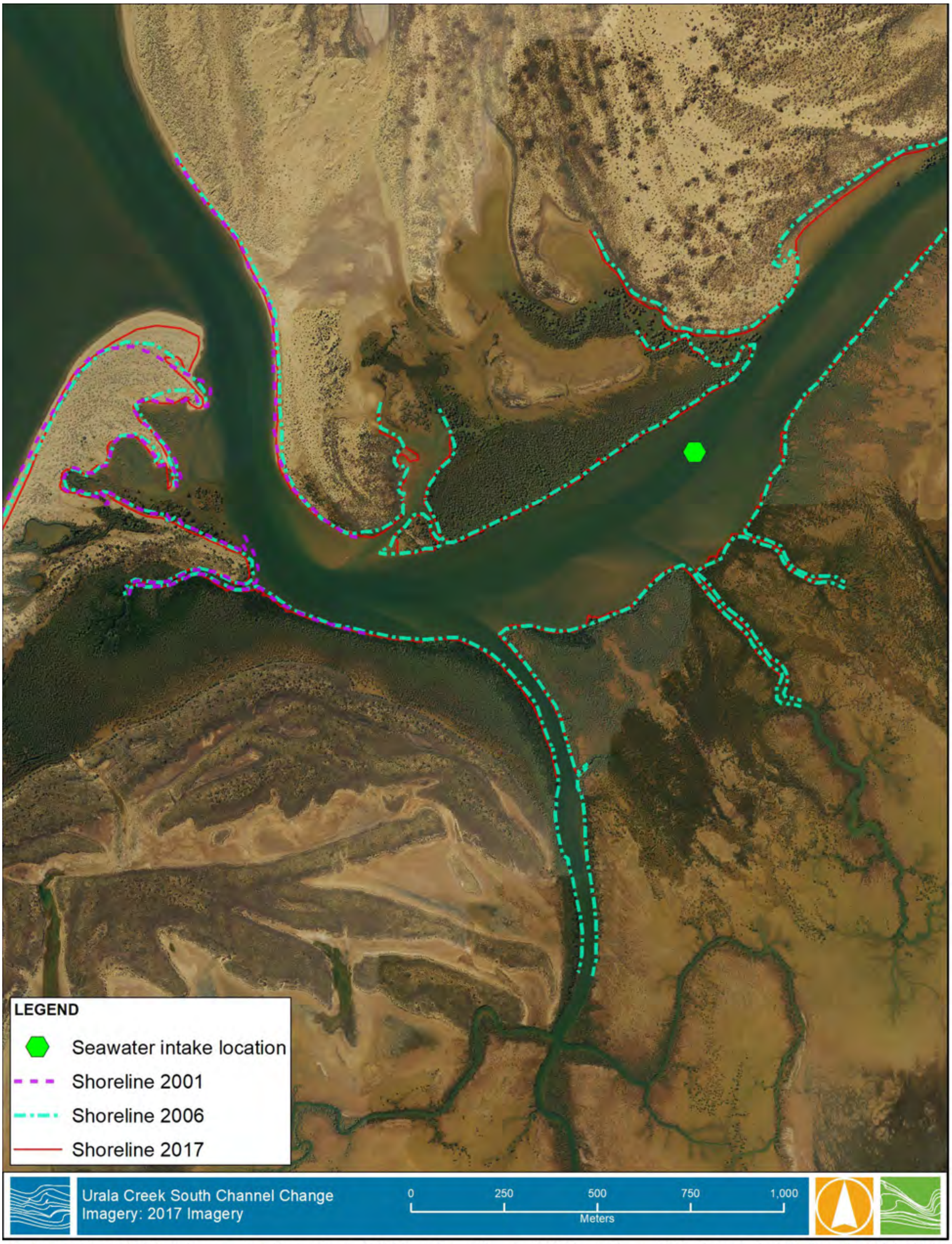

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FIGURE 2-11 URALA CREEK SOUTH SHORELINE CHANGE 2001-2017

3 CATCHMENT AND SURFACE HYDROLOGY

3.1 Overview

The proposed project is located approximately 40 km south west of Onslow Western Australia, between the Ashburton and Yannarie Rivers. Relevant surface water catchments are shown in Figure 3-1. The red boundary denoted as the ‘Hydraulic Model Extent’ in Figure 3-1 represents local surface water catchment relevant to the proposed project.

The Ashburton River is the largest waterway in the vicinity the project site. It has a catchment area of approximately 71,000km^2 and has a defined waterway all the way to the coast. The river is perched between natural levee banks, and any flood waters that escape from the channel tend to fan out across the floodplain, both to the west and east. The floodplain comprises a range of landforms and when flood waters from the river reach the outwash plain inland of the project area, they inundate interdunal basins and claypans. Much of the water that reaches these storages is eventually lost through evaporation and to a lesser extent through infiltration. There is no direct connection of the Ashburton River to the project site, however there are some overland flow paths across the floodplain to the west of the main Ashburton River channel, which direct flows towards the salt flats and intertidal areas, including those near the project site.

The Yannarie River lies to the south of the project site. It has a catchment area of approximately 4,300 km^2, and a stream length of 185 km. The channel becomes poorly defined where it reaches the outwash plain inland of the project site and its flood waters spread out across the outwash plain and dune field. Similarly, the adjacent Rouse Creek which has a catchment area of 1,700 km^2 and a stream length of 75 km has no defined channel once it reaches the outwash plain (Blandford et al 2005). As with Ashburton River flows, when waters from these systems reach the outwash plain, they flood interdunal basins and claypans, where much of the water is eventually lost through evaporation and to a lesser extent through infiltration. During significant flood events, water from these systems can enter the salt flats and intertidal areas to the west of the project area via overland flow paths.

Local rainfall across the local catchment also contributes to runoff toward the project area, during significant rainfall events.

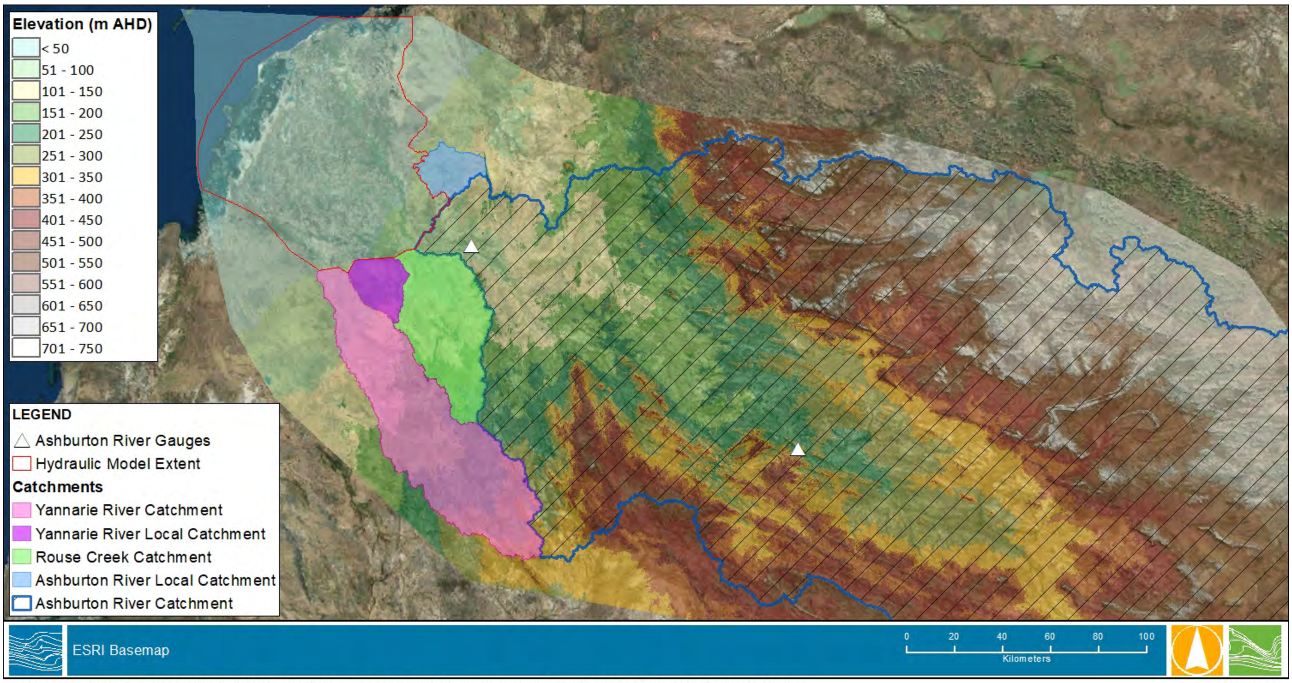

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FIGURE 3-1 SURFACE WATER CATCHMENTS

3.2 Local Surface Hydrology

The surface hydrology in and around the project site is a complex interaction between watercourses including the Ashburton River, Yannarie River and Rouse Creek and the wide outwash plain, salt flats and dune fields adjacent to the coast.

The results of floodplain hydraulic modelling indicate that catchment generated flows enter the salt flat areas during rainfall events of 2-year ARI and above. The more minor rainfall events cause shallow short-lived ponding within the salt flats, whilst larger rainfall events cause deeper and longer duration flood waters within the salt flats and flow connection with tidal creeks.

Within the report *Surface Water Assessment and Modelling* (Water Technology, 2021), an estimate of the duration of flooding within the salt flats was calculated for both minor and major rainfall events, based on average modelled flood depths and the evaporation rate of 12 mm per day (given evaporation causes removal of floodwaters). The adopted evaporation rate of 12 mm is the approximate average daily evaporation rate for the period November through to March, when the majority of rainfall occurs at Ashburton. Table 3-1 below summarises the modelled average flood depth and estimated flooding duration within the salt flats under both minor and major rainfall events. These estimates are conservative given infiltration rates are not considered.

TABLE 3-1 ESTIMATED SALT FLAT FLOODING EXTENT AND DURATION FOR VARIOUS RAINFALL EVENTS

Rainfall Event (AEP)	~ ARI	Average Depth of Flooding in Salt Flats	Estimate of Salt Flat Flooding Duration (Days)
50 %	2 year	0.25 m	20
20%	5 year	0.35 m	29
10%	10 year	0.50 m	41
5%	20 year	0.75 m	62
2%	50 year	1 m	83

Catchment inflows to the project area have been modelled within the report *Surface Water Assessment and Modelling* (Water Technology, 2021). The generalised flow paths are mapped below in Figure 3-2.

Breakout overland flows from Yannarie River and Rouse Creek typically enter the coastal system 35 km to the south of the proposed project.

Breakout overland flows from the Ashburton River combined with local runoff create sheet flow conditions across the catchment and flows that pass through the inland dune field and claypan system.

Overland flows from the hinterland dune field immediately to the east of the project enter the salt flats via large local claypans adjacent to the eastern boundary of the proposed salt evaporation ponds.

To the immediate north and south of the proposed project local flows are conveyed along more defined local flow paths, specifically 'Chinty Creek' to the north and an unnamed flow path to the south (Figure 3-2).

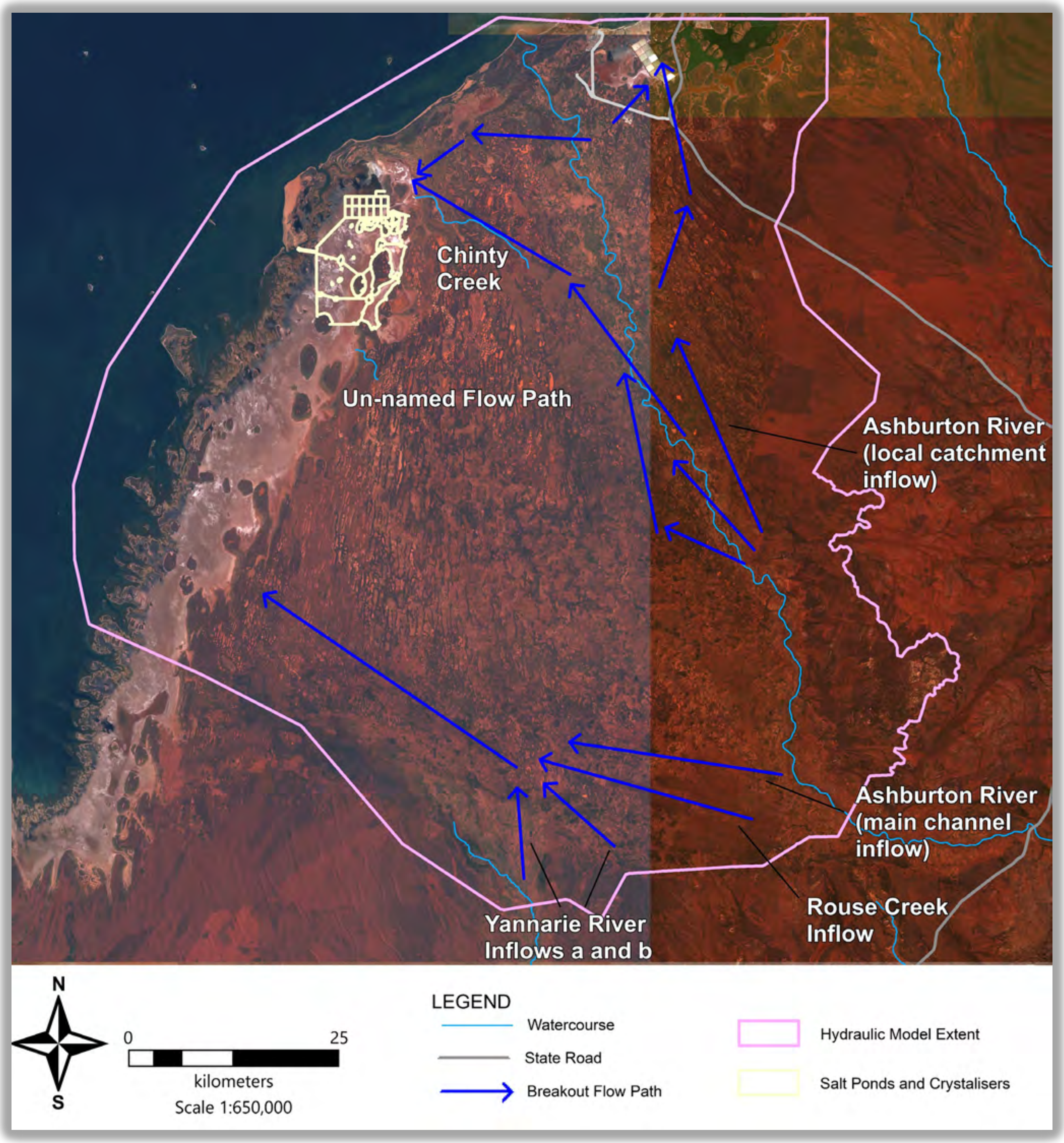

FIGURE 3-2 GENERALISED INFLOWS TO PROJECT AREA AND FLOW PATHS

4 BATHYMETRY AND TOPOGRAPHY

4.1 Regional Bathymetry

4.1.1 Pilbara System

The continental shelf in the Pilbara system is considered relatively smooth and featureless compared with the Kimberley and Ningaloo systems. The bathymetry of the Pilbara system and the continental shelf is shown in Figure 4-1. A cross section showing the bathymetry across the shallow shelf to the Murion Islands is also presented. The bathymetric profile illustrates the wide shallow waters offshore of the site where the depth remains less than 20 m close to 35 km offshore before gently sloping offshore to a small break in the shelf at 160 m depth which extends roughly 15 km. From this point, the bathymetry slopes downwards to below 1,000 m over approximately 50 km across the Exmouth Plateau.

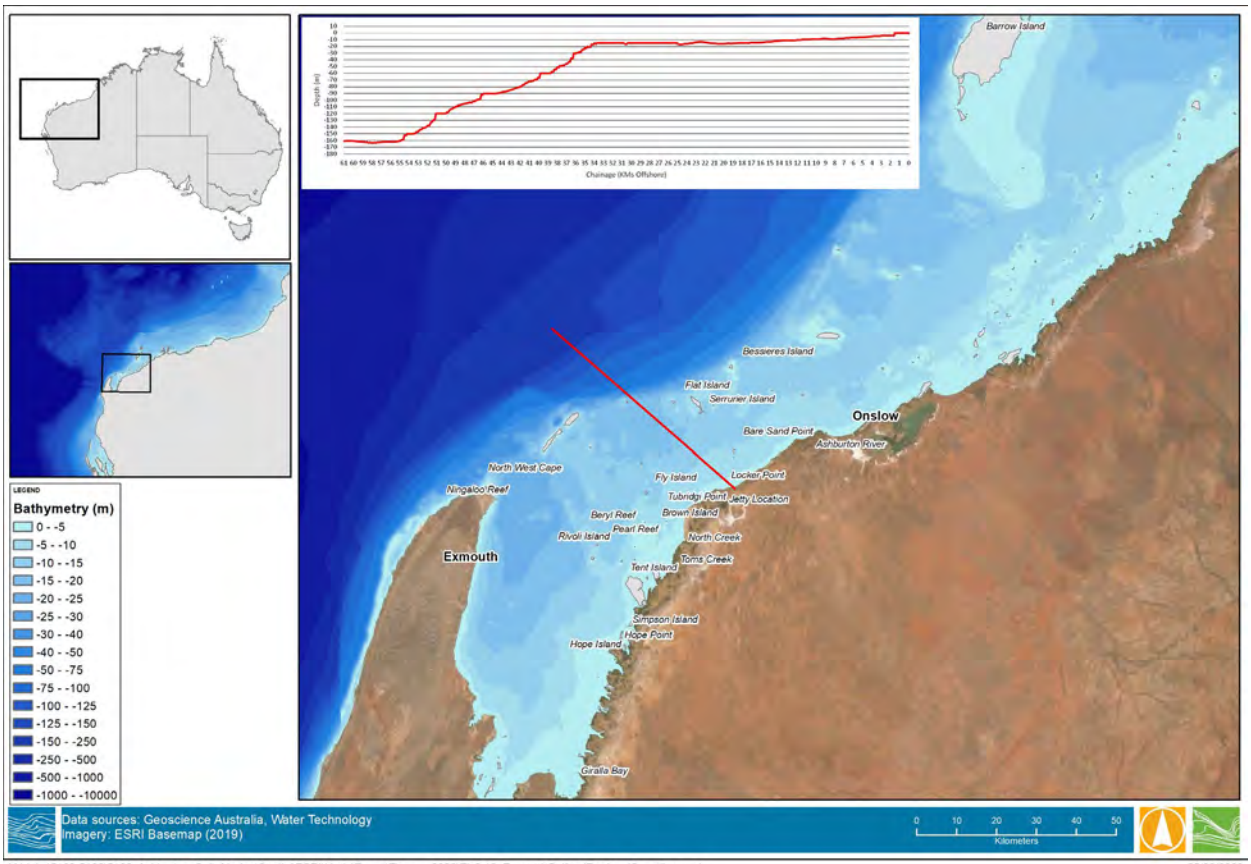

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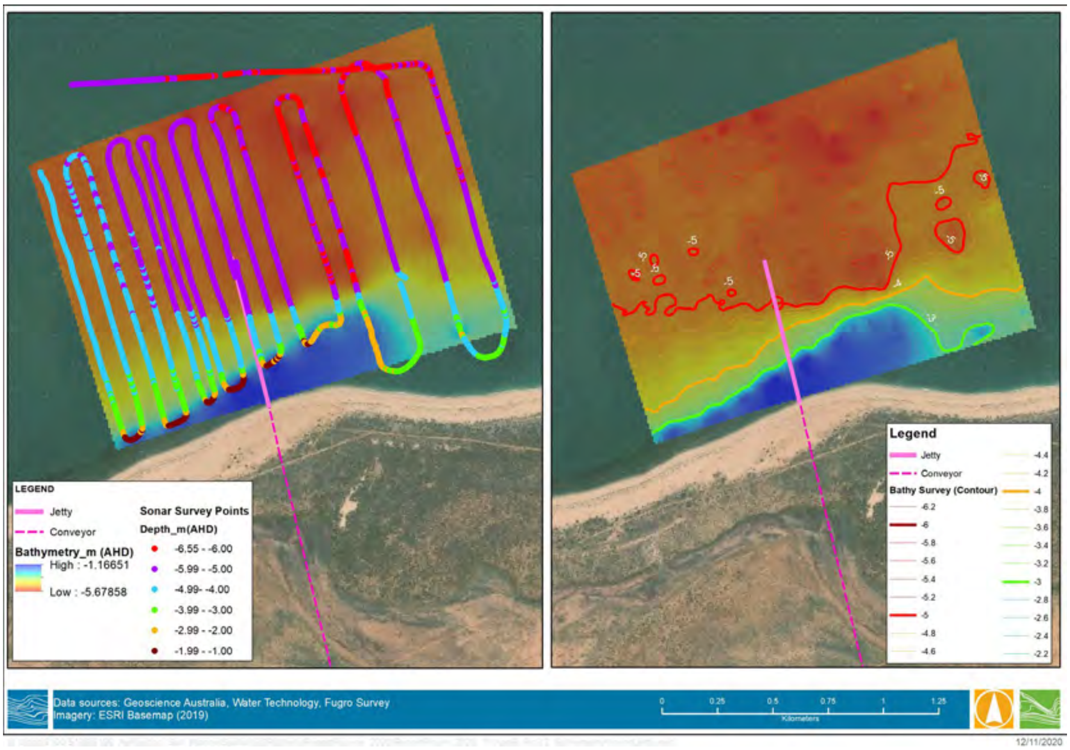
FIGURE 4-1 PILBARA SYSTEM BATHYMETRY

4.2 Local Bathymetry

4.2.1 Locker Point Coastline Bathymetry

A bathymetric survey was undertaken by Fugro along the coastline of the project in 2017. A digital terrain model was constructed from the 2017 survey and is presented in Figure 4-2. A gap in the bathymetric survey was infilled by additional sonar transects in mid-2020. The area of sonar transect infill is shown in Figure 4-2

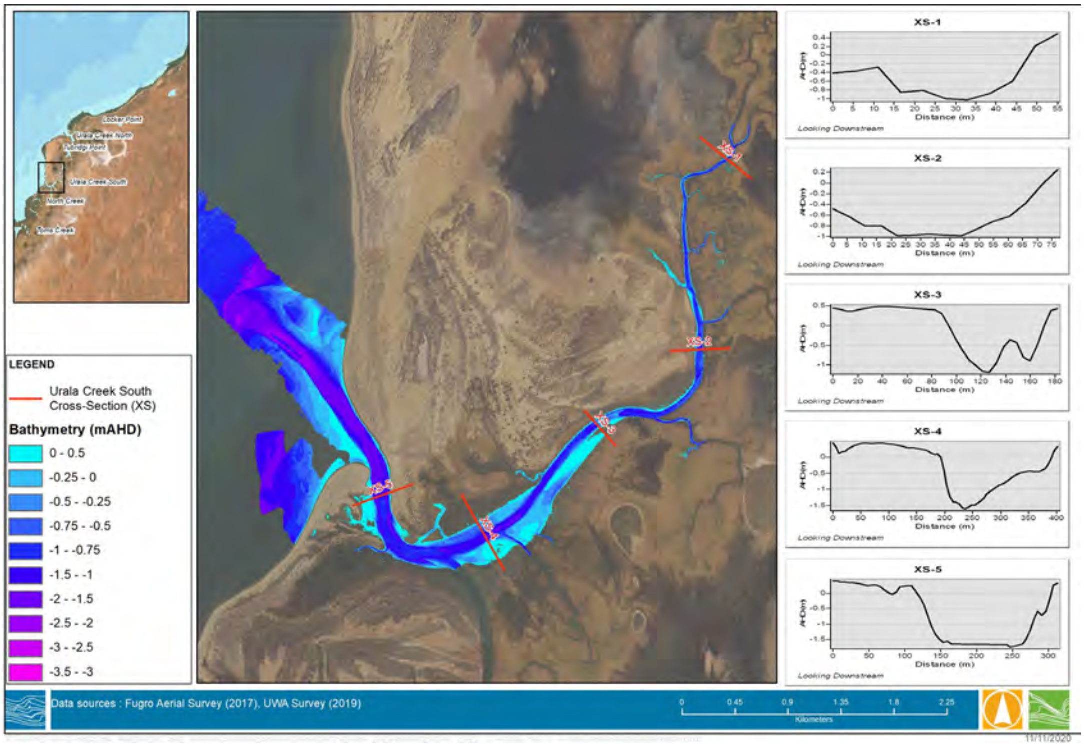


Data sources: Geoscience Australia, Water Technology, Fugro Survey
Imagery: ESRI Basemap (2019)

FIGURE 4-2 BATHYMETRY AT PROPOSED JETTY

4.2.2 Urala Creek South Bathymetry

A bathymetric survey of Urala Creek South was also undertaken by Fugro in 2017. The results of the survey are displayed in Figure 4-3 and show that channel depth and width decrease upstream of the river mouth with large intertidal areas in the mid estuary between XS-3 and XS-4.



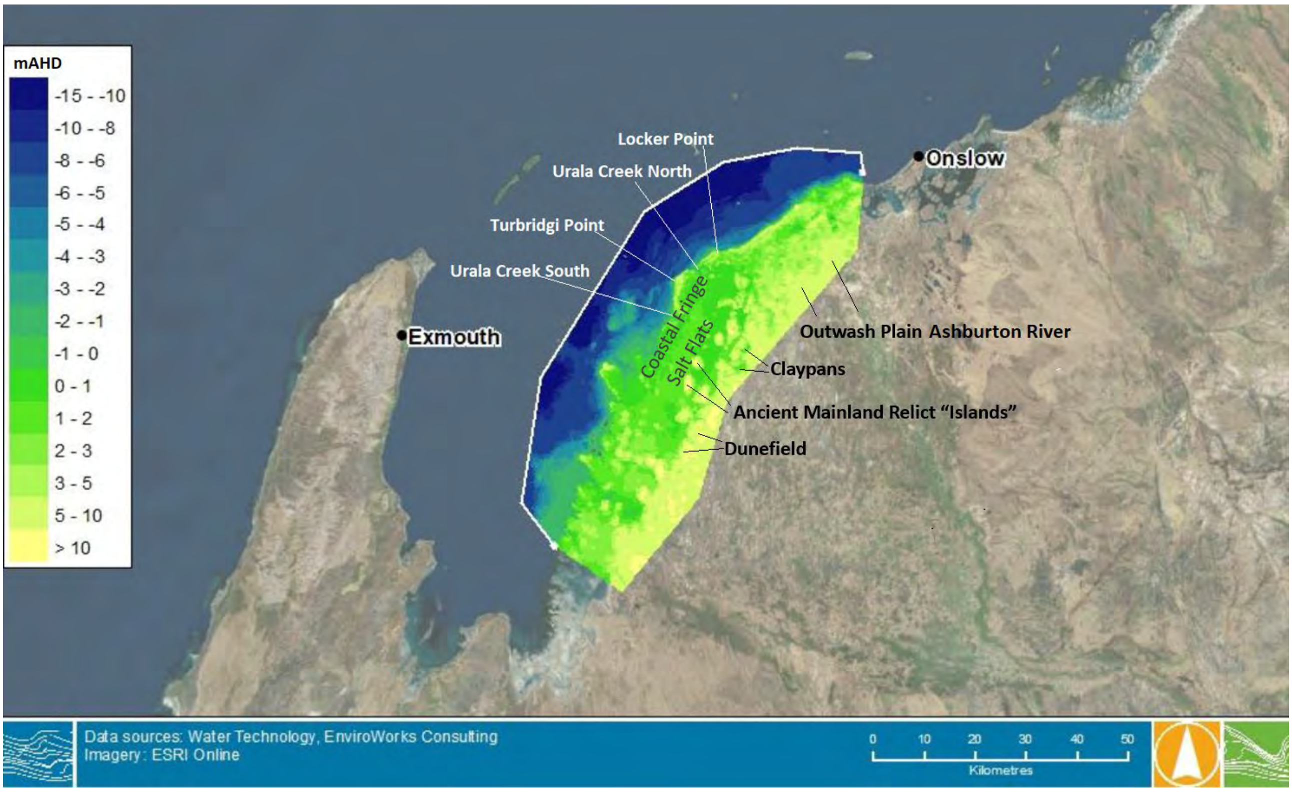
Data sources : Fugro Aerial Survey (2017), UWA Survey (2019)

FIGURE 4-3 URALA CREEK SOUTH BATHYMETRY

4.3 Local Topography

A Lidar topography survey of the landside project area was undertaken by Fugro in 2017, with the resulting data used by Water Technology (2021) to generate a Digital Elevation Model (DEM) as shown in Figure 4-4. The Project area exhibits the following landform (Blandford et. al., 2005) with topography as described below from the DEM:

- Coastal sand dunes exist along Turbridgi Point and extending north to Locker Point ranging in elevation 5 – 12 m AHD.
- The coastal fringe occupied by mangroves and algal mats ranges in elevation from 0 to 1 m AHD.
- The salt flat elevation ranges from 1 to 2 m AHD, interspersed with ancient mainland remnant “islands” with elevations of 3 – 16 m AHD.
- A longitudinal dune field sits inland of the salt flats with dune elevations up to 19 m AHD, interspersed with low lying claypans with elevation 0 – 3 m AHD.
- Outwash plains occur at elevation 3 – 5 m AHD, consisting of alluvial and colluvial sediments, due to floodplain flow from the Ashburton and Yannarie Rivers.



Data sources: Water Technology, EnviroWorks Consulting
Imagery: ESRI Online

FIGURE 4-4 LOCAL BATHYMETERY AND TOPOGRAPHY

5 METEOROLOGY

5.1 Overview

The climate at Ashburton is classified as hot, semi-arid with rainfall occurring from January through to July. The dry season occurs from late August through to December. There is a tropical cyclone season that runs from the middle of December to April with a peak occurring in the wet months of February and March.

Key climatic drivers are presented in Figure 5-1, presented by the Bureau of Meteorology (BoM, 2010). Along the Pilbara coast, the Indian Ocean Dipole, West Coast Troughs and Northwest Cloudbands dominate climatic conditions. In addition to this, the position of the subtropical ridge influences the seasonal change as the ridge shifts to the south in summer and to the north in winter, resulting in contrasting wet and dry seasons, respectively.

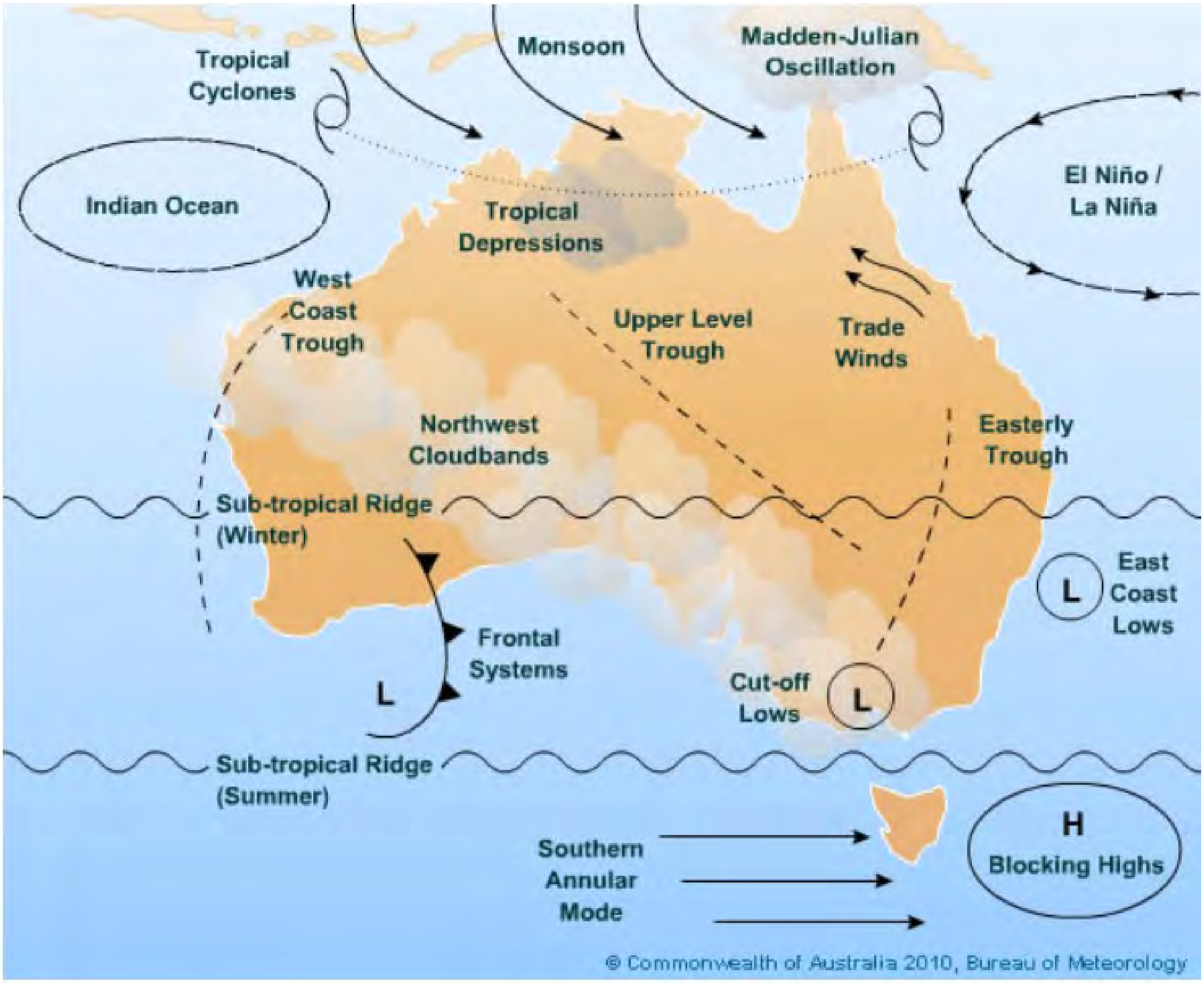
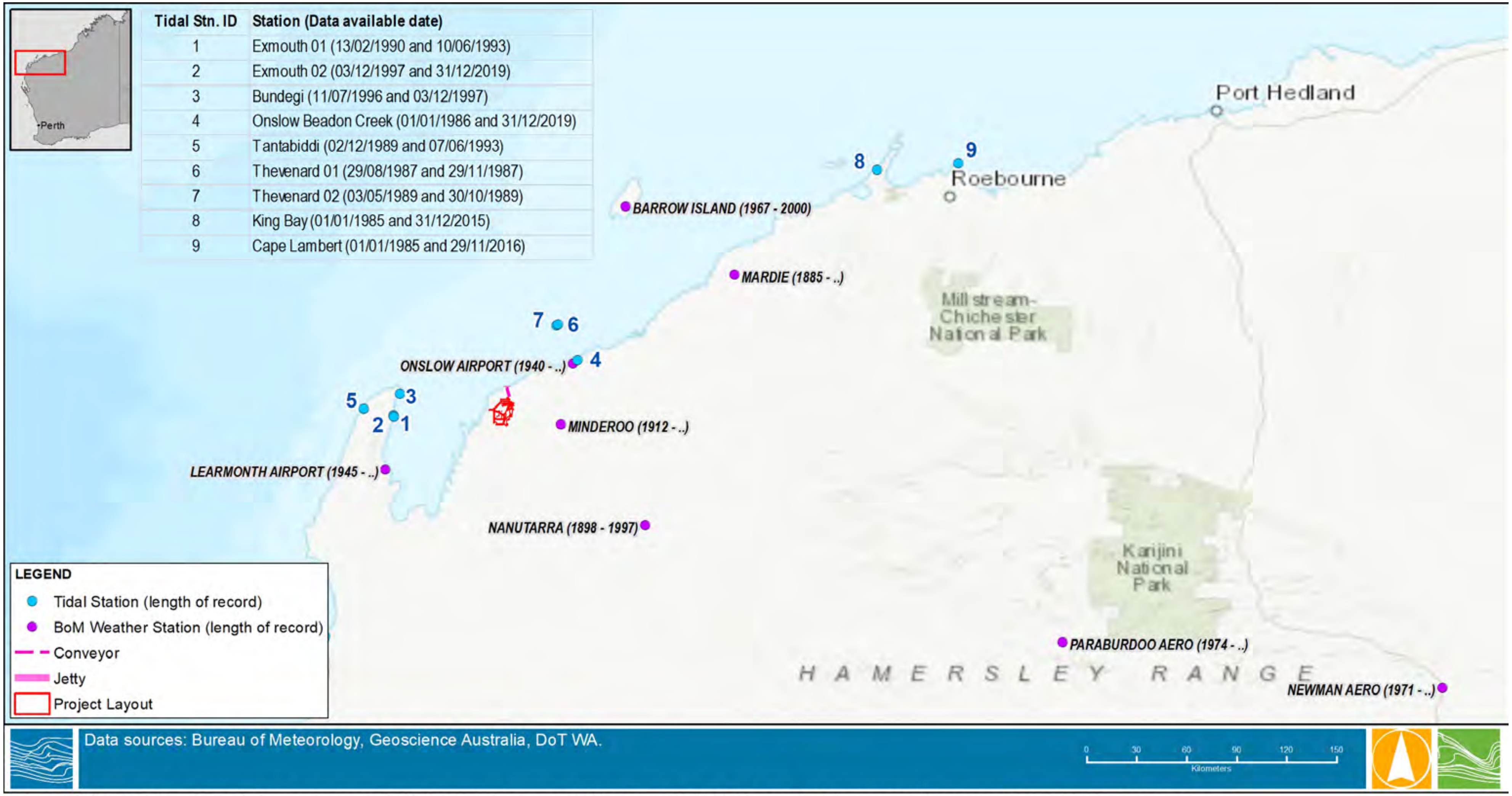


FIGURE 5-1 AUSTRALIAN CLIMATE DRIVERS (BOM 2010)

A description of climatic variation across the seasons, and typical and extreme values is provided below. Data has been sourced from the Bureau of Meteorology (BOM) at a number of stations around Ashburton. The stations for which data has been analysed are shown in Figure 5-2.

Recorded data in the area is relatively sparse; the distances between the site and the closest two stations of Learmonth and Onslow are approximately 82 km and 42 km respectively.



Tidal Stn. ID	Station (Data available date)
1	Exmouth 01 (13/02/1990 and 10/06/1993)
2	Exmouth 02 (03/12/1997 and 31/12/2019)
3	Bundegi (11/07/1996 and 03/12/1997)
4	Onslow Beadon Creek (01/01/1986 and 31/12/2019)
5	Tantabiddi (02/12/1989 and 07/06/1993)
6	Thevenard 01 (29/08/1987 and 29/11/1987)
7	Thevenard 02 (03/05/1989 and 30/10/1989)
8	King Bay (01/01/1985 and 31/12/2015)
9	Cape Lambert (01/01/1985 and 29/11/2016)

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FIGURE 5-2 LOCATION OF WEATHER AND TIDAL STATIONS AROUND ASHBURTON

5.2 Air Temperature

The average inland temperatures at Paraburdoo Airport (7185) and Newman Airport (7176) weather stations can be seen in Figure 5-3. The data periods for these monthly averages are based on long term available data from 2010 to 2020. The timeseries of temperature at Paraburdoo shows that across the year, the range in daily temperature is reasonably consistent at around 15ºC. The hottest months are December to March, with average monthly temperatures greater than 30ºC over this period. Winters are mild with average monthly temperatures between 15ºC and 20ºC, respectively.

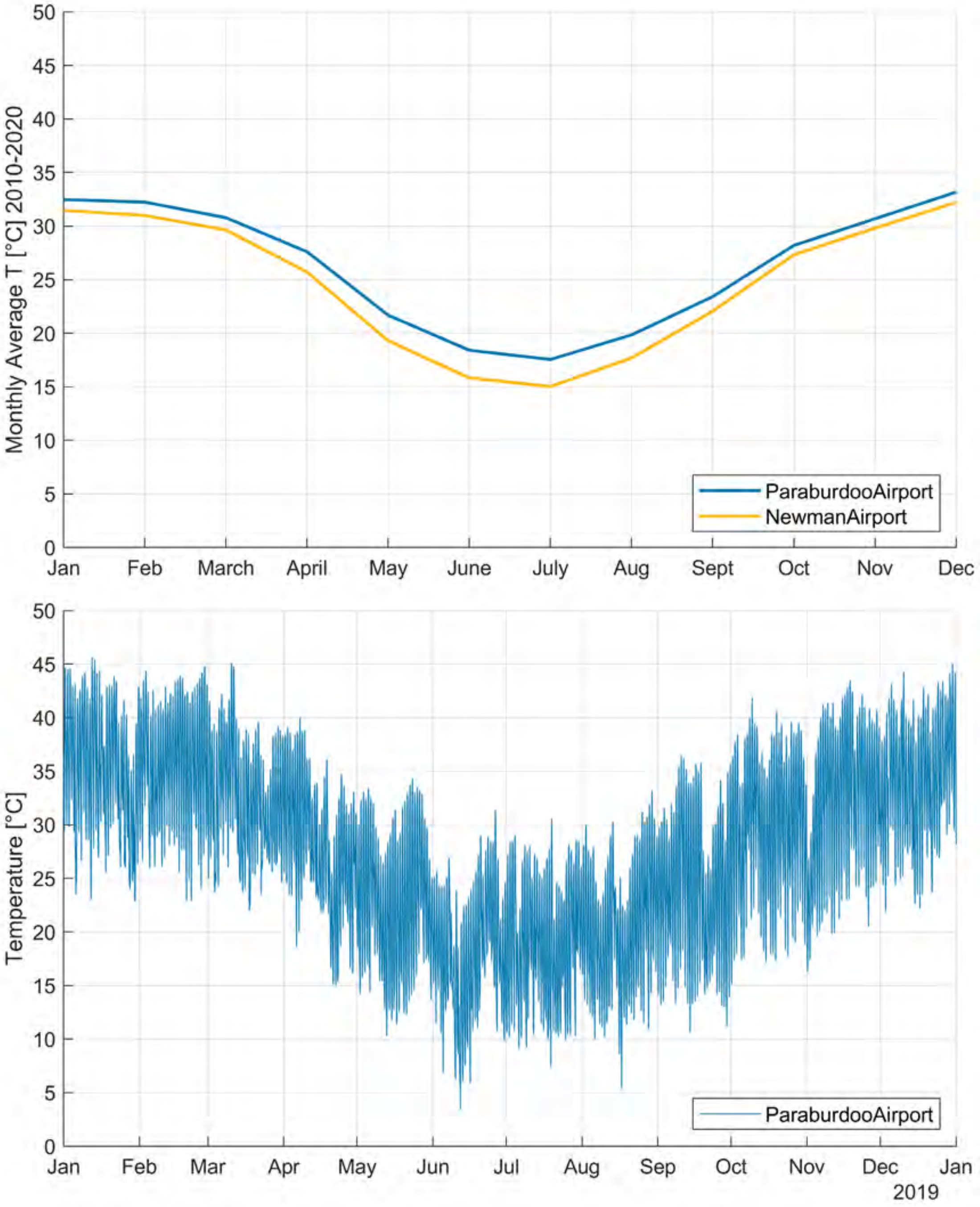


FIGURE 5-3 MONTHLY TEMPERATURE DATA

Figure 5-4 shows monthly average air temperatures for relevant sites near the coast. The data periods for these monthly averages are based on the last ten years of data from 2010 to 2020. There is some spatial variation across the region, reflective of the different conditions at each site.

The time series in the lower panel of Figure 5-4 show hourly temperature data at Onslow throughout 2019. The daily temperature range at Onslow is quite consistent at around 12.5ºC which isn't as large as the daily fluctuation inland at Paraburdoo. The hottest months occur from December through to March with average monthly temperatures above 28ºC within this period.

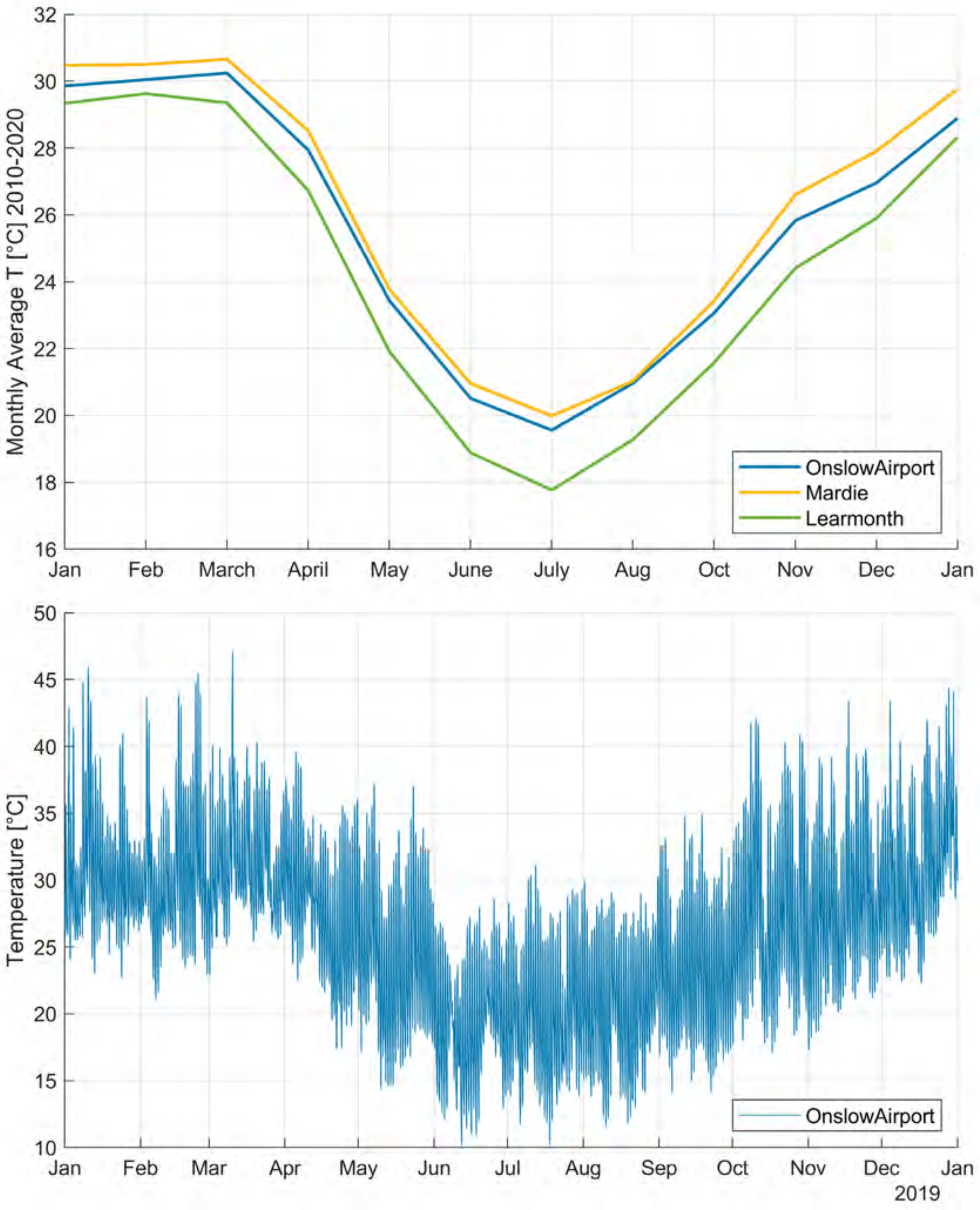


FIGURE 5-4 MONTHLY AVERAGE AIR TEMPERATURES AT BOM WEATHER STATIONS

5.3 Rainfall

Areas on the west margin of the eastern side of the Exmouth Gulf are located within the Australian Southern Semi-arid Pasture Region land use zone. Due to the sparse and highly variable rainfall in this region, surface runoff is usually only generated during extreme weather conditions, typically associated with tropical cyclones. During these events, discharge from the river system causes flooding of the salt flats. This is usually accompanied by storm tide inundation (Blandford et. al., 2005).

Rainfall across the inland Ashburton catchment is spatially variable due to its large size and varying elevation. The highest area within the catchment is in the Hamersley Ranges which runs along its northern border and reaches elevations of 1,200 m and higher. The northern side of the Hamersley Ranges, which lies outside the catchment, experiences greater rainfall than that inside the catchment due to the orographic effect of the mountain range which induces precipitation around twice the magnitude experienced within the catchment.

Figure 5-5 shows the average monthly rainfall for three locations within or near the Ashburton River catchment. Averages were calculated using the last ten years of data from 2010 to 2020. Most of the rainfall within the catchment occurs from January to March. The months of May and June experience moderate rainfall around 20mm. The period with the lowest rainfall is August to November with less than 10mm average monthly rainfall.

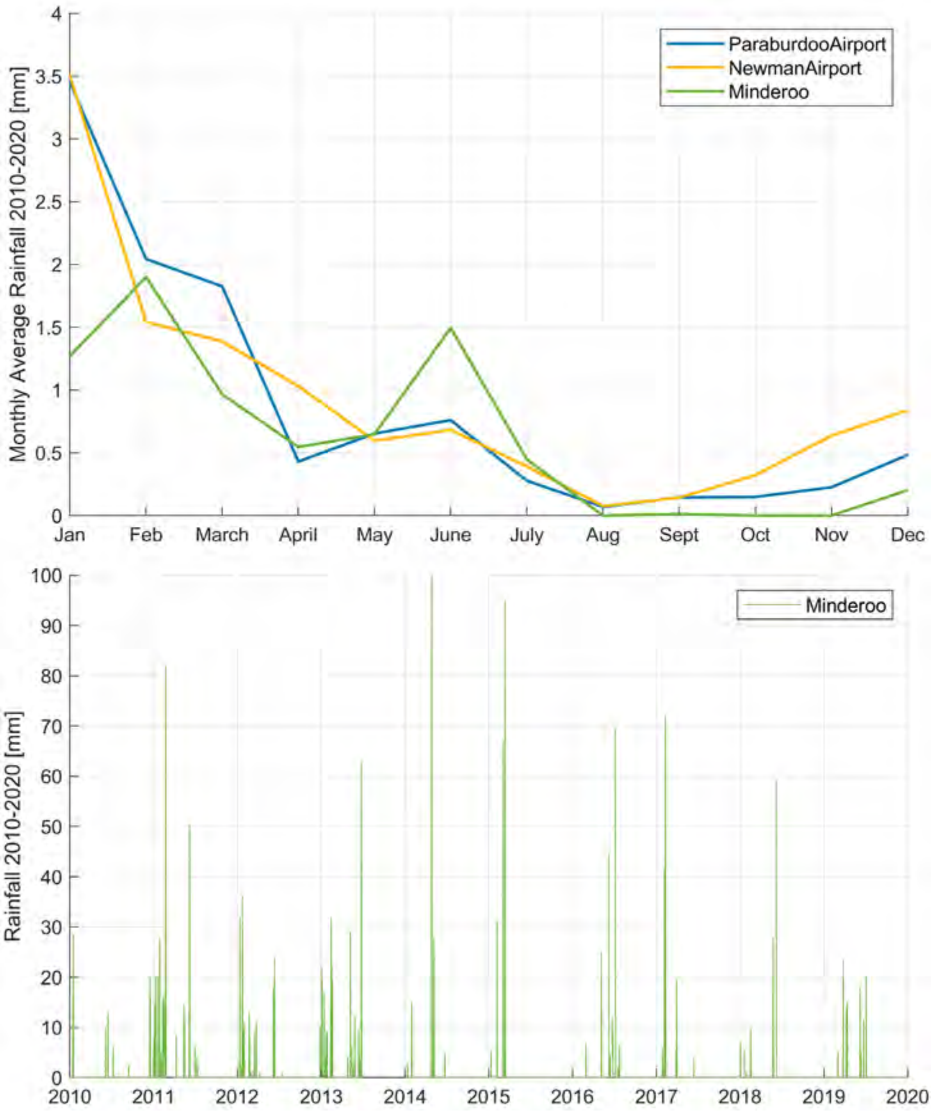


FIGURE 5-5 AVERAGE MONTHLY RAINFALL FOR BOM WEATHER STATIONS WITHIN OR IN CLOSE PROXIMITY TO THE ASHBURTON RIVER CATCHMENT

Average monthly rainfall recorded at the Onslow Airport, Learmonth Airport and Mardie stations is displayed in Figure 5-6. At Onslow Airport, the average annual rainfall is close to 350 mm with the majority occurring in late January to March (associated with the passage of tropical cyclones) and between May and June. A time series of daily rainfall at Onslow is presented in the figure and shows the seasonal nature of the rainfall.

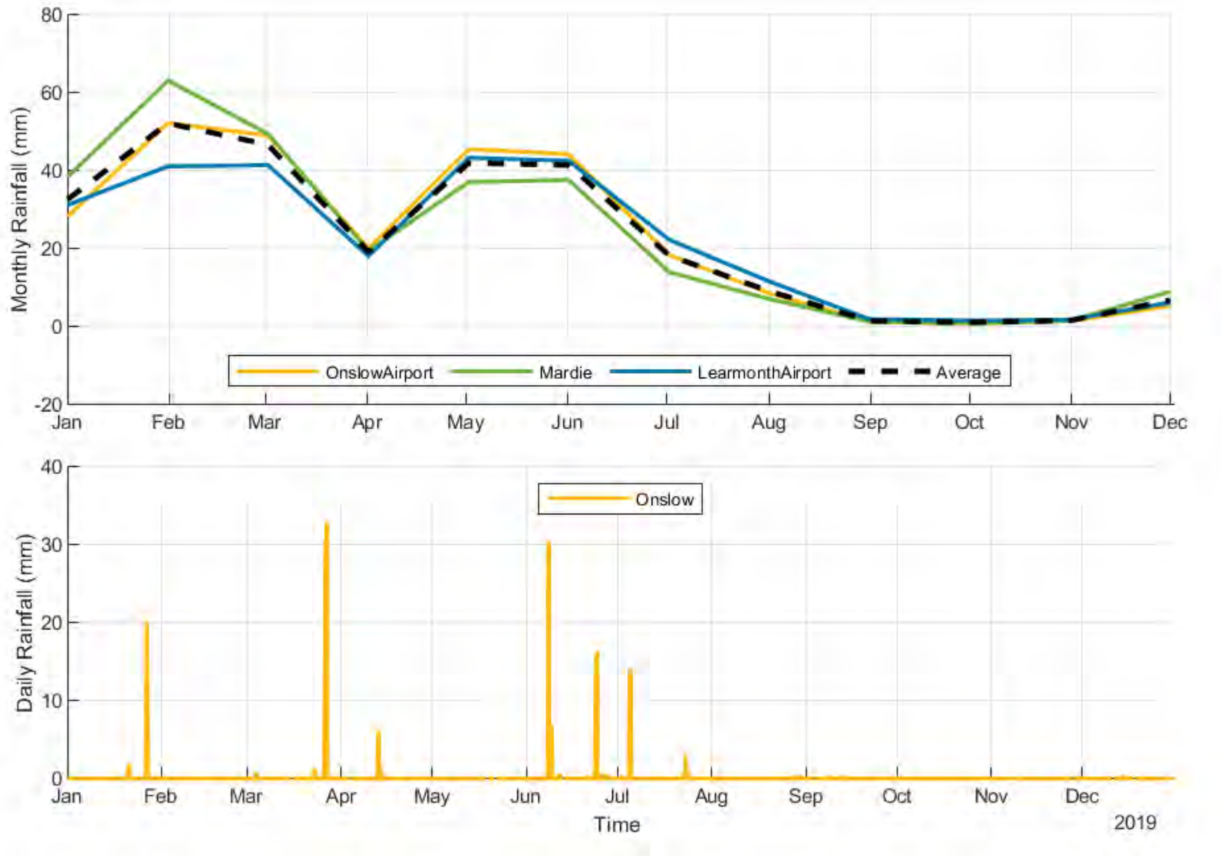


FIGURE 5-6 MONTHLY RAINFALL STATISTICS FROM SEVERAL SITES AND TIMESERIES OF RAINFALL AT ONSLOW (SOURCE: BOM)

5.4 Evaporation

High temperatures in the region lead to high rates of evaporation with a strong seasonal trend. This evaporation can impact shallow or still water bodies and cause increases in salinity in coastal estuaries. Evaporation follows the seasonal temperature pattern, with high levels of evaporation occurring during the summer months. This is attributable to the higher solar radiation, higher temperatures and stronger wind speeds.

Class A pan evaporation rates have been recorded by the BoM at the Onslow and Learmonth Airport stations periods of 8.5 and 45 years, respectively. A summary of monthly average daily evaporation rates (mm/d) at Learmonth is presented in Figure 5-7. It is noted that the Learmonth weather station ceased measuring evaporation in 2017.

Averages have been calculated for the entire datasets as well as for the last 7 years of evaporation measurement. The difference in data between analysis periods is high, with the most recent data showing higher evaporation. This could be due to natural interannual temperature variations or gradual temperature increases due to climate change. The evaporation rates are higher through the summer months (11-12 mm daily evaporation) and peak in December and over the last 6 years of the data record evaporation rates were higher on average. They are also lower through the winter months, with the lowest recorded evaporation occurring in June at 4 mm/d. In this region, annual average rainfall (~350 mm) is significantly exceeded by the mean annual evaporation of 3,140mm (Blandford et al, 2005).

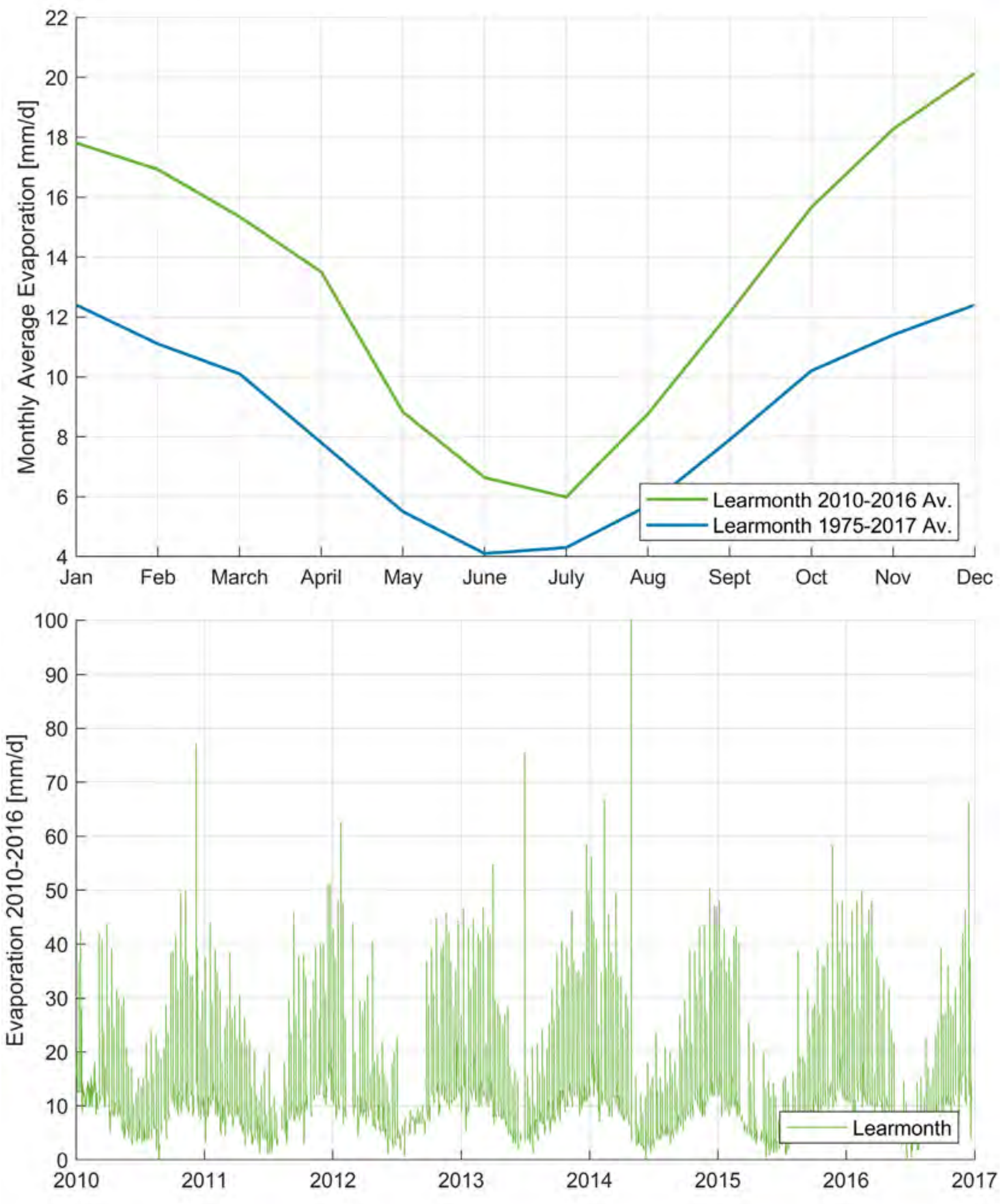


FIGURE 5-7 RECORDED EVAPORATION STATISTICS AT LEARMONTH

5.5 Wind Conditions

Dominant weather conditions around Exmouth Gulf are governed by:

- A synoptic sub-tropical high-pressure belt to the south; and
- A trough of low pressure that typically extends over the inland Pilbara during the summer months

These two processes contribute to a general south or south-westerly wind regime for the majority of the year, with more south-westerly winds common during the summer months.

On a daily scale, sea breezes are an important local-scale weather phenomenon. These breezes are generated by temperature differences between the land and the ocean and result in a strong contrast in wind conditions during the day. Generally, the daily variation in temperature of the land surface is greater than that of the ocean surface. Overnight, the land mass cools more than the ocean, resulting in lower air pressure and a drawing of air towards the ocean from the continent. In the case of Ashburton, this is an easterly wind. Through the day, as the landmass heats more than the ocean, the air pressure rises and air is drawn towards the coast, i.e. from the west or northwest.

Wind data recorded at Onslow Airport, Learmonth Airport and Barrow Island Airport has been reviewed. Wind roses showing wind direction and speed at Onslow Airport, Learmonth Airport and Barrow Island Airport stations for the period of record are presented in Figure 5-8. The three stations show varying wind conditions in line with their location on the coast and surrounding landforms.

Wind conditions at Learmonth Airport are dominated by south-westerly winds, with a strong southerly morning wind overshadowing lighter and more variable winds later in the day. Wind speeds are generally less than 7.5 m/s, with stronger winds above 10 m/s more common from the south-southwest, particularly during the summer months.

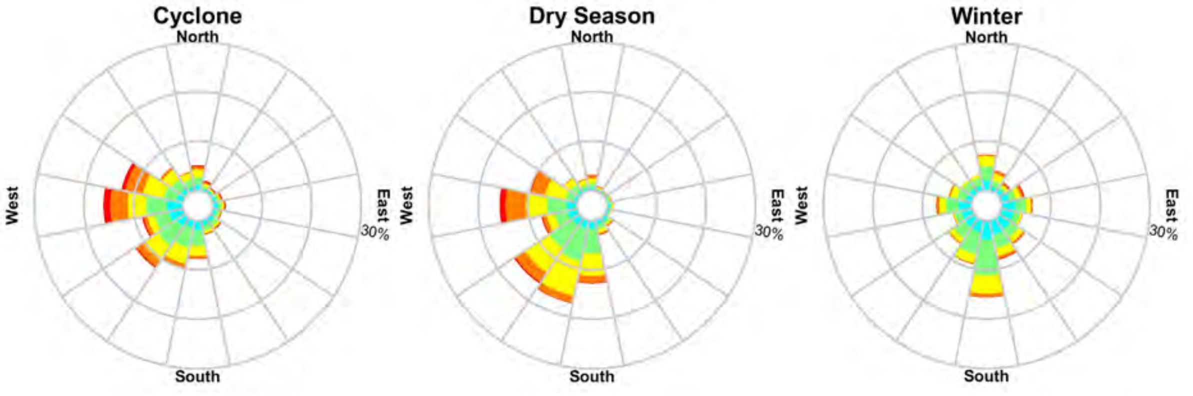
At Onslow, the wind climate is more variable and shows more westerly components compared to Learmonth, located on the western shore of Exmouth Gulf. The winds at Onslow are considered more typical of those likely to be experienced at Ashburton and as such the wind climate has been further analysed into winter (May through August), cyclone (mid-December through April) and dry (September to mid-December) season periods; noting as follows:

- Winter winds are largely northerly or southerly, with wind speeds less than 7.5 m/s;
- During the cyclone season, winds continue to be dominated by westerly conditions, however some additional northerly component is present, increasing towards the end of the season in April. Outside of a cyclone passing, winds are generally less than 10 m/s, although strong winds are observed from the west and west-northwest; and
- During the dry season, dominant winds are from the south through to west, with very little wind from the north through east to south. Wind speeds are stronger during this period, peaking through November when westerly breezes dominate. Winds can exceed 10 m/s during this period from the west.

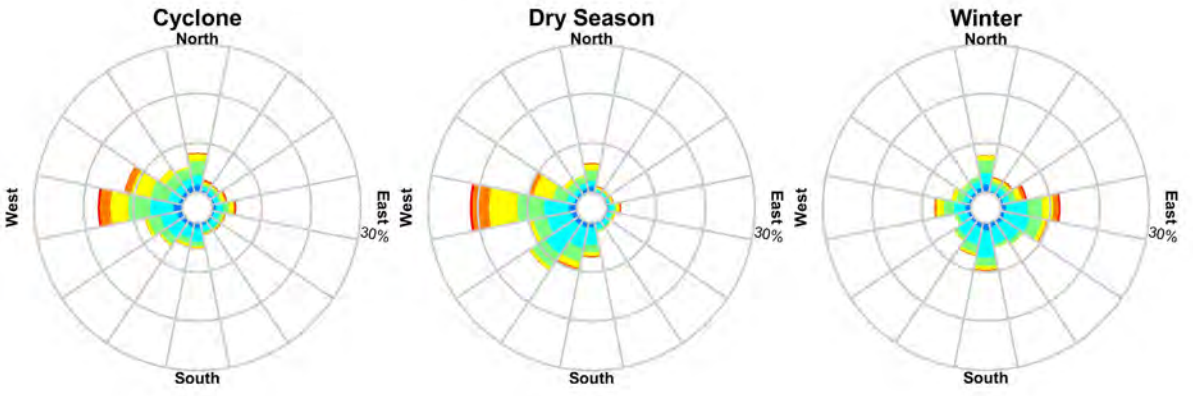
Based on these datasets, it can be inferred that a strong daily pattern will be present onsite, with lighter offshore winds in the morning followed by strong onshore conditions in the afternoon through evening year-round. During the winter months, light winds will blow across the site predominantly from the southeast in the morning or northwest in the afternoon. Winds will increase as the cyclone/summer season approaches and winds are likely to peak in November, driven by strong afternoon westerlies. Strong westerly afternoon breezes continue to dominate through to February until conditions gradually shift towards the winter pattern.

Onslow

Analysis Period: 01-Jan-2010 to 01-Nov-2020



Mardie



Learmonth

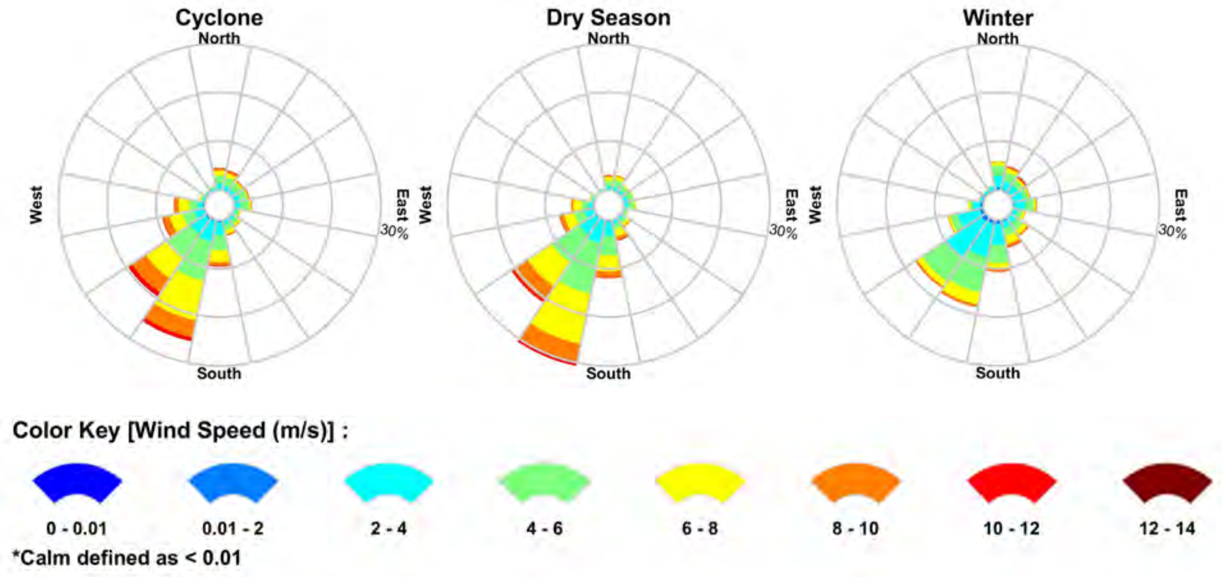


FIGURE 5-8 EXMOUTH GULF SEASONAL WIND CLIMATE

6 COASTAL OCEANOGRAPHY

Oceanographic conditions at Ashburton and along the Onslow Coast are driven by the variations in climate described above and astronomical tides. A suite of numerical models has been developed to simulate the oceanographic conditions in the region. The numerical modelling has been used to provide detailed oceanographic information at Ashburton as little recorded data existed prior to the data collection program implemented for this project (*Marine, Coastal and Surface Water Data Collection*, Water Technology 2021).

6.1 Tidal Water Levels

6.1.1 Ashburton Coast and Exmouth Gulf

Ocean tidal conditions force water into and out of the Exmouth Gulf on the flood and ebb tides. Tides along the Ashburton coast flow north and south with the forcing of water through the deeper channel to the north of the Northwest Cape. There is typically a well-defined spring-neap lunar cycle.

The closest “Standard Port” tidal stations to the site are located approximately 40 km north-northeast of the site at the entrance to Beadon Creek (herein referred to as Onslow), and in Exmouth Gulf approximately 80 km to the west-south-west at Exmouth (herein referred to as Exmouth) as shown in Figure 5-2.

A Standard Port has a longer period of more reliable data than a secondary port. The Royal Australian Navy’s (RAN) ‘Australian National Tide Tables’ (ANTT) uses a tidal datum epoch of 20 years for Standard Ports which covers 1992 – 2011. Tidal information at the nearby secondary ports (Point Murat, Y Island, North Muiron Island Roller and Ashburton North) is also provided by the ANTT. Tidal plane information for the Standard Ports is shown Table 6-1.

Tidal planes are also presented based on tidal constituents provided by RPS (2017) for the previous Ashburton Jetty Location. These tidal constituents are based on blending and adjusting a range of available data sources, primarily from ANTT data and RPS’s own historic tidal data in the area.

The astronomical tide along the coast and within Exmouth Gulf is semi-diurnal (i.e. two high and two low tides daily) with a slight diurnal inequality resulting in one higher tide and one lower tide per day. The mean spring tide range (0.89 m AHD) at Exmouth is the same as Onslow, whilst the range between the Highest Astronomical Tide (HAT) and the Lowest Astronomical Tide (LAT) is slightly smaller at Exmouth. This demonstrates the general consistency of tidal height magnitude along the coast and within Exmouth Gulf.

TABLE 6-1 ASTRONOMICAL TIDAL PLANES (M AHD)

	Data Source	Data Length	HAT	MHWS	MHWN	MSL	MLWN	MLWS	LAT
Ashburton Jetty	RPS	~	1.20	0.99	0.16	0.07	-0.05	-0.96	-1.18
Exmouth	ANTT	20 year	1.39	0.89	0.29	-0.01	-0.31	-0.91	-1.51
Onslow/Beadon Creek	ANTT	20 year	1.49	0.89	0.29	-0.01	-0.31	-0.91	-1.61

**The accuracy of water level data (including that provided by ANTT) should be considered to be in the order of ±0.2m*

Measured and predicted water levels at Onslow provided by the Department of Transport (DoT) are presented in Figure 6-1. These data show the tidal range and variation across a 3-year period (top), together with the residual (difference between measured and predicted tide) and a one month record illustrating the spring and neap tide signals.

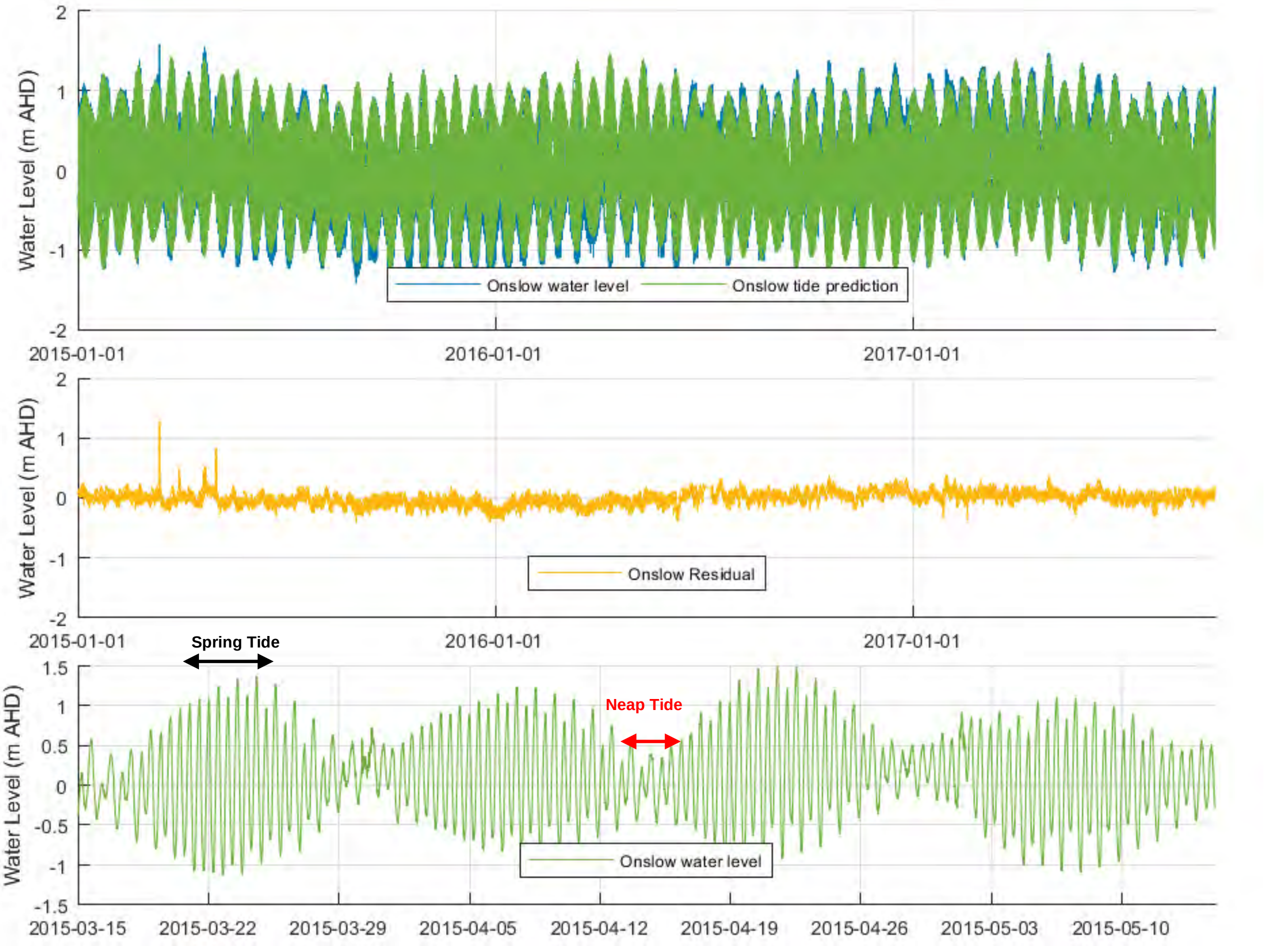


FIGURE 6-1 MEASURED AND PREDICTED WATER LEVEL AT ONSLOW (DOT)

6.1.2 Urala Creek South and Jetty Location (Locker Point)

Water level measurement locations, including loggers deployed for the study and permanent tide stations in the area, are displayed Figure 6-2.

Data sources: K+S Salt, EnviroWorks Consulting
Imagery: ESRI Online (2019)

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FIGURE 6-2 WATER LEVEL MONITORING LOCATIONS

Raw water level data measured at Urala Creek South and Locker Point are illustrated in Figure 6-3. Due to the difficulties of long-term deployments, there were some data retrieval and quality issues, most noticeable is from April 2020 to July 2020 at Locker Point where the amplitude decreases. This data was not relied on for the Water Technology studies (2021). Using the remaining reliable data, astronomical tidal constituents were calculated and the tidal plane information, based on harmonic tidal analysis, is shown in Table 6-2.

The tides within the Urala Creek North and South are similar to those within Exmouth Gulf and along the coast - semi-diurnal with a slight diurnal inequality. The mean spring tide range is lower than within the Gulf.

Based on measured data, the highest astronomical tide (HAT) of 1.2 m and 1.1 m AHD for Urala Creek North and South, as noted in Table 6-2, is the predicted highest tide which could theoretically occur in a tidal epoch – a period of 18.6 years. It should be noted that the derived HAT and LAT estimations should be used with caution as they are based on a limited dataset. Meteorological impacts such as storm surge and regional seasonal and inter-annual variability discussed below may result in a water level higher, or lower, than the HAT and the LAT respectively. However this can be overcome in modelling by ensuring robust calibration and validation of water models using available monitoring data and satellite imagery as described in Water Technology (2021) modelling reports.

TABLE 6-2 ASTRONOMICAL TIDAL PLANES (M AHD); WATER TECHNOLOGY (WT) VALUES ARE TO M MSL

	Data Source	Data Length	HAT	MHWS	MHWN	MSL	MLWN	MLWS	LAT
Locker Point / Outfall	WT/UWA	9 months	1.3	0.9	0.2	0.0	-0.2	-0.9	-1.1
Urala Creek North	WT	2 months	1.2	0.8	0.2	0.0	-0.2	-0.8	-1.1
Urala Creek South	WT/UWA	12 months	1.1	0.75	0.2	0.0	-0.2	-0.75	-1.1

**The accuracy of water level data (including that provided by ANTT) should be considered to be in the order of ±0.2m*

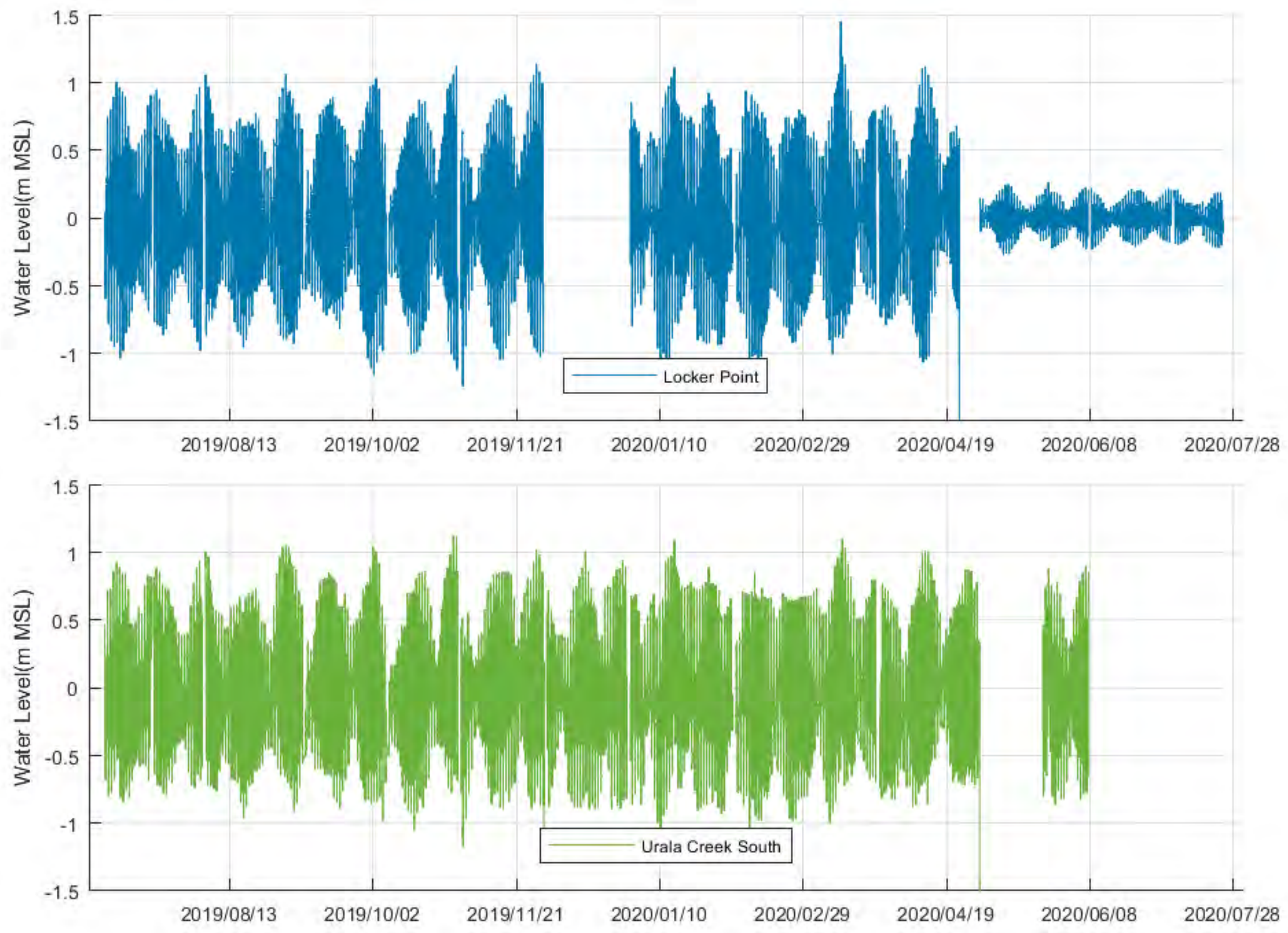


FIGURE 6-3 WATER LEVELS AT URALA CREEK SOUTH AND LOCKER POINT

6.2 Sea Levels

In addition to tidal water level variations, longer term changes in water levels at the site occur in response to local weather conditions including tropical cyclones, seasonal climatology and global climate forces. A summary of the period and magnitude of these changes is provided in Table 6-3 and described in more detail below. Water level data was obtained from the Beadon Creek (Onslow) tide gauge from 1986 to 2020, and the Exmouth Boat Harbour tide gauge from 1997 to 2020. The greatest observed surge levels occurred during Tropical Cyclone Vance which crossed the coast on the 22nd of March 1999. It led to storm surge of the order of 3.6 m at Exmouth and of the order of 3.3 m at Onslow according to tidal gauge records.

TABLE 6-3 MAJOR PROCESSES IMPACTING SEA LEVEL VARIABILITY

Sea level driver	Period	Range
Astronomical Tide	0.5 – 1 day	0.5 – 2.0m
Shelf waves	5 – 30 days	0.1 – 0.3 m
Storm Surge	1 – 10 days	0.2 – 3.6m
Seasonal/Monsoon	3 – 6 Months	0.1 – 0.2m
El Nino southern oscillation (ENSO)/Indian Ocean Dipole (IOD)	Inter-annual	0.1 – 0.2m

6.2.1 Seasonal Variations

Mean sea levels in northwest Australia are influenced by seasonal changes in atmospheric pressure, air temperature and wind conditions. Figure 6-4 shows the monthly difference of mean sea levels when compared to the long-term average. The data has been sourced from 25 years of measured data at Broome to the northeast, and Hillarys to the south, collected by the BoM as part of the Australian Baseline Sea Level Monitoring Plan (ABSLMP). A seasonal pattern is clearly evident at both sites, with mean sea levels peaking during the wet season in Broome when atmospheric pressure and temperatures are high and peaking in May/June in the south of Western Australia as winter southerlies begin to occur. Conditions at Ashburton are likely to be closer to those at Broome, although there will be less influence from the monsoonal winds which occur further north during the wet season, and more daily variance due to the land/sea breeze pattern discussed in Section 5.

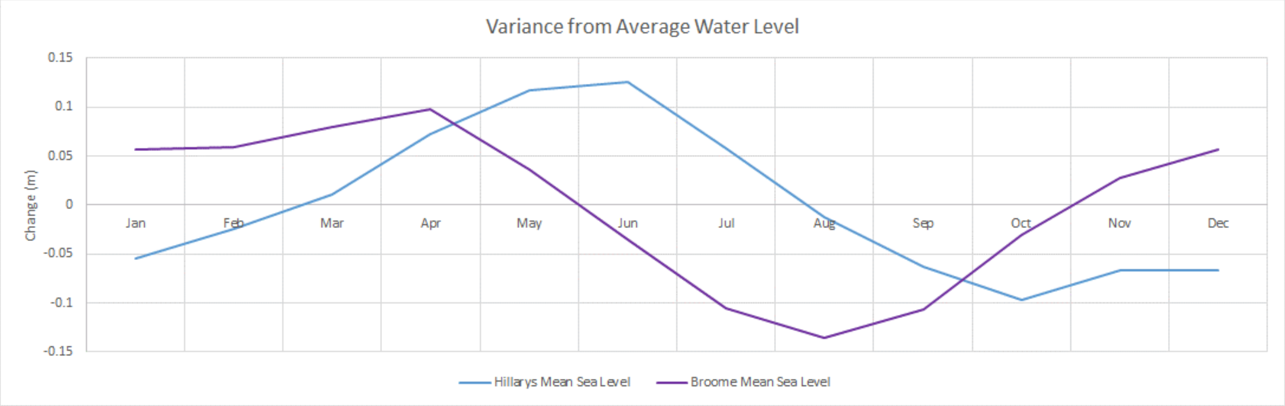


FIGURE 6-4 SEASONAL VARIATION OF MEAN SEA LEVEL AT BROOME AND HILLARYS

A water level analysis was undertaken on measured data from Locker Point and is displayed in Figure 6-6. No seasonal trend can be observed within the data but there are fluctuations of up to 0.1 m over a timescale of 5 to 15 days. These fluctuations could be due to more short-term processes such as shelf waves or storm surge. The lack of an identifiable seasonal trend could be due to slight datum shifts that occur with the monthly servicing.

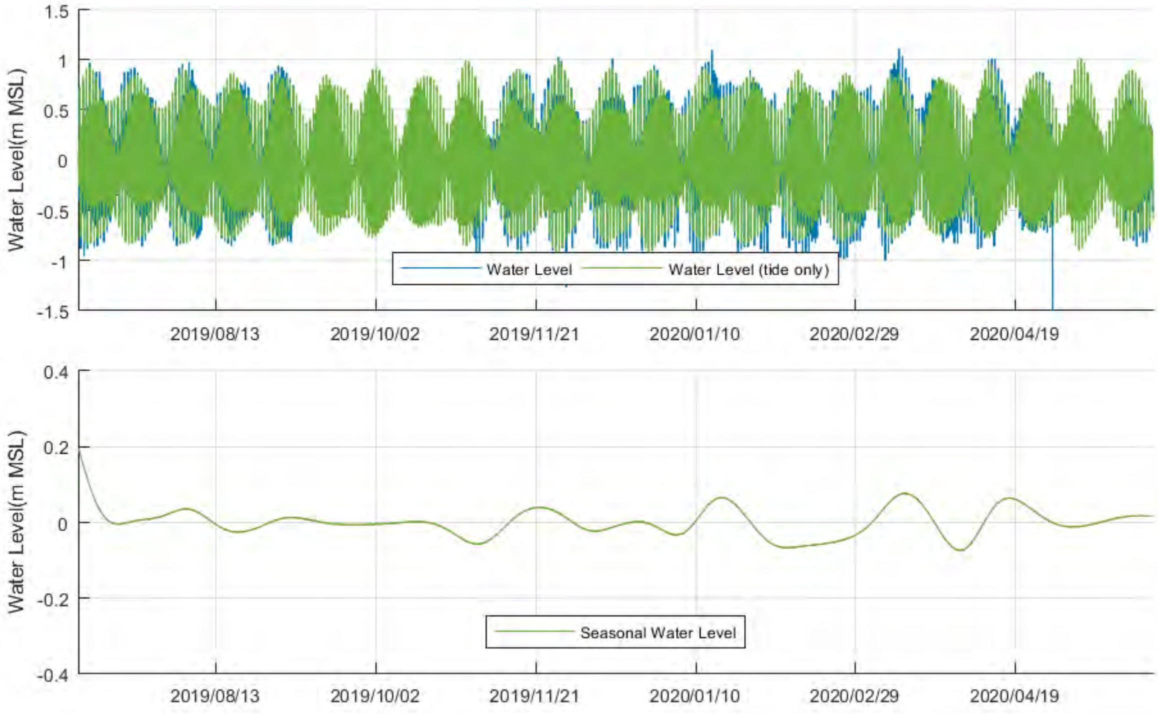


FIGURE 6-5 WATER LEVEL ANALYSIS AT LOCKER POINT

6.2.2 Interannual Variation

Along the coast of Western Australia, it has long been recognised that ocean climate variability can have a substantial influence on seasonal and interannual variability in coastal sea levels which shows some correlation with the El Nino ~ southern oscillation (ENSO).

Since the 1990s, the Pacific Decadal Oscillation (PDO), with its multidecadal time scale of 20–30 years, has also swung to a negative phase sustaining positive heat content and more frequent cyclonic winds off the Western Australian coast. These large-scale ocean climate drivers are thought to have led to stronger La Niña over the past two decades.

These oceanographic processes led to approximately an 0.3 m water level increase in the 2011 La Niña Event which is not related to either tide or local winds. Impacts from these oceanographic processes may be enhanced in the future due to the increased risk of extreme La Niña events under warmer climate conditions.

Figure 6-6 shows the variation of annual sea level anomalies based on measured data at Broome and Hillarys. The data has been adjusted to remove the impact of sea level rise. The yellow line represents the Southern Oscillation Index (SOI) where levels above zero represent periods of La Niña and levels below zero are representative of El Niño. Figure 6-6 illustrates that regional water level anomalies on the Western Australian coastline are influenced by the SOI, with annual average water levels following a similar pattern to the fluctuation between La Niña and El Niño. During a prolonged period of La Niña, such as between 1998 – 2001, regional water levels can on average be 0.1m higher than average whilst during a strong El Niño as was present in 2015, regional water levels can be 0.05 - 0.1m below the long term average.

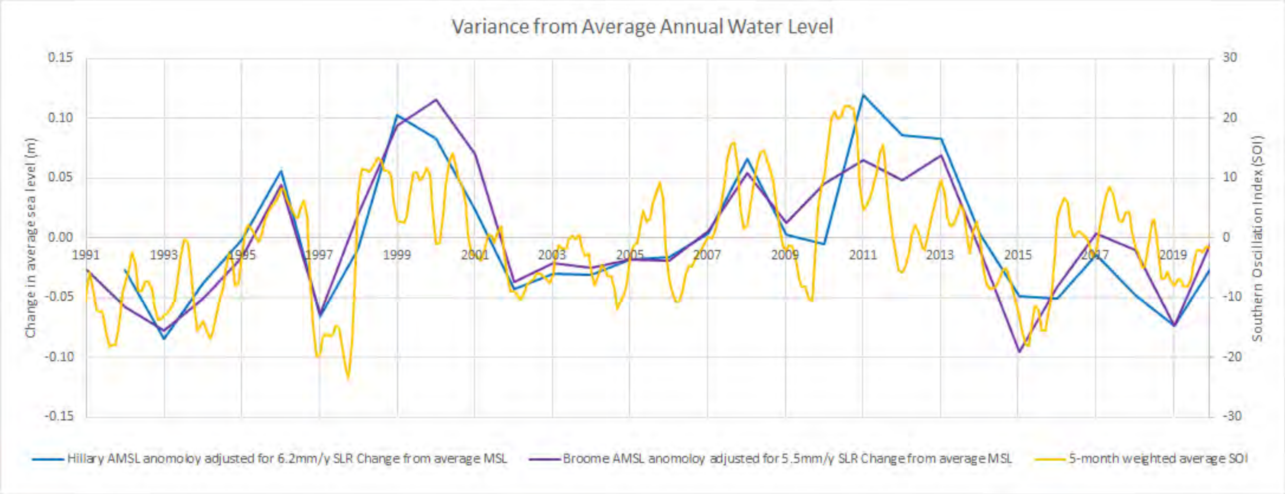


FIGURE 6-6 ANNUAL VARIATION OF MEAN SEA LEVEL AT BROOME (PURPLE) AND HILLARYS (BLUE)

6.3 Regional Currents

The site is located within the Indo-Australian Basin, the region of ocean between the northwest coast of Australia and the Indonesian islands of Java and Sumatra. Dominant currents relevant to the study site include: South Equatorial Current, the Indonesian Through-Flow (ITF), the Eastern Gyral Current, the Holloway Current and the Leeuwin Current.

Figure 6-7 illustrates the main surface currents of the region (from DEWHA, 2007). All of these current systems experience strong seasonal to inter-annual variations, which indicate that they are likely to be influenced by climate change over the coming decades. Although there are strong seasonal trends, there are also periods when strong winds can cause intermittent reversals of these currents, with occasional weak upwellings of colder deep water. The Ningaloo Current is one such current that can strength in summer and cause upwelling on the shelf.

Whilst the Holloway Current is an ongoing topic of research, it can be described as a seasonal current, occurring from the end of the monsoonal period to drain waters which have built up in the Arafura Sea and Gulf of Carpentaria as a result of dominant north-westerly winds during the monsoon. As the monsoonal period finishes, the winds cease, and water flows west and south along the West Australian coast towards Exmouth Gulf. The strength of this regional current may therefore be closely related to the strength and frequency of monsoonal fronts which occur during the wet season. Inter-annual variability may also be present, with pressure and ocean temperature changes in the Pacific driven by the ENSO causing a reduction in the ITF during El Niño periods and vice versa for La Niña events.

Current moorings by the Institute of Marine Science (IMOS) north east of Barrow Island between 2012 and 2014 indicate a dominant south-westward current in both the surface layer (0-30 m depth) and at depths to 150 m.

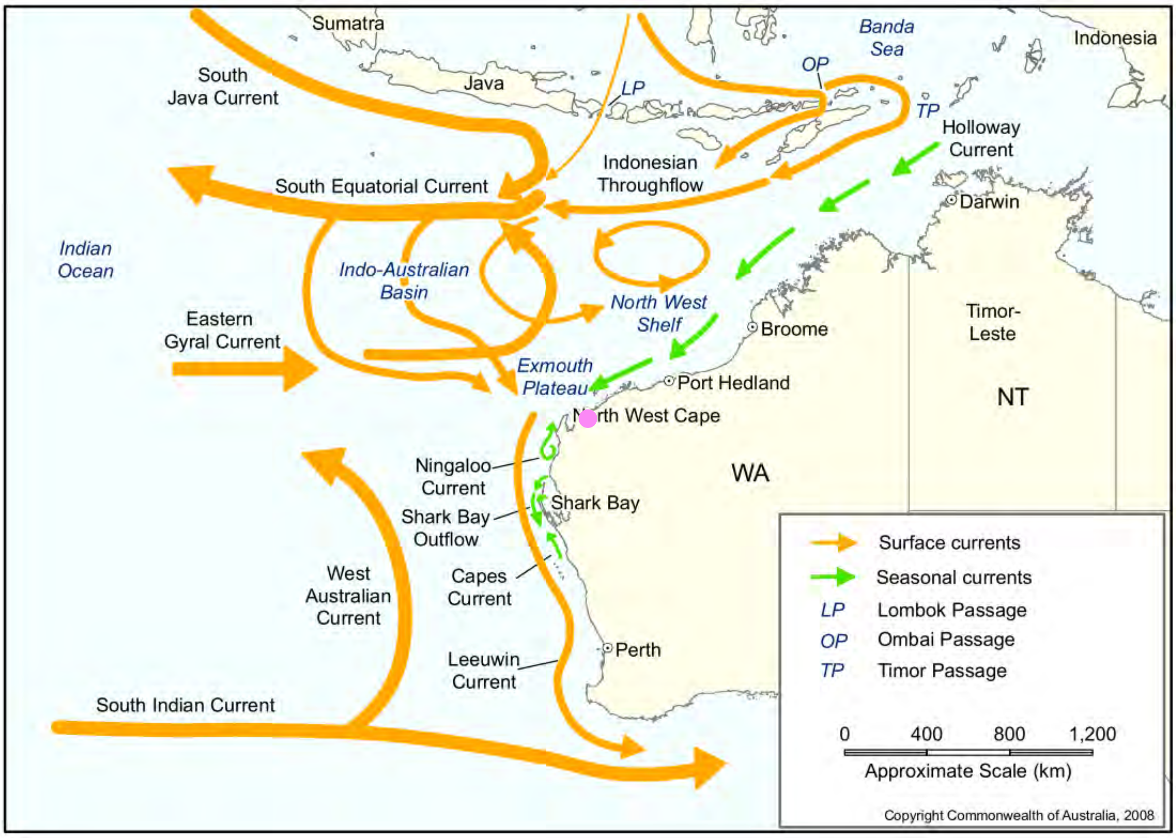


FIGURE 6-7 REGIONAL OCEANOGRAPHY AND CURRENTS (DEWHA 2007). APPROXIMATE FACILITY LOCATION INDICATED BY THE PINK DOT

6.4 Ocean Upwelling

Ocean upwelling is the process by which deep, cold, nutrient rich water rises toward the surface. Winds blowing across the ocean surface push water away. Water then rises up from beneath the surface to replace the water that was pushed away. This process is known as “upwelling.” Conditions are optimal for upwelling along the coast when winds blow along the shore.

Ocean upwelling is a well-established phenomenon on the inner shelf near Exmouth and can be caused by seasonal winds, counter currents, or internal waves. Seasonal upwelling around Ningaloo Reef, which most commonly occurs in summer, is affected by the wind-driven, northward-flowing Ningaloo Current that periodically flows inshore of the Leeuwin Current. This current strengthens in summer as the Indonesian Throughflow and Leeuwin Current weaken and the absence of warm oligotrophic surface water allows nutrient rich upwelling to occur in the euphotic zone (Hanson and McKinnon 2009, Taylor and Pearce 1999). This process is well studied, with Holloway et al. (1985) concluding that tides and persistent upwellings contributed substantially to the flux of nitrate in Exmouth Gulf, as tidal forcing advects the nutrient rich surface waters into nearshore waters.

Recent studies have also confirmed that the complex interaction between the southward flowing Leeuwin Current and wind driven currents can episodically reverse the coastal flow toward the north, forming the Ningaloo Counter Current (Xu, et al 2013). This occurs during summer when there is strong stratification on the shelf combined with persistent southerly winds (Zhang et al. 2016). The Ningaloo Current has been studied extensively, with Hanson et al. (2005) finding that the oligotrophic (low nutrient) Leeuwin Current can be offset by these equatorial counter currents which create upwelling events and deliver nutrients which increase primary productivity. The upwelled water is sourced from the interior of the water column and likely influences the sources and fluxes of nutrients to Ningaloo Reef, which can then be transported past the North West Cape into Exmouth Gulf (Xu et al. 2013, Zhang, et al. 2016). Meekan et al. (2006) concluded that flood tide intrusions of upwelled nutrient rich waters are mixed throughout the Exmouth Gulf, and play a major role in supporting primary productivity in Exmouth Gulf.

In addition to upwelling from the Ningaloo Current, there is also the potential for offshore nutrient delivery to nearshore waters related to the formation of offshore eddies (Xu. Et al 2016). Exmouth Gulf is reliant on these transient coastal upwelling events and eddies as they provide substantial fluxes of deep-water nutrients which support primary productivity (Meekan et al. 2006, Xu. Et al 2016, Hanson et al. 2005).

6.5 Water Temperature

6.5.1 Regional Water Temperature

The Pilbara coastline, including the nearshore region of Ashburton, is characterised by its shallow and wide continental shelf (Section 2). The shallow water results in a more direct response to daily air temperature variations than deeper offshore waters. Temperature within offshore waters of the northwest shelf are driven by currents including the Indonesian Throughflow (ITF) to the north and Leeuwin Current to the south. A review of available measured data and literature regarding water temperature is provided below:

- Monthly average Sea Surface Temperature (SST) data downloaded from Group for High Resolution Sea Surface Temperature (or GHRSST) is presented in Figure 6-8. The maps of SST indicate a range of close to 10ºC between the summer and winter seasons, with SST around 20ºC in August at the Project site and up to 30ºC in March. Waters to the north of the Project site are in excess of 30ºC in the shallower water between Barrow Island and the coast.
- Between February and June, the warm Leeuwin Current flows southward along the outer North West shelf. During the winter months (June–August), southerly winds create localised upwellings of colder water nearshore and force the warmer waters away from the shallower coastal waters. During this period, waters in Exmouth Gulf are generally colder than offshore waters. This will lead to long-term convective exchange patterns and residual flows.
- A timeseries of measured water temperature at Urala Creek South and Locker Point is displayed in Figure 6-9. The clear seasonal variation is shown, with temperature rising from around 20ºC in July to 30ºC and above in late summer.
- The site has experienced extreme temperature fluctuations including two major marine heat waves in 2011 and 2013 and a more recent event in December 2019. These events have been associated with coral bleaching and significant marine life kills. Risk of extreme temperature could be associated with main La Niña events and elongated summer heating.
- Tropical cyclones (Section 7) can cause a rapid drop in surface water temperature within the region as wind driven ocean turbulence causes vertical mixing and transient upwelling. In general, a slower moving cyclone will have a greater impact on water temperature than one which moves rapidly.

6.5.2 Urala Creek South and Locker Point

A continuous period of water temperature was measured at Urala Creek South and Locker Point (jetty site) as part of the data collection project, with the timeseries data shown in Figure 6-9. Water temperature profiles were also collected as part of the project between December 2018 and February 2020 by the University of Western Australia (UWA), including offshore of the proposed jetty.

The water temperature is presented in Figure 6-9 and illustrates the small daily variation at the open coast location of the jetty through the cooler winter months. Water temperature during July and August is largely around 20ºC before increasing at the beginning of September as maximum daily air temperatures increase to more than 30ºC.

Temperature profiles at the Jetty location (Locker Point) are shown in the top image in Figure 6-10, with the temperature at 2m depth shown in the lower image. Profiles show water temperature through the depth of water is consistent, with only minor changes on the surface compared with at depths of 5-6 m.

More extreme temperature fluctuations were measured in the channel of Urala Creek South as shown in Figure 6-9 and Figure 6-11. Measurements from the logger show a semi-diurnal variation of 3 to 5ºC throughout all seasons, which is an order of magnitude higher than the diurnal variation at the jetty site. This is directly attributed to the depth of water within the creek due to tidal movements, as shallow water heats more rapidly during low tide. Temperature within the creek also shows a more dramatic response to climate conditions with a 5-10ºC drop in temperature during storm events. The temperature response to storms was not as pronounced at the jetty location.

Vertical water profiles displayed in Figure 6-11 show the water in the creek is well mixed with very little temperature stratification. During the winter months (June and July), surface water was up to 0.5ºC cooler.

The data collection is described further in the *'Marine, Coastal and Surface Water Data Collection'*, Water Technology 2021.

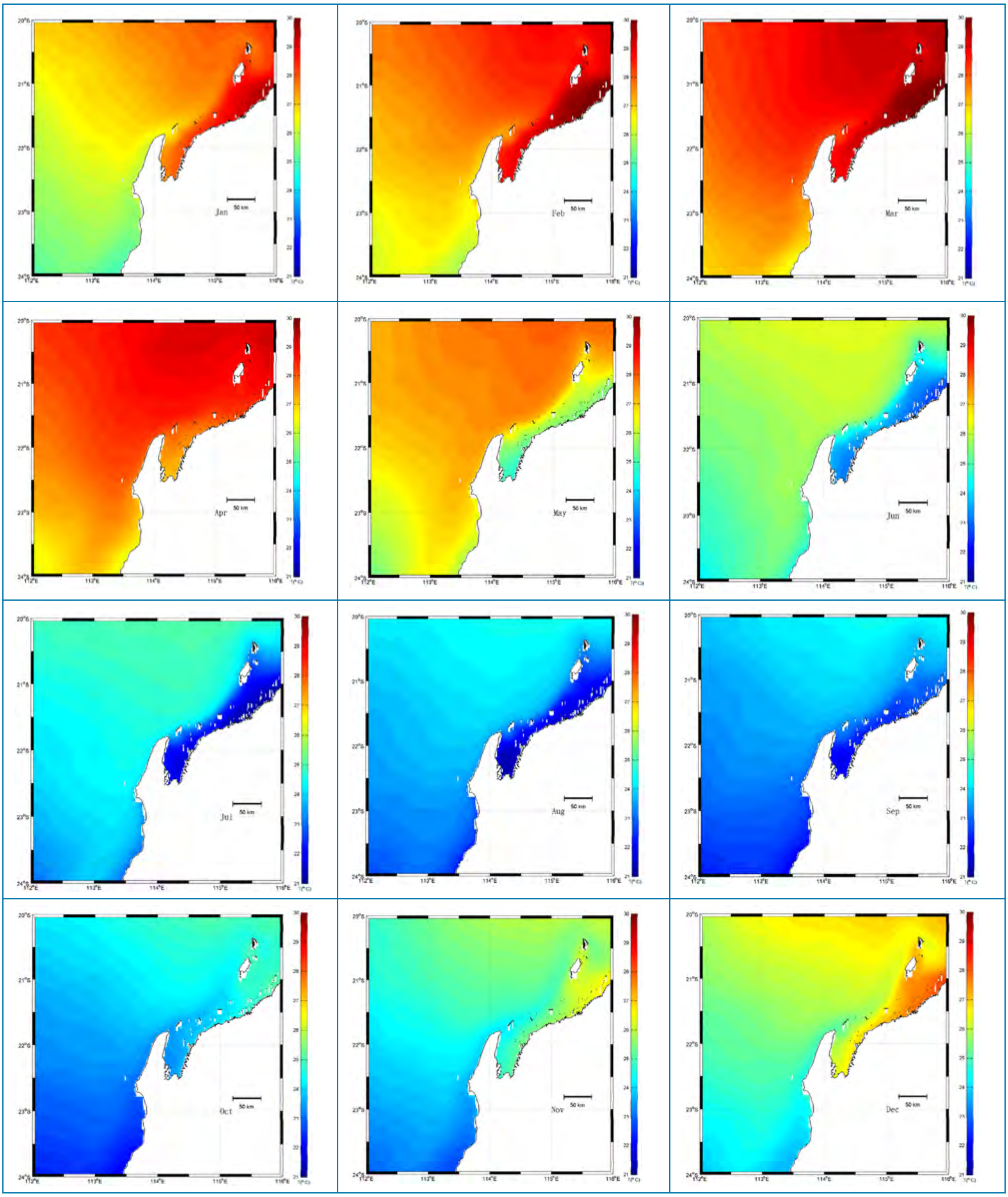


FIGURE 6-8 MONTHLY MEAN SEA SURFACE TEMPERATURE (https://www.ghrsst.org/)

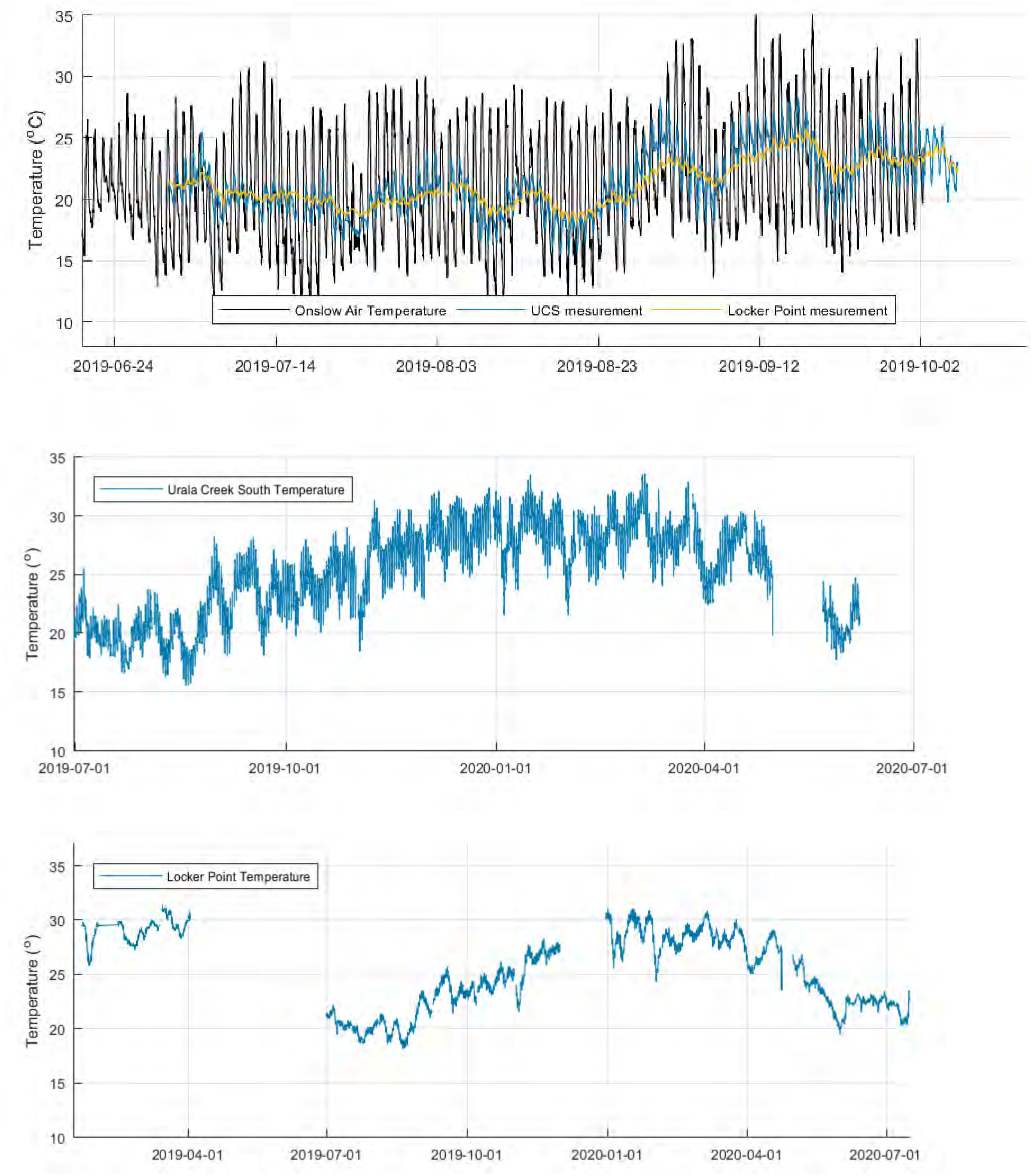


FIGURE 6-9 MEASURED AIR AND WATER TEMPERATURE AT URALA CREEK SOUTH AND LOCKER POINT

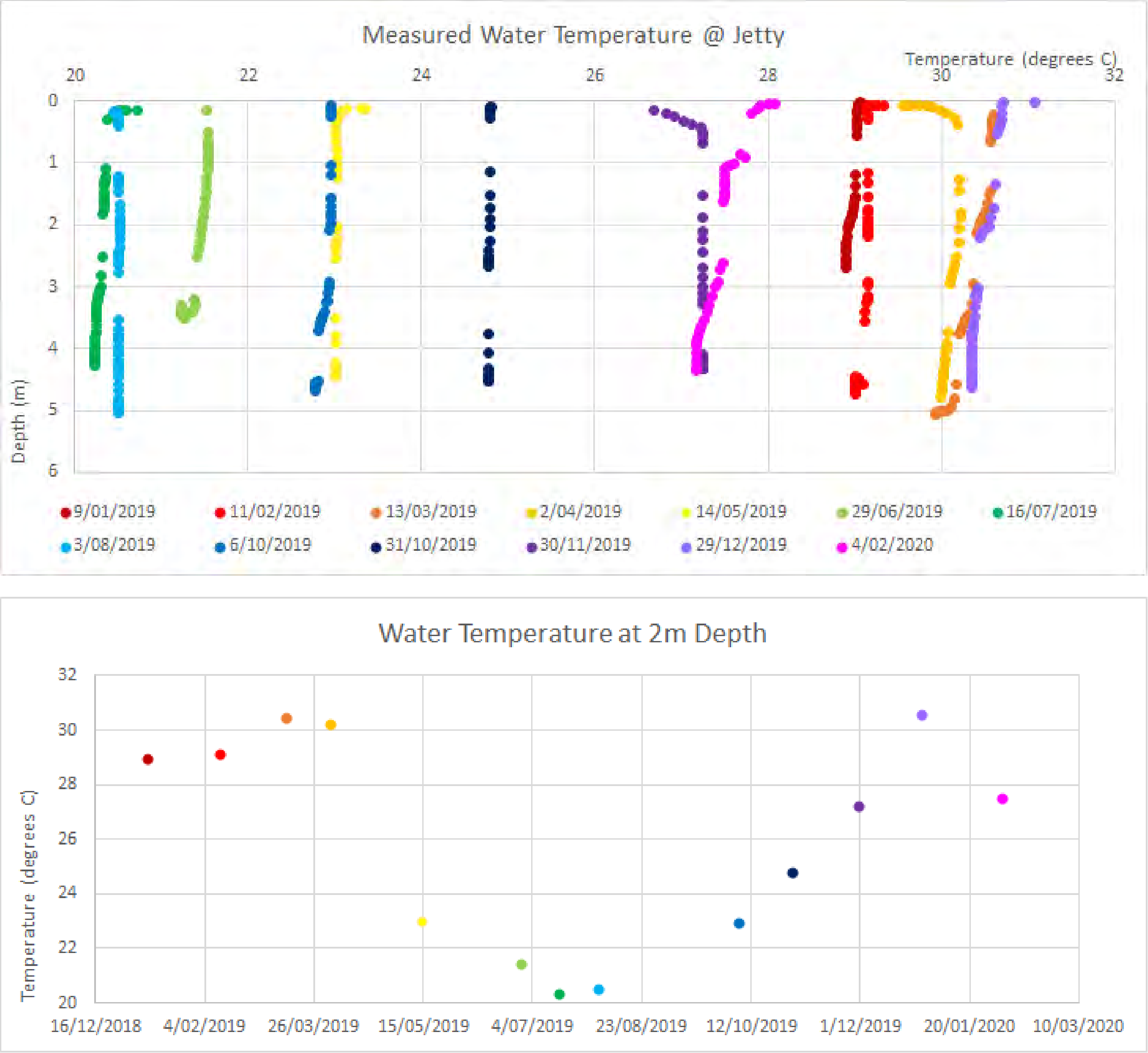


FIGURE 6-10 WATER TEMPERATURE PROFILES AT 2M DEPTH – LOCKER POINT (JETTY)

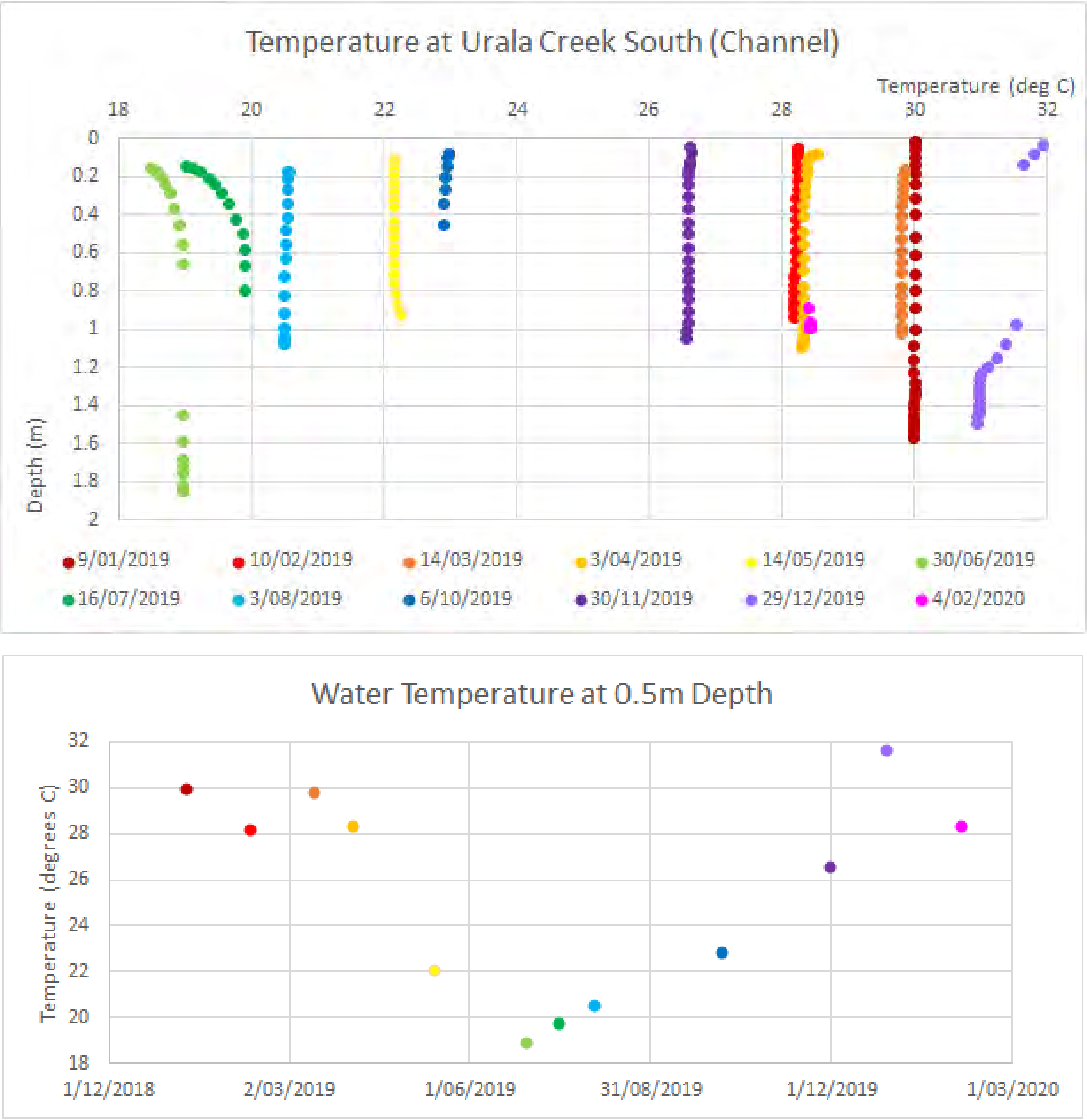


FIGURE 6-11 WATER TEMPERATURE PROFILES – URALA CREEK SOUTH

6.6 Waves

Exmouth Gulf is sheltered from the swell wave energy approaching from the south-west by the North West Cape. The fetch at more exposed sites however extends approximately 8,000 km away across the Indian Ocean, and therefore large swells (with peak wave periods of up to 20s) could be experienced along the shoreline during both wet and dry seasons. Swell waves are generated by storms thousands of kilometres away and therefore do not follow local wind patterns. Swells can also be generated during cyclones and these are more likely to arrive from the north and northwest.

Some attenuation of wave heights from the west through north will be provided by the Murion to Serrurier Island chain (Oceanica 2006). Locally generated wind waves inshore of this are relatively weak due to the weak wind energy environment, particularly from the north through northwest.

Wave conditions have been measured by the WA Department of Transport (DoT) near the Onslow training wall in a water depth of 3.7 m. Wave heights at Onslow were predominantly less than 0.4 m, approaching from the west through north-northeast. The waves had a distinct separation between swell and sea wave component, with 30% of measured waves with a period of between 2 and 6 seconds, largely with a Hs of 0.2-0.6m; whilst 40% of waves had a peak period between 12 and 18 seconds. These longer period waves were smaller, with the heights less than 0.4 m.

It is noted that the location of the DoT data collection site would result in it being sheltered from direct wave action from the south through west-northwest. The data was recorded between 2014 and 2016.

Locker Point would be exposed to locally generated wind-waves and is generally low wave energy environment (Hs <0.6 m for 99% of the time), whilst Urala Creek South is a tidal creek and as such is largely sheltered from nearshore waves.

7 TROPICAL CYCLONES

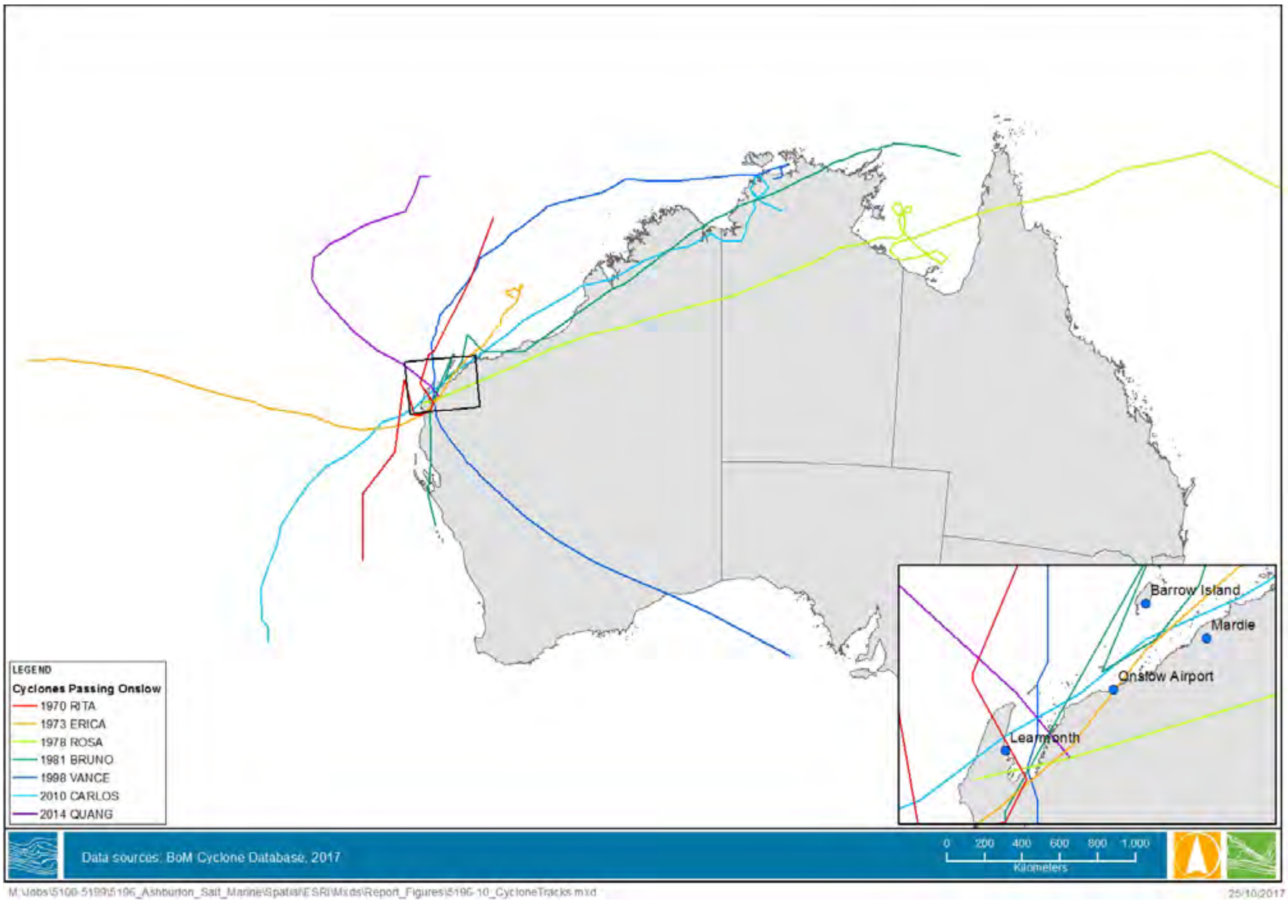
7.1 Past Cyclonic Events

The northwest Australian coastline is one of the most cyclone-prone regions of the world. The project site (in the vicinity of Onslow) experiences, on average, one cyclone every second year according to BoM records.

A higher chance of a tropical cyclone forming exists during La Niña conditions, whilst there are less tropical cyclones along the Pilbara coast during El Niño years. Tropical cyclones (TC) in the northwest typically form in the Timor Sea and move along a south easterly track.

Cyclones in this area occur primarily between mid-December and April and peak in February and March. A review of available cyclone records indicates that half of the cyclones were reported to have gust speeds exceeding 50 m/s, although these speeds were not measured at land. Typical cyclonic wind speeds on land have regularly exceeded 25 m/s.

The main cyclones passing between Exmouth and Onslow since 1969 are presented in Figure 7-1.



Data sources: BoM Cyclone Database, 2017

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FIGURE 7-1 CYCLONES PASSING CLOSE TO EXMOUTH (BOM CYCLONE DATASET, 1943 - 2019)

A summary of the impact of some of the recent tropical cyclones affecting the local coastal environment is provided below:

- **TC Bobby -** TC Bobby was classified as a Category 4 cyclone. It started as a tropical low and formed its cyclone shape on 22nd of February 1995 about 500 km north of Port Hedland. The cyclone continued to intensify during the next two days in an environment of decreasing shear as it moved south-westwards. TC Bobby reached tropical cyclone intensity early on the 23rd of February and peaked with estimated mean winds of 55 m/s (estimated central pressure 925 hPa) at 9 am universal coordinated time (UTC) on the 24th of February, as it approached the Western Australian coast near Mardie (100 km west southwest of Karratha).

  TC Bobby landed near Onslow at around 6 pm UTC on the 25th of February, leading to a recorded maximum wind gust of 51 m/s and minimum pressure of 952 hPa. A storm surge of 1.3 m was recorded at King Bay about 30 km west of Karratha.

- **TC Vance** - TC Vance (Category 5) is one of the most intense tropical cyclones ever recorded to cross Western Australia shoreline. TC Vance first developed off Darwin on the 17th-18th of March 1999 and gradually intensified as it moved southwest, before landing near Exmouth on the 22nd of March.

  TC Vance had an extremely low central pressure (910 hpa) and produced the highest ever recorded wind gust on the Australian mainland of 267 km/hr at Learmonth Airport (Blandford et al, 2005).

  A post event survey estimates that TC Vance caused a more than 5 m storm surge to the west of Onslow. It also caused widespread cumulative rainfall of 100-150 mm, with some areas receiving 200-300 mm.

- **TC Quang** - TC Quang was classified as a Category 2 cyclone according to BoM information. It originally formed about 1,000km to the northwest of Exmouth and reached tropical cyclone strength on the 28th of April 2015. The cyclone intensified rapidly and reached a peak wind gust of 185 km/h at 6 am UTC on the 30th of April. It then weakened and lost its structure before landing at Exmouth in the 1st of May.

  Learmonth Airport weather station recorded a maximum wind gust of 120 km/h and a lowest air pressure of 997.4 hPa. The highest cumulative rainfall was 84 mm.

7.2 Cyclone Parameters

The main structural features of a tropical cyclone are the eye, the eye wall and the spiral rainbands. The four main components of a tropical cyclone that combine to make up total cyclone hazard are described below:

- **Extreme Winds** – Maximum wind speeds are a function of the central pressure, the radius to maximum winds, the forward speed of the cyclone and local topographic effects. Cyclonic winds circulate clockwise in the Southern Hemisphere; however, wind fields are generally asymmetric such that the strongest winds are generally observed on the left-hand side of the direction of cyclone movement.

  Tropical cyclonic intensity is rated Category 1 through 5 depending on the maximum average wind speed. A Category 1 cyclone has a 10-minute average maximum wind speed between 63 and 88 km/h (17.5 m/s – 24 m/s) whilst Category 5 cyclones have a 10-minute average maximum wind speed greater than 200 km/h (55.5 m/s). The gust speeds (i.e. wind duration of 2-3 seconds) are considerably higher at <125km/h (34 m/s) and greater than 279 km/h (77.5 m/s) for Category 1 and Category 5 tropical cyclones, respectively. These winds are limited to a relatively small distance around the eye of the cyclone, with wind speeds rapidly decreasing with distance from the cyclone centre.

- **Extreme Waves** – Tropical cyclones generate extreme ocean waves as a result of energy transfer from the cyclone winds to the ocean surface. The growth of ocean waves is determined by water depth, wind speed, wind duration and the distance for winds to act over (fetch). The Project site is exposed to open sea to the north which is likely affected by direct landing of cyclones as well as extreme waves generated.

- **Storm Surge** – A phenomenon of rising water commonly associated with low pressure weather systems (such as tropical cyclones and strong extratropical cyclones). It is driven by the combined action of wind setup, atmospheric pressure reduction and wave setup. Its severity is affected by the shallowness and orientation of the water body relative to the storm path and the magnitude of storm surge may be amplified in a semi-enclosed water body. The peak storm surge often only lasts for a few hours near the region of maximum wind speeds. Occurrence of extreme storm surge at high tide is relatively rare, however such a combination would have catastrophic consequences particularly in semi-enclosed shallow waters, such as Exmouth Gulf.

- **Intense Rainfall** – The rain bands of a tropical cyclone can expand up to 1,000 km in diameter, with heaviest rainfall usually located at the eye wall. The heaviest rainfalls in Exmouth Gulf are generally associated with tropical cyclones and can cause severe flooding in the region.

The impacts that various cyclone tracks may have on conditions at Ashburton are summarised in Table 7-1.

TABLE 7-1 CYCLONE TRACK AND IMPACT AT ASHBURTON

Cyclone track	Impacts
Crosses coastline west to east north of site	Offshore winds prior to and after cyclone passing will cause a set down in water levels and no onshore waves
Crosses west to east south of site	Onshore winds prior to and following cyclone shore crossing will have significant impact on water levels and waves, causing storm surge and high wave energy at Ashburton
Crosses north to south over site	Depends on cyclone radius, however easterly winds prior to cyclone crossing will have minimal impact. Westerly winds after cyclone passes will have an impact on the open coast
Crosses north to south west of site	Onshore and north-easterly winds prior to and following cyclone shore crossing will have a significant impact on water levels and waves, causing storm surge and high wave energy at open coast locations and within Exmouth Gulf. Considered most critical track for oceanographic conditions

7.3 Storm Tides

Extreme water levels are primarily driven by storm surges associated with onshore winds and low atmospheric pressure from tropical cyclones. The water level components of an extreme topical cyclone storm surge are displayed in Figure 7-2.

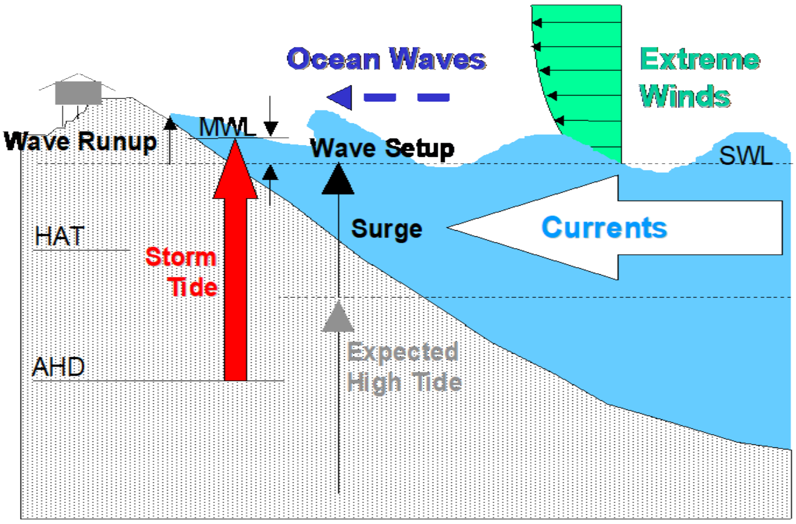

FIGURE 7-2 WATER LEVEL COMPONENTS OF AN EXTREME TROPICAL CYCLONE STORM SURGE (SEA 2005).

As there are no historical water level measurements at the project site, water level data was obtained from the Onslow (Beadon Creek) tide gauge from 1986 to 2017, and the Exmouth Boat Harbour tide gauge from 1997 to 2017. The greatest observed surge levels occurred during TC Vance which crossed the coast on the 22nd of March 1999. It led to a 3.6 m storm surge at Exmouth and a 3.3 m storm surge at Onslow according to the tidal gauge records.

Measured water level records were analysed to extract the highest independent water level observations at each gauge over the years of record. A 4-day constraint (two days either side of a peak water level) was used to ensure that all observations used in the extreme value analysis were independent. The top 30 events were used in the extreme value analysis for the Onslow gauge, and the top 20 events for the Exmouth Boat Harbour site.

The results from this analysis are presented in Table 7-2. The first two columns present the analysis from the two tide gauges and the third column presents the levels selected to design the Exmouth Boat Harbour facility in consideration of the cyclone modelling. This is to act as a point of a reference for design levels pertaining to the project site.

TABLE 7-2 STORM TIDE LEVEL, PRESENT DAY

ARI	Water Level Exmouth (m AHD)	Water Level Onslow (m AHD)	Exmouth Boat Harbour Adopted Design Water Level (m AHD)
1	1.4	1.4	1.4
10	1.8	1.7	1.8
20	1.9	1.75	1.85
50	2.2	1.8	2.0

7.4 Extreme Wave Conditions

The open ocean to the south-west, west and north offshore from the Project site has sufficient fetch for the growth of cyclone waves. The theoretical unlimited fetch wave height may exceed 15 m offshore, however these waves are significantly attenuated through either refraction or diffusion of wave energy across the Murion to Serrurier Island chain.

8 TSUNAMIS

A tsunami is a wave or series of waves, generated in a water body by sudden, largescale displacement of water e.g., earthquake or volcanic eruptions. Due to its orientation and proximity to the Indonesian fault zone known as the Sunda Arc, the north-west is considered as Western Australia's most at risk region from damage of tsunamis.

It is a requirement of SPP2.6, WAPC (2013), to include allowance for inundation due to tsunami when planning for development in the coastal zone. A literature review of existing studies has been undertaken to provide this allowance for the study site.

8.1 Tsunami hazards

8.1.1 Offshore Hazard

Geoscience Australia has mapped tsunami hazard at the 100 m depth contour across the Australian coastline (Geoscience Australia, 2009). Figure 8-1 presents the predicted wave amplitude offshore from the study site for the 500-year ARI tsunami hazard. These hazard maps, and the corresponding probabilistic tsunami hazard assessment by Burbidge et al (2008), identify the coastline from Carnarvon to Dampier, including the Pilbara coastline as the region with the highest level of hazard in Australia. The hazard offshore from the proposed project has a predicted wave amplitude of approximately 2.1 m.

8.1.2 Inshore Hazard

Tsunami waves have very low frequencies (wavelengths may exceed 100 km) with wave propagation speeds approaching 1,000 km/hr in deep water. The wave slows in shallow water as the wavelength shortens and wave energy is concentrated. Shoaling then occurs from the edge of the continental shelf to the coastline and acts as a critical mechanism to dampen tsunami energy, resulting in a lower wave height at the coast.

8.2 Pilbara Region Tsunami Assessments

The Indian Ocean region experienced its most devastating tsunami on the 26th of December 2004, which was triggered by an earthquake off the coast of Sumatra. This resulted in widespread damage to property and human lives in the overall region. Western Australia itself was impacted by the tsunami, with all coastal tide gauges recording water level oscillations (about 1 m amplitude) related to the tsunami - but this event did not result in any large-scale property damage. Subsequent to the 2004 event, Western Australia was impacted by tsunamis on an annual basis with tsunamis occurring in 2004, 2005, 2006 and 2007.

Burbidge et al (2008) conducted a detailed tsunami assessment in this region. All tsunamis were assessed as generated from the Sunda Arc Subduction Zone. Whilst the maximum magnitude earthquake possible on the Sunda Arc Subduction Zone is not known, Figure 8-2 shows a suite of possible earthquake magnitudes: blue Mw 8.5, cyan Mw 9.0, orange Mw 9.3 and red Mw 9.5 and their corresponding return period and wave heights for the 50 m depth contour offshore from Exmouth (Burbidge et al, 2008). The purple line is the preferred model which is a weighted mean of all values. Table 8-1 presents the wave amplitudes for a range of return periods; the 500-year amplitude is 0.5 m.

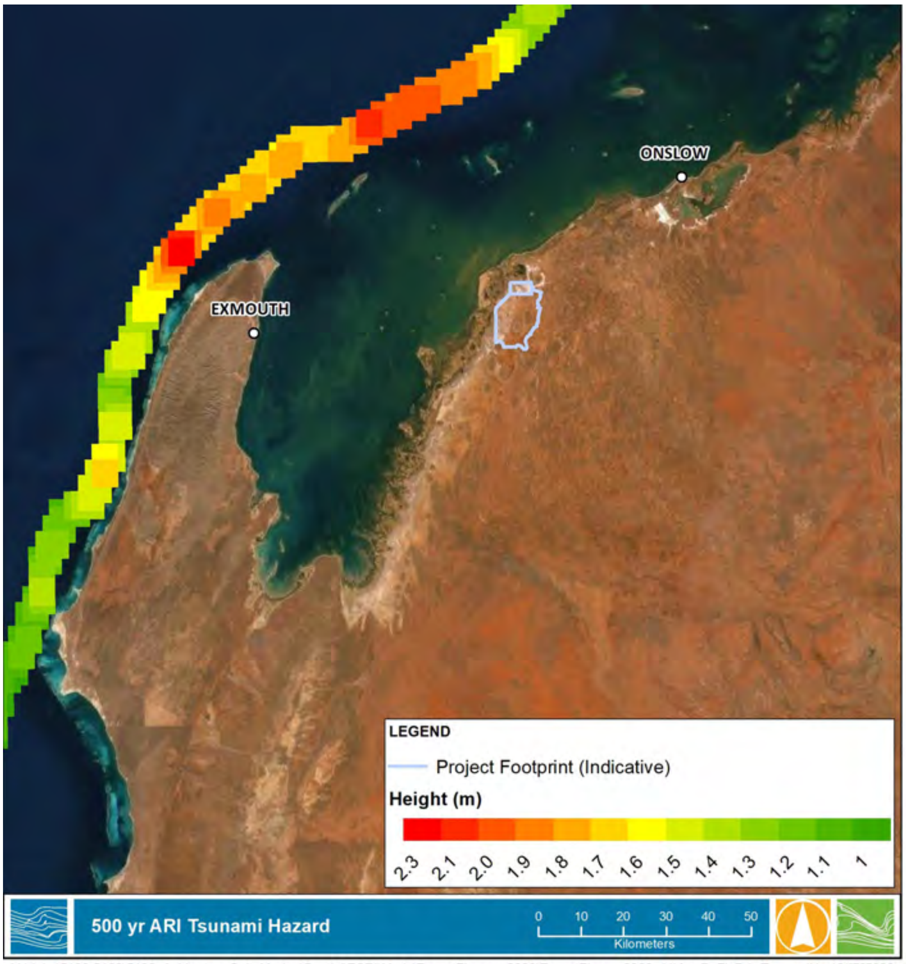

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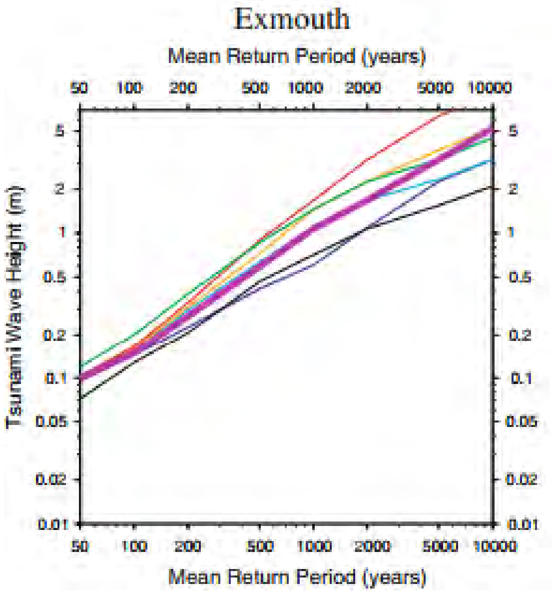
FIGURE 8-1 500-YEAR OFFSHORE TSUNAMI HAZARD (GEOSCIENCE AUSTRALIA 2009)



Earthquake magnitudes

Blue	Mw 8.5
Cyan	Mw 9.0
Orange	Mw 9.3
Red	Mw 9.5
Purple	Weighted mean

FIGURE 8-2 EXMOUTH TSUNAMI WAVE HEIGHT AT 50M WATER DEPTH (BURBIDGE ET AL, 2008)

TABLE 8-1 PREFERRED MODEL: TSUNAMI WAVE HEIGHT AND RETURN PERIOD FOR EXMOUTH (BURBIDGE ET AL, 2008)

Return Period (Years)	Tsunami Wave Height (m)
50	0.10
100	0.15
200	0.21
500	0.50
1000	1.0

Geoscience Australia (2006) undertook further tsunami modelling to assess the vulnerability of the nearshore Onslow coastline from earthquake generated tsunamis originating from the Sunda Arc Subduction Zone. The Project site is just outside the model domain from the Geoscience Australia (2006), so results from Onslow were extracted. The assessment was undertaken using a Method Of Splitting Tsunamis (MOST) model to generate and propagate the tsunami from its source to a location slightly offshore from the coastline. The hydrodynamic and inundation modelling tool ANUGA was then used to translate the wave from offshore to onshore.

As per the above assessment, the maximum magnitude earthquake off the coast of Java is predicted to be between Mw 8.5 and Mw 9. A Mw 9 earthquake was used for the model. As per Figure 8-2, this corresponds with the preferred model. The offshore wave height selected for the study corresponds well with the 500-year ARI values discussed above. The simulation was run for Highest Astronomical Tide (HAT), Lowest Astronomical Tide (LAT) and Mean Sea Level (MSL). Local bathymetry played a large role in the measured tsunami water level in the nearshore. Figure 8-3 presents inundation levels for the HAT scenario at Onslow.

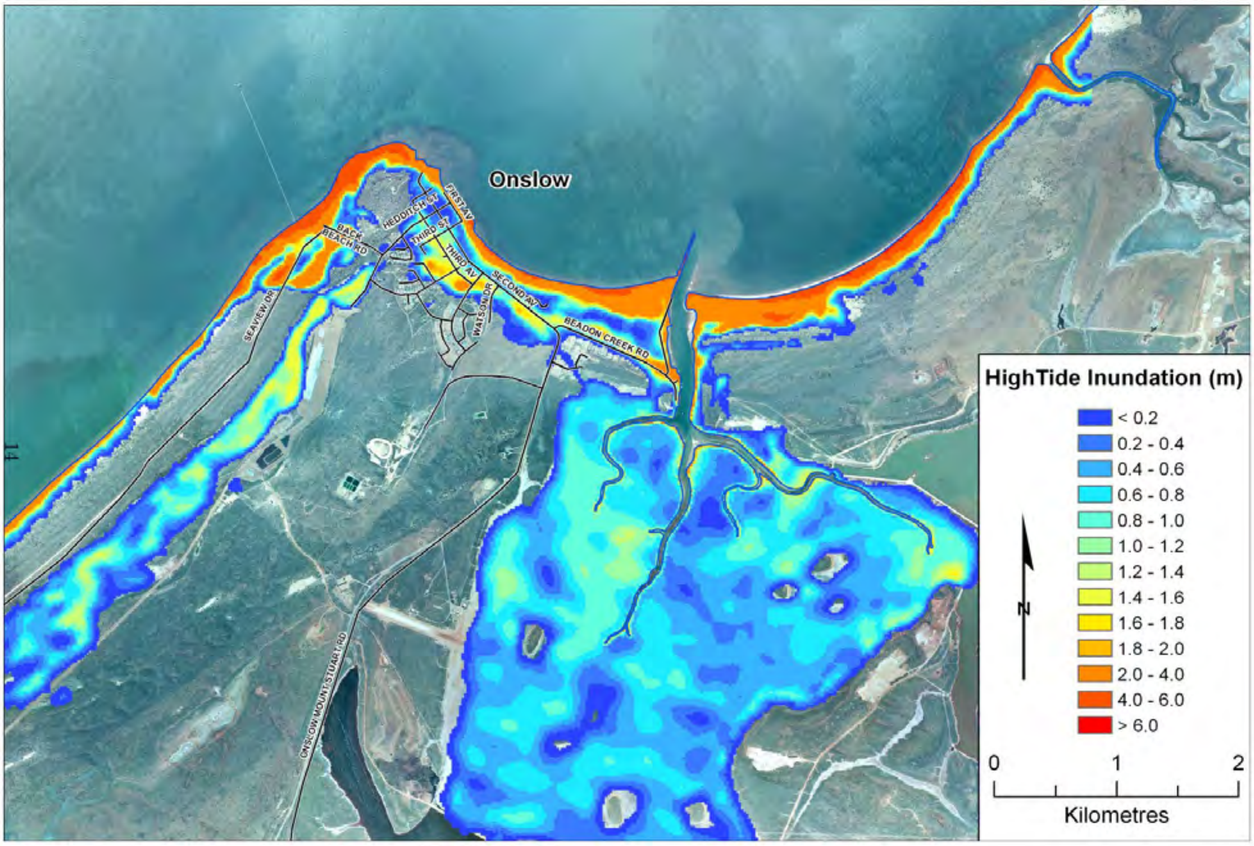


FIGURE 8-3 MAXIMUM TSUMANI INUNDATION MAP AT HAT (GEOSCIENCE AUSTRALIA, 2006)

The maximum observed water level occurred in Beadon Bay East for the HAT scenario where an inundation level of approximately 5m AHD was modelled (Geoscience Australia, 2006). The inundation varied spatially across the Onslow townsite, as well as with the different water level scenarios. The results are summarised in Table 8-2.

TABLE 8-2 PREDICTED INUNDATION LEVELS AT ONSLOW (ADAPTED FROM GEOSCIENCE AUSTRALIA, 2006)

Water Level Scenario	Inundation Level (m AHD)
HAT	2.5 – 5
MSL	3 – 4
LAT	0.5 – 1

As there is no current study available for the Project site, Onslow which is 45 km north from Locker Point, has been used as a proxy. This is considered appropriate as Onslow and the Project site share similar oceanographic and climatic conditions. For the purposes of this study, a range of 3-5 m AHD appears to be reasonable estimate of tsunami inundation, with 5 m AHD a conservative estimate for a 500-year ARI tsunami inundation.

The literature review showed that a detailed tsunami study is scientifically extremely demanding; indeed, the reports by Geoscience Australia indicated there are still many unknowns in assessing this hazard. As such, it is recommended that planning for the impacts of a tsunami should be included as part of the proposed facility’s risk management plans.

However, values up to twice this level could be experienced in an extremely rare event. The maximum run-up ever recorded in Australia occurred at Steep Point (Shark Bay) in 2006, with a value of 9.0 m.

9 WATER QUALITY

Water quality in the study area is influenced by tides, seasonal oceanographic, meteorological dynamics and locations. Historic studies have shown that the water in Exmouth Gulf in the vicinity of the proposed Project site can be characterised by its high salinity, primarily caused by high evaporation rates, low rainfall and therefore insignificant fluvial flows (Oceanica, 2006).

9.1 Surface Water Quality

9.1.1 Regional Surface Water Quality

The Ashburton River is located approximately 25 km north east of the proposed salt ponds. The Ashburton River is generally fresh, with Total Dissolved Solids (TDS) (a measure of salinity) being around 133 mg/L (Ruprecht and Ivanescu, 2000). This is similar to other rivers in the Pilbara region (TDS range 50 - 1,000 mg/L). Salinity in the Ashburton River, and all Pilbara region rivers, generally decreases with increasing flow and becomes more saline during times of low flow (URS, 2010).

Total Suspended Solids (TSS) and turbidity in the Ashburton River are generally low, and generally increase with increasing flow. The turbidity of the Ashburton River ranges from less than 10 NTU over a range of flows, from 30 m3/sec to 250 m3/sec, to 3,300 NTU at a flow rate of around 250 m3/sec. The flow weighted turbidity for Ashburton River is 1,705 NTU, which is higher than other Pilbara river sites, which range from 10 - 587 NTU (Ruprecht and Ivanescu, 2000).

9.1.2 Local Surface Water Quality

Due to the low frequency of significant rainfall events resulting in surface water flows or flooding, limited local surface water quality data is available. Two significant rainfall events have occurred in the project area since 2019 which have allowed K+S to sample the flooded salt flat areas (one rainfall event of 44 mm in April 2019 and another of 79.5 mm in March 2021). The data from this sampling is presented in *Marine, Coastal and Surface Water Data Collection Report* (Water Technology, 2021). The results show:

- Total Dissolved Solids (TDS) measurements indicate that surface water is saline to hypersaline on the salt flats with TDS in salt flat samples ranging from 45,000 mg/L to 120,000 mg/L.
- pH across the salt flats and inland flow paths ranged from neutral to slightly alkaline (pH range 7.3 – 8.6).
- Total Suspended Solids (TSS) varied significantly with lower levels on the salt flats (<5 – 87 mg/L) and higher levels inland of the salt flats (up to 19,000 mg/L). Levels within an inland flow path were extremely high (resembling a slurry) at 510,000 mg/L.
- Levels of chlorophyll-a were low in all samples (<0.001 to 0.006 mg/L) except that from the overland flow sample which resembled a slurry (0.32 mg/L).
- The mean total nitrogen concentration across nine sites (excluding the high sediment sample) was 1.1 mg/L. The high sediment sample was excluded as it was more a sediment slurry, as opposed to a representative surface water sample.
- Samples were comprised of predominantly dissolved organic nitrogen (ranging from <.0.2 mg/L to 1.7 mg/L).
- The overland flow sample which resembled a slurry and had high total nitrogen content (120 mg/L), representative of nitrogen within the sediments from overland flows.
- Phosphorus was highest at the most inland sites and largely particulate at these locations. The sites with the high phosphorus also corresponded to sites with the highest TSS. This is the result of phosphorus adsorption to sediment. This observation adds further confidence to the assertation that the environment is nitrogen limited, as there is phosphorus readily available in soils across the site.

- The results show that the nitrogen in the water ponding on the bare salt flats is low compared with the other samples, particularly those received as suspended solids in overland flows (such as the highly turbid water from overland flows entering the salt flats). The data shows that the bare salt flats do not generate comparatively large amounts of nitrogen in ponded water, even after inundation with rainfall, compared with turbid overland flows/ponding from the hinterland.
- High levels of total dissolved solids (TDS) in the samples from the bare salt flats indicate that the surface salt crust was dissolving into the ponded water on the bare salt flats, but there are comparatively low levels of nitrogen in this dissolved salt crust compared with overland flows.

9.2 Marine and Tidal Creek Water Quality

A detailed marine and tidal creek water quality monitoring program was conducted for the project between 2017 and 2021 with the methods and resulting data provided in *Marine, Coastal and Surface Water Data Collection Report* (Water Technology, 2021). The results are also broadly summarised below, although the above report should be consulted for more detailed results.

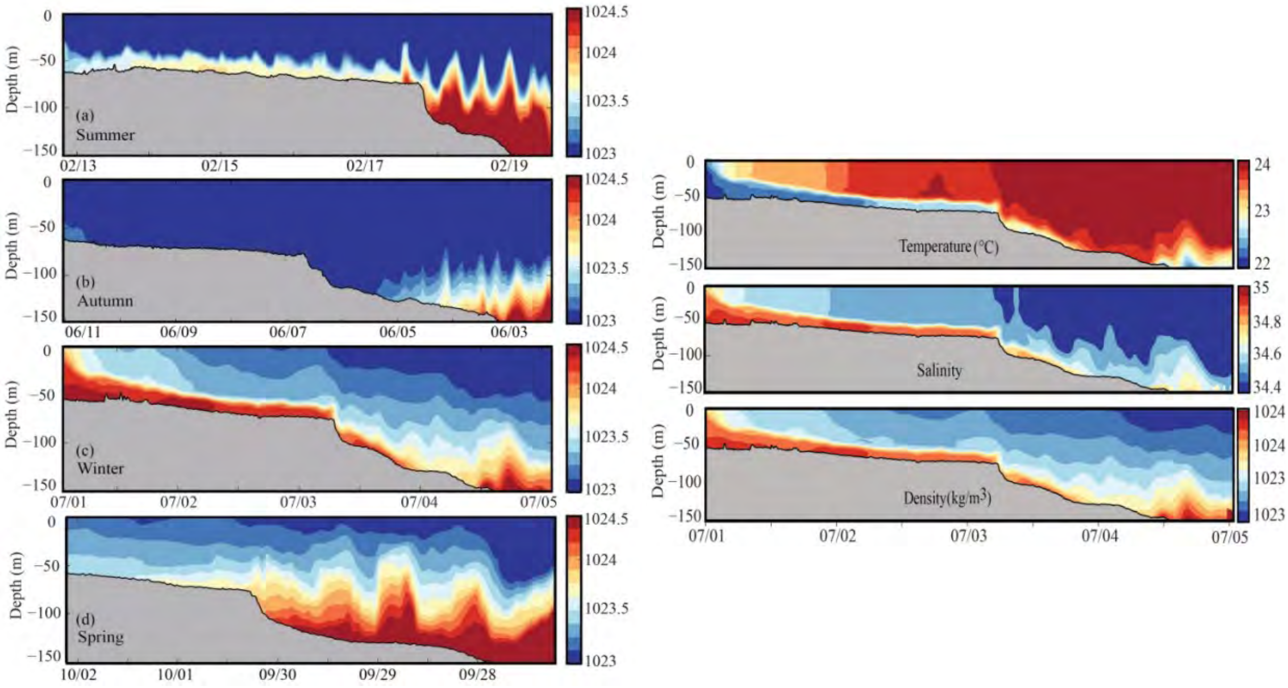
9.2.1 Salinity

9.2.1.1 Regional Salinity

Ashburton has a dry coast with sporadic ephemeral freshwater inputs. The lack of freshwater inputs, high air temperatures and evaporation rates contribute to the generation of high salinity nearshore waters. Strong evaporative processes at the coast can lead to underflows of hot saline water.

The Pilbara inner shelf is characterised by high salinity water with seasonal variations driven by seasonal rainfall, evaporation and wind/current climate. Across the Pilbara shelf, higher salinity nearshore waters drive a gravitational circulation with offshore transport of higher density water along the seafloor. This type of vertical flow pattern was observed by the Integrated Marine Observing System (IMOS) Ocean Glider, which confirmed the formation of dense water flows on a regular basis during winter months (Figure 9-1) (Mahjabin, 2016) and that this is the primary dissipation mechanism of cumulative salinity increases in inner shelf waters. In summer months, nonetheless, coastal warming counteracts the density increase from salinity concentration, leading to reduced stratification and increased vertical mixing, also shown in Figure 9-1.

The background salinity offshore (beyond the continental shelf) is relatively stable at about 34.5 PSU, as are most open oceans. Salinity monitoring as part of the project monitoring program show that the nearshore salinity is about 3 to 5 PSU higher. Coastal water in the region has a long residence time under “day to day” climatic conditions as tidal excursions are small (of the order of a few km) and there are weak water exchanges with offshore water. Without rainfall or freshwater inputs, nearshore salinity changes slowly which is observable at a seasonal time scale. Tropical Cyclones induce intensive storm flows, upwelling and vertical mixing which may rapidly affect the nearshore salinity field.



Seasonal density structure of Pilbara shelf water (Glider Profiling)

August 2014 profile (Glider Profiling)

FIGURE 9-1 CROSS-SHELF STRUCTURE OF PILBARA SHELF WATER (MAHJABIN, 2016)

9.2.1.2 Local Salinity

Monthly vertical profiles of salinity show that the waters at Locker Point and Urala Creek South are well mixed with no observed salinity stratification.

A timeseries of in-situ salinity (PSU) and total dissolved solids (TDS g/L) measured in laboratory samples at Urala Creek South and Locker Point is provided in Figure 9-2.

TDS is frequently used as a salinity indicator and has been plotted for context. The data is considered to be a reliable representation of salinity throughout the year. There is not a clear seasonal trend, but there are still episodic drops and spikes in salinity.

Spatial plots provided in *Marine, Coastal and Surface Water Data Collection Report* (Water Technology, 2021) highlight the salinity variability over the coast with more saline waters closer to the creeks and less saline water off-shore.

Establishing baseline salinity levels at Locker Point is particularly important given this is the proposed location of the bitterns outfall and salinity is defined as the key physical chemical stressor within the bitterns discharge stream.

Salinity was monitored at Locker Point from December 2018 until October 2020 with both in-situ probe readings (at 1 m depth) and samples for NATA accredited laboratory analysis of samples collected in the top 1 m. The resulting data presented in *Marine, Coastal and Surface Water Data Collection Report* (Water Technology, 2021) indicate that at Locker Point during the monitoring period:

- In-situ salinity ranged from 36.3 PSU to 41.6 PSU, with a median salinity of 40 PSU and an 80th percentile salinity of 40.7 PSU.
- In-situ TDS ranged from 35,621 to 40,155 mg/L, with a median TDS of 38,755 mg/L and an 80th percentile TDS of 39,456.

- Laboratory TDS ranged from 36,000 to 41,000 mg/L, with a median TDS of 39,000 mg/L and an 80th percentile TDS of 41,000 mg/L.

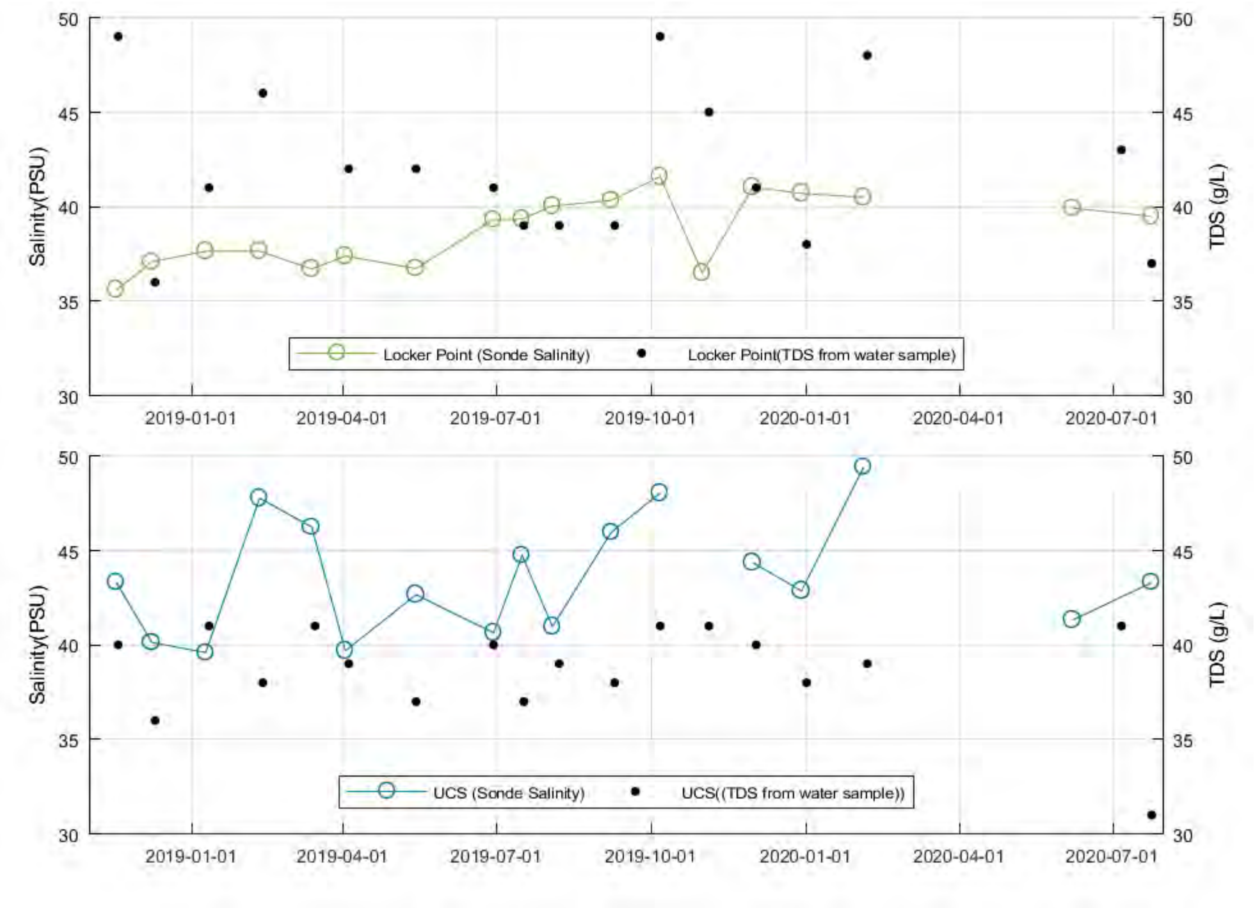


FIGURE 9-2 TIMESERIES OF SALINITY AND TDS AT URALA CREEK SOUTH AND LOCKER POINT

9.2.2 Turbidity

Turbidity profiles have been collected as part of this project between December 2018 and February 2020 by the University of Western Australia (UWA) at several locations, including offshore of the proposed Jetty (Locker Point) and within Urala Creek South. The data is described in detail in '*Marine, Coastal and Surface Water Data Collection*'(Water Technology 2021).

Turbidity data throughout the water column at both Locker Point and Urala Creek South are presented in Figure 9-3. A longer timeseries of turbidity measured at the Locker Point is shown in Figure 9-4.

General turbidity characteristics at both Urala Creek South and Locker Point are summarised below:

- Water turbidity in this region is predominantly determined by tidal flow along the shallow coast and through the creek channel, with additional impacts from wind/wave weather conditions. Discharge from the Ashburton and Yannarie Rivers may temporarily affect nearshore turbidity while such influence is secondary to long-term background turbidity levels.
- Due to the lack of consistent rainfall, the area shows no distinguishable seasonal turbidity pattern as would occur in areas with greater seasonal rainfalls/runoff/wave climate.
- Tidal currents appear to be the main driver of turbidity as indicated by the diurnal turbidity variation in Figure 9-4. The measured turbidity increases from less than 5 NTU under neap tide conditions to over 30 NTU under spring tide conditions.
- In general, turbidity increases with proximity to the coastline. Measured turbidity in areas over 2 km from the coast is usually less than 5 NTU in the middle of the water column.
- Data from the profiles from the inshore locations indicate:
  - Background turbidity in Urala Creek was moderate (<5 NTU) near the water surface and often increased dramatically with depth.
  - Locker Point is a more turbid environment and frequently had large turbidity fluctuations.
  - The elevated turbidity recorded at the seabed in the profiles is likely related to the instrument interacting with the seabed and disturbing sediments.
  - The continuous measured turbidity at Locker Ponit ranges from 1 NTU to over 30 NTU under different tidal phases (Figure 9-4), and may occasionally exceed 200 NTU for very limited time periods.
  - Reverse turbidity profiles (higher turbidity near the surface and lower turbidity near the seabed) are observed for some profiles as shown in Figure 9-3.

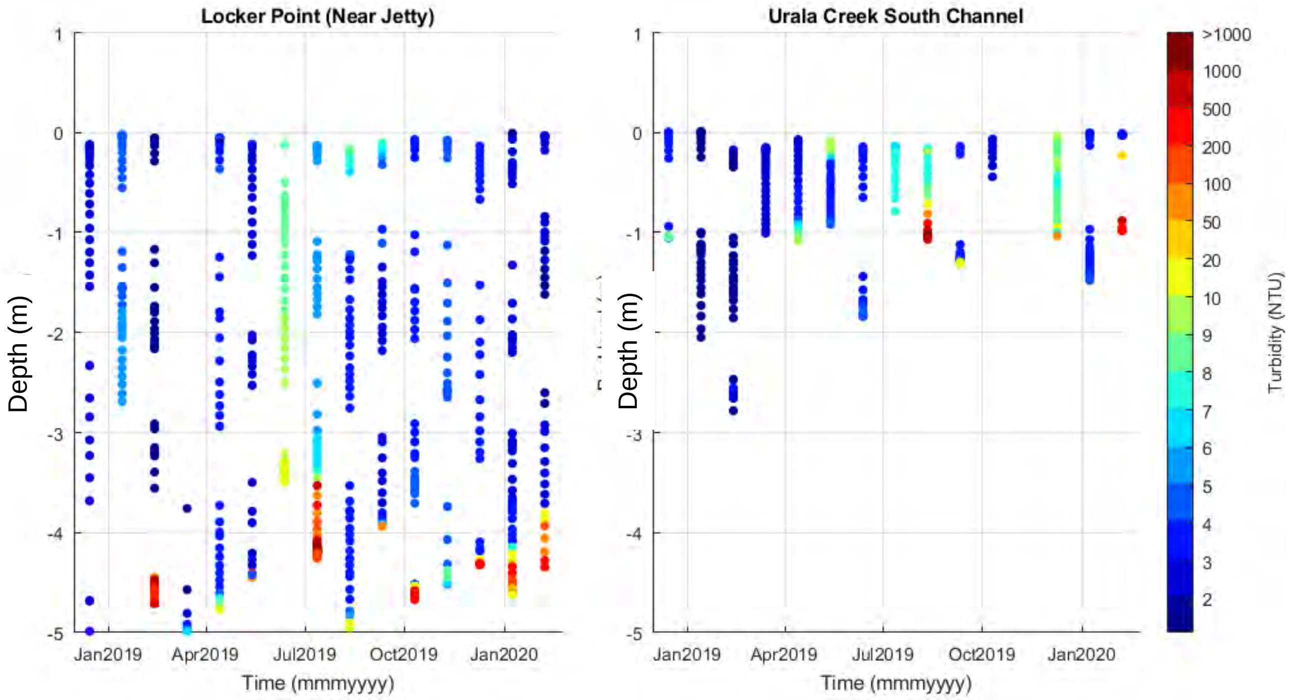


FIGURE 9-3 TURBIDITY (NTU) PROFILE MEASURED AT THE INTAKE (URALA CREEK SOUTH) AND OUTFALL (LOCKER POINT) LOCATIONS

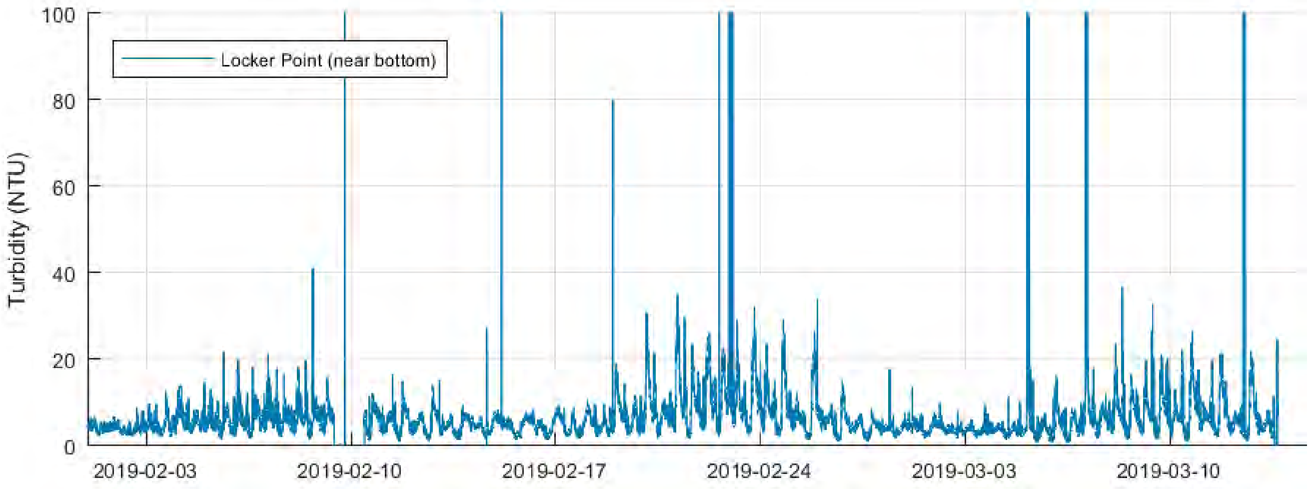


FIGURE 9-4 TURBIDITY (NTU) SEQUENCE MEASURED AT THE JETTY SITE

9.2.3 Nutrients

Water samples for nutrient analysis have been collected as part of this project between December 2018 and February 2020 by the University of Western Australia (UWA) at several locations, including offshore of the proposed Jetty (Locker Point) and within Urala Creek South. The data is described in greater detail in *Marine, Coastal and Surface Water Data Collection* (Water Technology 2021).

Total Nitrogen concentrations ranged between 0.2 mg/L (the laboratory PQL) and 1.1 mg/L. The results in indicate that nitrogen is primarily organic. There are two significant pulses in nitrogen observed in January and August 2019, however these do not correspond to rainfall events and are likely related to upwelling events as discussed further in *Nutrient Pathways Assessment and Modelling* (Water Technology, 2021). Phosphorus, carbon and chlorophyll-a remained consistently low and frequently below the laboratory PQL.

The monitoring and statistical analysis indicates that the marine waters are nitrogen limited, as TN:TP ratios ranged from 18-50:1. The offshore sites had slightly lower nitrogen concentrations, with the area around Locker Point and Locker Island recording higher levels. Median nitrogen concentrations in Urala Creek North and South were quite similar for the nearshore and channel locations. Concentrations at the bottom were slightly higher than those recorded at the surface, likely due to higher particulate content in water closer to the seabed.

AECOM undertook targeted sampling events in Urala Creek North and South in February and October 2019 with samples taken for NATA accredited laboratory analysis. The data is detailed further *Marine, Coastal and Surface Water Data Collection* (Water Technology 2021). The monitoring shows:

- The majority of nitrogen detected was dissolved organic nitrogen. Particulate nitrogen and dissolved inorganic nitrogen made up only a small portion of total nitrogen.
- Total nitrogen concentrations ranged from 140 µg/L at Urala Creek North Middle to 640 ug/L at Urala Creek South Upper.
- Total nitrogen concentrations were higher during the neap tide in October, this could be due to less dilution due to decreased tidal flows.
- The average Total Nitrogen to Total Phosphorous (TN:TP) ratio was 14:1 which indicates the creeks are nitrogen limited.
- There is an observable gradient whereby nitrogen concentrations are greatest upstream, however this trend is not observed in Urala Creek North.
- Median nitrogen concentrations were more consistent between upstream and downstream sites in Urala Creek North, indicating little to no gradient. Concentrations were slightly higher in the mid-estuary at Urala Creek North which is closest to the tributary that leads to algal mats.
- Particulate samples collected at each site were predominantly comprised of the zooplankton size class (50 – 1,000 µm).

AECOM undertook targeted sampling events in two sub-creeks in August/September 2019 with samples for NATA accredited laboratory analysis. The purpose was to provide an additional understanding of the contribution of the algal mats to nutrient levels in adjacent waterways. The nitrogen results for the sub-creek monitoring are provided in *Marine, Coastal and Surface Water Data Collection* (Water Technology 2021). Sub-creek monitoring results show that:

- Nitrogen concentrations are lowest at highwater, which could be related to the dilution of nitrogen rich water in the sub-creeks by less nutrient rich oceanic water brought in with incoming tide.
- Concentrations of nitrogen then increase after highwater on the ebb tide. Adame et al. (2012) observed similar trends in creeks adjacent to algal mats within Exmouth Gulf and concluded that these tidal related increases in nitrogen were due to nutrient influx from flooded algal mats. In the AECOM survey, the trend

was most noticeable for nitrogen and indicates the sub-creeks act as a nitrogen source for the nearshore waters (Adame. et. al., 2012).

- With regard to speciation, nitrogen concentrations are largely comprised of dissolved organic nitrogen. Although the plots only show organic nitrogen, it can be inferred that this is predominately dissolved due to the low levels of particulate nitrogen.
- Similar tidal trends were also shown for phosphorus and carbon indicating tidal influx of these nutrients from algal mat areas into tidal sub-creeks.

9.2.4 Dissolved Metals

Establishing baseline dissolved metals levels at Locker Point is particularly important given this is the proposed location of the bitterns outfall and naturally occurring metals (from the intake seawater) are defined as the key toxicants within the bitterns discharge stream.

Dissolved metals in water were monitored at Locker Point from December 2018 until February 2020 with samples for NATA accredited laboratory analysis. The resulting data is presented in *Marine, Coastal and Surface Water Data Collection* (Water Technology 2021) and shows that at Locker Point during the monitoring period:

- Most of the metals analysed were below the recommended Environmental Quality Criteria (EQC) specified for the protection of North West Shelf ecosystems (99% species protection levels for all metals, except cobalt which is set at 95% species protection) (Wenziker et al., 2006), (EPA, 2016), (ANZG, 2018).
- Aluminium exceeded the ANZG (2018) low reliability screening level of 0.0005 mg/L on two occasions. However, it should be noted that the Laboratory Practical Quantitation Level (PQL) was set above this this screening level of 0.0005 mg/L, with a PQL of 0.01 mg/L. This is the lowest PQL that can be achieved by the laboratories engaged, without additional onerous laboratory validation work which is considered not be necessary given the proposed bitterns discharge characteristics.
- A recent study of aluminium combining chronic biological effects data generated over several years with toxicity data from the open literature to construct species sensitivity distributions (SSDs) has enabled the computation of water quality guidelines for aluminium. An EQC concentration of 0.002 mg/L was derived for a 99% species protection level in tropical waters (van Dam et. al., 2018). Aluminium monitoring for this project exceeded this EQC of 0.002 mg/L on two occasions. However, it should be noted that the Laboratory PQL was set above this this EQC level of 0.002 mg/L, with a PQL of 0.01 mg/L as described above.
- Zinc exceeded the ANZG (2018) EQC (99% species protection level) of 0.007 mg/L on two occasions.
- Copper exceeded the ANZG (2018) EQC (99% species protection level) of 0.0003 mg/L on two occasions. However, it should be noted that the Laboratory PQL was set above this EQC level of 0.003 mg/L, with a PQL of 0.001 mg/L.

From December 2020 until March 2021, targeted marine water quality sampling was conducted at Locker Point, for laboratory analysis to determine if the ANZG (2018) EQC (99% species protection level) for copper of 0.0003 mg/L is regularly exceeded in natural seawater at the location. The results of the monitoring are provided in in *Marine, Coastal and Surface Water Data Collection* (Water Technology 2021) and show that the ANZG (2018) EQC (99% species protection level) of 0.0003 mg/L is regularly exceeded naturally in background seawater at Locker Point (with exceedances recorded in January, February and March 2021).

10 CLIMATE CHANGE

10.1 Meteorology

The predicted impacts of climate change on meteorological conditions are well documented. The 2015 CSIRO report “Climate Change in Australia Projections, Cluster Report – Rangelands” (CSIRO 2015) provides a summary of the projected impacts for the western coast and central areas of Australia. The data has been further broken down into a North and South rangelands cluster. The Project site sits near the border of these two clusters and an average of both clusters was considered for the site.

Key points are summarised below:

- Average temperatures are predicted to increase in all seasons (CSIRO note this is prediction that has a very high confidence);
- A higher number of hot days and warm spells are projected (again with a very high confidence);
- A change to summer rainfall is possible but unclear. Particularly in the south of the area, winter rainfall is projected to decrease (CSIRO notes this has a high confidence); and
- An increased intensity of extreme rainfall events is projected (high confidence).

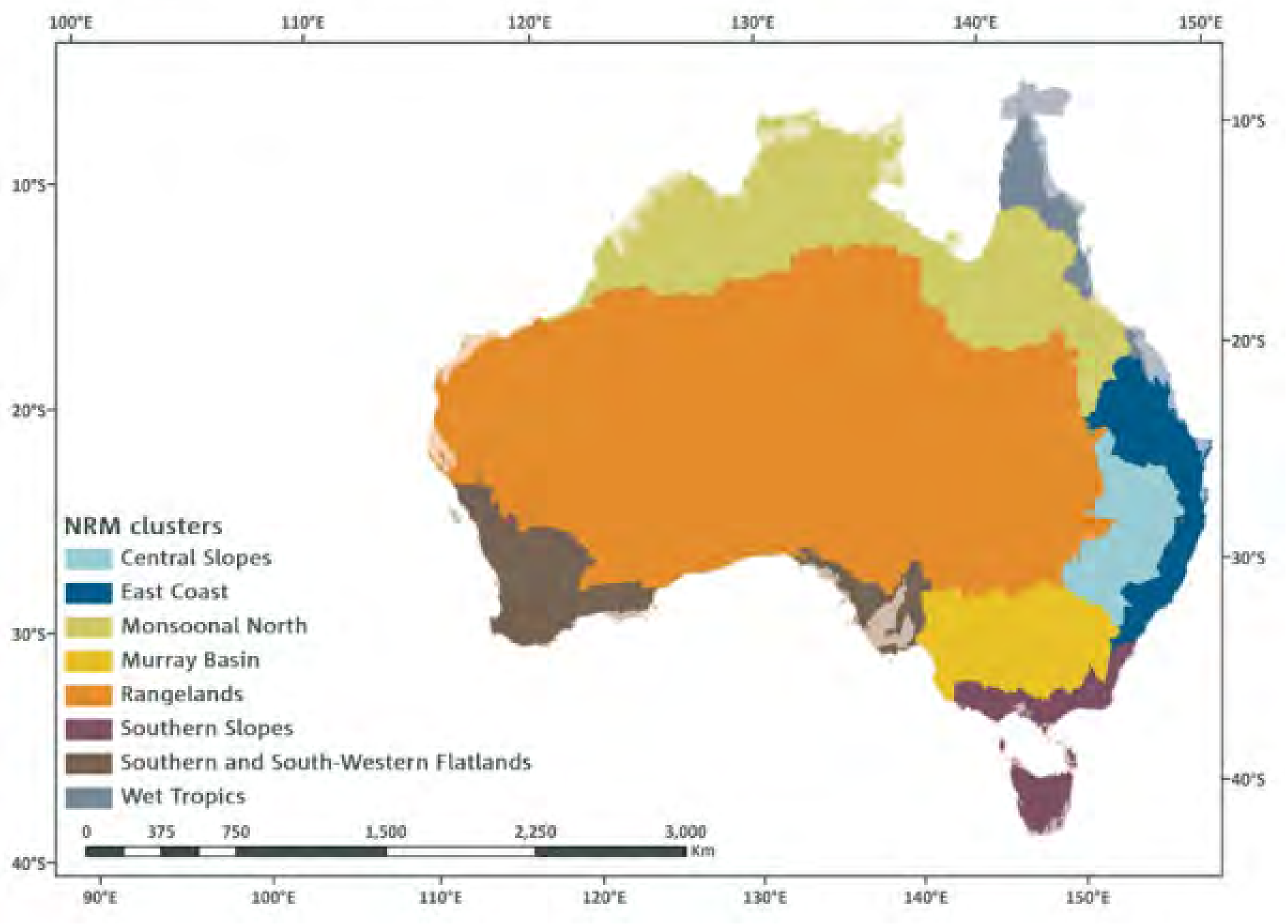


FIGURE 10-1 EIGHT NATURAL RESOURCE CLUSTERS (SOURCE: CSIRO 2015)

10.1.1 Temperature

Air temperatures in the region have increased gradually by an average of 1.0^{o}C over the last century. Global models predict that temperatures in the Rangelands will increase by an additional 0.6 – 1.4^{o}C above 1986-2005 average levels by the year 2030 depending on modelled emission scenario. By 2090, the projected increase in temperature rises from 1.3^{o}C to as much as 3.1^{o}C above 1986-2005 levels.

Along with the increase in average temperatures, the number of hot days (i.e. above 35^{o}C) is predicted to increase.

10.1.2 Evaporation

As would be expected given the increases in average temperature and the number of hot days, the rate of surface evaporation in western and central Australia is also likely to increase in the future. The magnitude of this increase relies on a number of climatic conditions and there is low confidence from CSIRO in the estimates of evaporation magnitude.

10.1.3 Rainfall

Over the long-term, there has been an increase in summer rainfall experienced within the project catchment. Natural climate variability will be the main factor influencing rainfall changes by 2030. The confidence of predicting these changes is low with anything from a 20% decrease in rainfall to a 20% increase possible. It is predicted with a high confidence however that the intensity of large rainfall events will increase.

10.1.4 Wind Conditions

Global models do not provide a consistent understanding of wind conditions into the future and the Pilbara coast in particular is noted for the “considerable spatial variation in wind trends”. Changes to wind conditions, which are not well understood, may impact local currents.

10.2 Oceanography

10.2.1 Water Levels

The Bureau of Meteorology has been collecting high accuracy sea level data across Australia since the early 1990s as part of the Australian Baseline Sea Level Monitoring Program (AMSLMP). As noted in Section 6.2.1, the ABSLMP records data at Broome and Hillarys on the West Australian coast. Analysis of this water level data is presented in the monthly data report which provides an updated overall rate of sea level movement since recording began at the station. The monthly report notes that since November 1991, sea level has risen at Broome by 5.5 mm/year and Hillarys by 6.2 mm/year.

The rate of global sea level rise is predicted to increase into the future, with projected global sea level rise of between 0.12 m and 0.35 m by 2065 and between 0.16 m and 0.55 m by 2090 (CSIRO, 2012). The CSIRO 2015 report “*Climate Change in Australia Projections: Cluster Report - Rangelands*” provides an estimated increase of 0.40 to 0.85 m at Onslow.

The increasing mean sea levels will result in a corresponding increase in the tidal planes presented in Table 6-1 and the level of MHWS offshore of the Project site may rise from 0.89m AHD currently to between 1.3 0m and 1.75 m AHD by 2090. These increases will increase the extent of inundation across the tidal floodplain.

From a policy perspective, included in SPP 2.6 is the current policy relating to Sea Level Rise (SLR) projection for the 100 year planning period up to 2110. These projections are:

- +0.15 m for a 30-year (2040) planning period.
- +0.4 m for a 60-year (2070) planning period.

- +0.9 m for a 100-year (2110) planning period.

The development has a design life of 50-years. As such, all assessments have focussed on the present day and 2070 planning periods.

10.2.2 Water Temperature

Bureau of Meteorology analysis of annual sea surface temperature data indicates that surface temperatures are rising at a rate of 0.12 to 0.16ºC per decade along the Pilbara coastline. The CSIRO Monsoonal Cluster report also details predicted changes to sea surface temperature in the northwest of Australia. The sea surface temperature is expected to increase with increasing global temperatures by a range of 2.4 to 3.7ºC by the year 2090.

10.2.3 Regional Currents

The effects of climate change on boundary currents such as the Leeuwin and Holloway Currents are relatively unknown. Although there is a high degree of uncertainty, modelling indicates that the Leeuwin current could be weakened by climate change (Pattiaratchi and Buchan 1991).

10.2.4 Local Wind Driven Currents

Changes to wind conditions, which are not well understood, may have a minor impact on local currents.

10.2.5 Tidal Currents

Changes in water levels as a result of sea level rise could result in less attenuation of tidal currents within the Urala Creek system and see further penetration of currents upstream. At the jetty location, tidal currents may reduce very slightly due to the increase in mean sea level and associated deeper water across the shallow tidal platform in this area.

10.2.6 Waves

Similar to local wind driven currents, changes to wind conditions along the Pilbara coastline may have a minor impact on non-cyclonic wave conditions around the site, however regular wind generated waves are generally small and have a minor impact on the site. The combination of increased mean sea levels and any increase in winds may have more impact on the shoreline due to different areas of inundation which may face new wave action in the vicinity of the creeks.

10.2.7 Tropical Cyclone

The impact of climate change on cyclone frequency and intensity is complicated as many oceanographic and meteorologic conditions combine to provide optimum conditions for cyclone generation. The CSIRO (2015) Climate Change cluster report indicated that there was medium confidence in predicting that there would be less frequent, but more intense cyclones, in the future.

It is more likely that the frequency and duration of ENSO cycles will have a greater impact on the number and intensity of cyclones, with the average annual number of cyclones on the Pilbara coastline increasing from 0.2 to 0.4-0.6 between El Niño and La Niña.

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