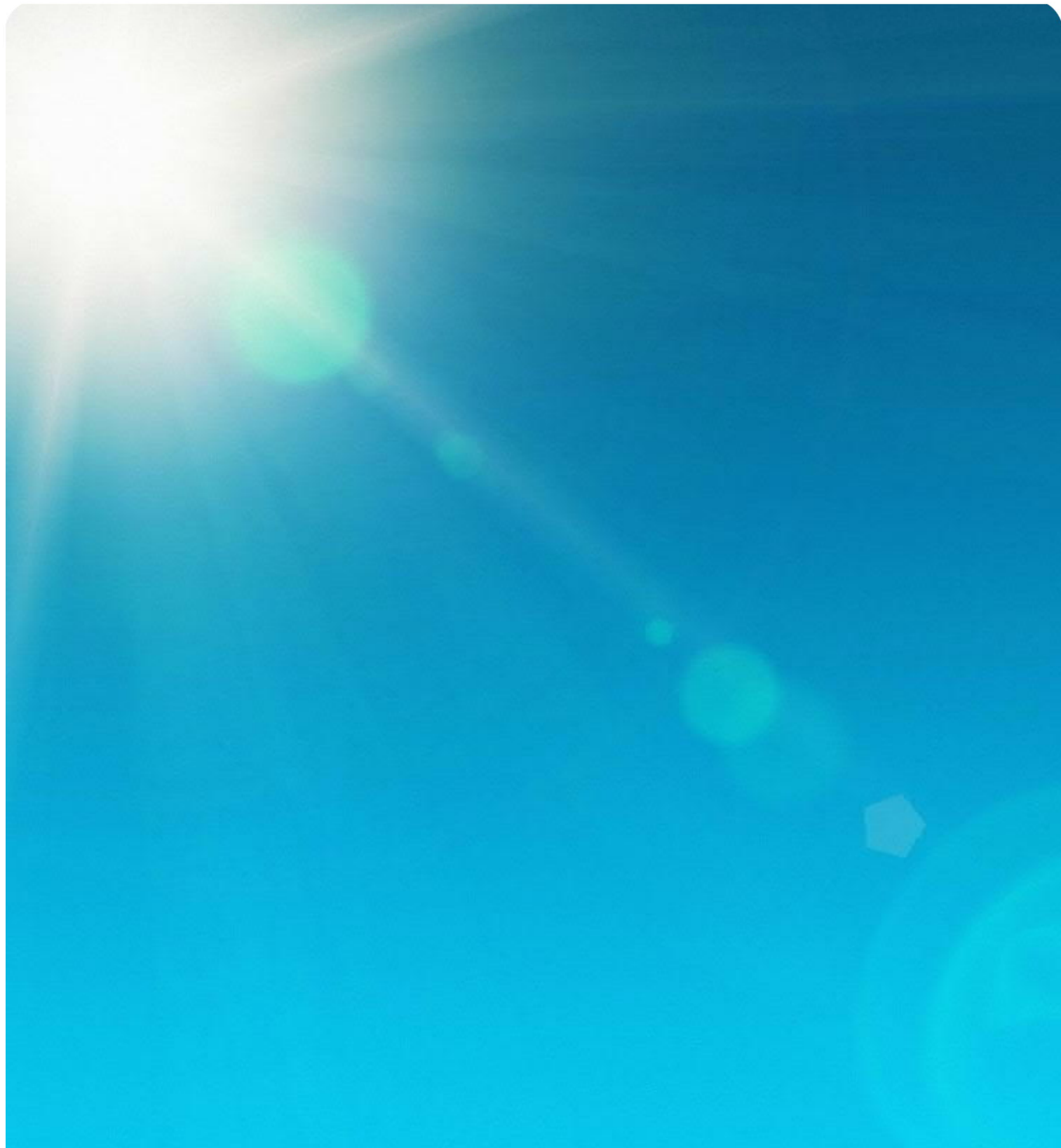


March 2022

Appendix S – Marine Environmental Quality Report

Australia-Asia PowerLink Environmental Impact Statement



Marine Environmental Quality

Sun Cable EIS



Marine Environmental Quality

Sun Cable EIS

Prepared by MetOcean Dynamic Solutions Pty Ltd

Job No.: 2021_2

Quality Information

Document Marine Environmental Quality

Ref 2021_2

Date 29/10/2021

Prepared by Dr Dina Makarynska

Reviewed by Dr Oleg Makarynskyy

Revision History

Revision	Revision Date	Details	Authorised	
			Name/Position	Signature
1	30/08/2021	Draft	Dr Dina Makarynska	
2	08/10/2021	Revision 1	Dr Dina Makarynska	
3	29/10/2021	Final	Dr Dina Makarynska	

Table of Contents

Executive Summary	i
1.0 Introduction	2
1.1 Study areas	4
1.2 Purpose	4
1.3 Method	4
2.0 Numerical data sources	4
3.0 Existing marine environment	6
3.1 Regional setting	6
3.1.1 Nearshore	6
3.1.2 Offshore	7
3.2 Regional climate	7
3.2.1 Wet season	8
3.2.2 Dry season	8
3.2.3 Transitional seasons	8
3.3 Geomorphology and geology	10
3.3.1 Nearshore	10
3.3.2 Offshore	12
3.4 Bathymetry	13
3.4.1 Nearshore	13
3.4.2 Offshore	15
3.5 Sediment characteristics	15
3.5.1 Nearshore	15
3.5.2 Offshore	17
3.6 Oceanographic processes	17
3.6.1 Tides	17
3.6.2 Currents	18
3.6.3 Waves	23
3.7 Extreme conditions	26
3.7.1 Tropical cyclones	26
3.7.2 Storm surge	27
3.7.3 Tsunami	28
4.0 Marine water quality	28
4.1 Overview	28
4.2 Darwin Harbour Report Cards	29
4.3 Water quality objectives	29
4.4 Physical properties	30
4.4.1 Water temperature	30
4.4.2 Turbidity and suspended sediments	31
4.5 Chemical properties	33
4.5.1 Salinity	33
4.5.2 Dissolved oxygen	36
4.6 Biological properties	38
4.6.1 Nutrients	38
4.6.2 Phytoplankton biomass	42
4.6.3 Euphotic depth	44
5.0 Quality of marine sediments	46
5.1 Nearshore	46
5.2 Offshore	48
6.0 References	49
7.0 Report Limitations	0

List of Tables

Table 1	Sources of data used in analyses	4
Table 2	Estimated 2050 total storm tide levels (m AHD) for selected locations within Darwin Harbour (SEA, 2010)	27
Table 3	Water Quality Objectives for Outer Estuary (from Fortune, 2019)	29
Table 4	Median background nutrient concentrations derived from Water Technology (2017), and the Outer Darwin Harbour water quality Objectives	40

List of Figures

Figure 1	Project area in Australian waters (upper panel), zoom in into NT coastal waters (lower panel)	3
Figure 2	Location of monitoring stations (red circles)	5
Figure 3	Reserves associated with Shoal Bay in proximity to the land sea joint station	7
Figure 4	Monthly-average minimum and maximum air temperature and rainfall based on data for 1991 to 2020 from Darwin Airport (BoM, 014015)	9
Figure 5	Wind roses for January representing wet season (left) and July representing dry season (right) based on 1991-2020 data from Darwin SEAFRAME station (BoM, 071014)	9
Figure 6	Examples of typical wind fields for wet (upper panel) and dry (lower panel) seasons in the Project offshore area based on data extracted from WaveWatch III hindcast	10
Figure 7	Mapped interpreted morphology features overlain on bathymetry (from Nicholas et al., 2019)	11
Figure 8	Geomorphology of the Project offshore area (from CARS)	12
Figure 9	Mapped sedimentary environment (upper panel) (after Bourget et al., 2013) and regional structural elements (lower panel) overlain on bathymetry of the Project offshore area (from Saqab, 2016). Dashed line indicates Project submarine route	13
Figure 10	Model mesh and bathymetry in nearshore Project area (adopted from Nicholas et al., 2019) based on AIMS model (e. g. Williams et al., 2006)	14
Figure 11	Local bathymetry (upper panel) and depth profile (lower panel) near Murrumujuk in Shoal Bay (from Water Technology, 2017)	15
Figure 12	Spatial variation in the dominant sediment textural classes, mud (M), sand (S) and gravel (G) (adopted from Nicholas et al., 2019)	16
Figure 13	Spatial distribution of clay, silt, sand and gravel along submarine route based on Sun Cable survey data shown by coloured circles. Circle size is proportional to percentage of sediment constituent in seabed material. Red line indicates submarine cable route, black dots show sampling locations	17
Figure 14	Darwin Harbour sea level records from January 2011 to December 2020 (BoM, 071014)	18
Figure 15	Sea level (MSL) predicted at the nearshore (magenta line) and offshore (blue line) Project locations	18
Figure 16	Current rose based on data from IMOS buoy deployed in Beagle Gulf from May 2015 to July 2017	19
Figure 17	Example of Delft3D modelled current velocities for flood (incoming) tide (upper panel) and ebb (outgoing) tide (lower panel) in nearshore Project part. Red line indicates submarine route. Arrow size is proportional to current speed	20
Figure 18	Examples of typical current field for wet (upper panel) and dry (lower panel) seasons in the Project offshore area based on daily averaged current speed from BRAN hindcast. Arrow size is proportional to current speed	21
Figure 19	Example of Delft3D modelled current velocities for flood (incoming) tide (upper panel) and for ebb (outgoing) tide (lower panel) in offshore Project part. Red line indicates submarine route. Arrow size is proportional to current speed	22
Figure 20	Example of Delft3D modelled significant wave height (Hs), vectors show peak wave direction in Project nearshore area. Red line indicates submarine route. Arrow size is proportional to Hs	23
Figure 21	Wave rose (left panel) and scatter plot (right panel) based on data from IMOS buoy deployed in Beagle Gulf from May 2015 to July 2017	24

Figure 22	Seasonal wave roses based on data from IMOS buoy deployed in Beagle Gulf from May 2015 to July 2017; nearshore Project area	24
Figure 23	Example of typical wave field for wet (upper panel) and dry (lower panel) seasons in the Project offshore area based on hourly significant wave heights and directions from WaveWatch III hindcast	25
Figure 24	Seasonal wave roses based on hourly significant wave heights and peak direction derived from WaveWatch III hindcast for 2015-2016; offshore Project area	26
Figure 25	Tropical cyclones in study area based on 1969-2018 data from BoM. Black circle indicates radius of 200 km from Darwin	26
Figure 26	Storm surge map for Shoal Bay area (Darwin Storm Surge, 2020)	28
Figure 27	Monthly box plot of near-surface water temperature based on long-term data in Darwin Harbour (BoM, 071014) (upper panel, left) and based on seasonal data in Outer Darwin Harbour (upper panel, right) (from Makarynska, 2019b) and water temperature and daily rainfall (brown line) timeseries based on data from IMOS buoys in Darwin Harbour and Beagle Gulf and loggers at Gunn Point in Shoal Bay (from Water Technology, 2017) (lower panel)	30
Figure 28	Example of typical water temperature field for wet (upper panel) and dry (lower panel) seasons in the Project offshore area based on daily averaged temperature from BRAN hindcast	31
Figure 29	Daily average turbidity at 1 m (near-surface) and 28 m (near-seabed) depth (upper panel) and zoom in 1 m depth (lower panel) based on data from IMOS buoy deployed in Beagle Gulf from May 2015 to July, 2017	32
Figure 30	Box and whisker plots of near-surface TSS (upper panel) and turbidity (lower panel) grouped by months based on 2004-2018 DEPWS data from a number of sites in Shoal Bay. Red line indicates median values, red crosses indicate outliers	33
Figure 31	Box and whisker plots of near-surface salinity in Outer Darwin Harbour; dashed line separates different months (from Makarynska, 2019b)	34
Figure 32	Timeseries of daily average salinity at 1m and 28 m depth based on data from IMOS buoy deployed in Darwin Harbour (upper panel), Beagle Gulf (lower panel) and loggers at Gunn Point (lower panel) (from Water Technology, 2017)	35
Figure 33	Example of typical salinity field for wet (upper panel) and dry (lower panel) seasons in the offshore Project area based on daily averaged salinity from BRAN hindcast	36
Figure 34	Box and whisker plots of near-surface dissolved oxygen (% saturation) grouped by months based on 2004-2018 DEPWS data from a number of sites in Shoal Bay (upper panel) and based on 2017-2018 transect data from Outer Darwin Harbour grouped by days (lower panel) (from Makarynska, 2019b). Red line indicates median values	37
Figure 35	Annual mean near-surface dissolved oxygen from CARS (Rothlisberg et al., 2005)	38
Figure 36	Box and whisker plots of near-surface ammonia (NH ₃) (upper panel), oxides of nitrogen (NO _x) (middle panel) and total nitrogen (TN) (lower panel) concentrations grouped by months based on 2004-2018 DEPWS data from nine sites in Shoal Bay. Red line indicates median values	39
Figure 37	Annual mean near-surface dissolved nitrate from CARS (Rothlisberg et al., 2005)	40
Figure 38	Box and whisker plots of near-surface soluble reactive phosphorus (SRP) (upper panel), and total phosphorus (TP) (lower panel) concentrations grouped by months based on 2004-2018 DEPWS data from a number of sites in Shoal Bay. Red line indicates median values	41
Figure 39	Annual mean near-surface dissolved phosphate from CARS (Rothlisberg et al., 2005)	42
Figure 40	Box and whisker plots of near-surface chlorophyll concentrations grouped by months based on 2004-2018 DEPWS data from a number of sites in Shoal Bay (upper panel) and daily average chlorophyll concentrations at 1m and 28 m depth based on data from IMOS buoy deployed in Beagle Gulf from May 2015 to July 2017 (lower panel)	43
Figure 41	MODIS remotely sensed monthly mean near-surface chlorophyll: January (upper panel) and July (lower panel) (from Rothlisberg et al., 2005)	44
Figure 42	Box and whisker plots of euphotic depth (ZEU) grouped by months based on 2004-2018 DEPWS data from six sites in Shoal Bay	45
Figure 43	Mean incident light for wet season (left panel) and for dry season (right panel) from CARS (Rothlisberg et al., 2005)	45

Figure 44	Locations of Ni (nickel) and As (arsenic) exceedances of DGVs and GV-high values (from Radke et al., 2020)	47
Figure 45	Comparison of hydrocarbon parameters with DGVs. NOR-high refers to high value of non-outlier range, and DL refers to detection limit (from Radke et al., 2020)	47

Abbreviations

Abbreviation / Unit	Description
AAPOWERLINK	Australia-ASEAN Power Link
AHD	Australian Height Datum
AIMS	Australian Institute of Marine Science
ANZECC	Australian and New Zealand Environment and Conservation Council
ARI	Average Recurrence Interval
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
As	Arsenic
BoM	Bureau of Meteorology
BRAN	Bluelink ReANalysis
BTEXN	Benzene, toluene, ethylbenzene, xylene and naphthalene compounds
CARS	CSIRO Atlas of Regional Seas
CMR	Commonwealth Marine Reserve
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEPWS	Department of Environment, Parks and Water Security
DGVs	Default Guideline Values
DL	Detection Limit
EA Act	Environmental Assessment Act
EcOz	EcOz Environmental Consultants
EEZ	Exclusive Economic Zone
EIS	Environmental Impact Statement
EP Act	NT Environmental Protection Act
EPA	Environmental Protection Authority
EPBC Act	Environment Protection and Biodiversity Conservation Act
GV-high	Upper guideline value
IMOS	Integrated Marine Observing System
ha	hectare
HAT	Highest Astronomical Tide
HVDC	High-Voltage Direct Current
km	kilometre
LAT	Lowest Astronomical Tide
Metal(oids)	Metals and metalloids
MetOcean	MetOcean Dynamic Solutions Pty Ltd
MODIS	Moderate Resolution Imaging Spectroradiometer
m AHD	metres Australian Height Datum

Abbreviation / Unit	Description
mg/L	Milligrams per Litre
m/s	metres per second
μM	Micromole
μg/L	Micrograms per Litre
MSL	Mean Sea Level
N	Nitrogen
NH ₃	Ammonia
Ni	Nickel
NO _x	Nitrogen Oxides
NT	Northern Territory
NTU	Nephelometric Turbidity Units
ODH	Outer Darwin Harbour
OHTL	Overhead Power Transmission Line
P	Phosphorus
PAHs	Polycyclic Aromatic Hydrocarbons
PAR	Photosynthetically Active Radiation
ppt	Parts per thousand
PSU	Practical Salinity Units
SCM	Subsurface Chlorophyll Maximum
SRP	Soluble Reactive Phosphorus
SSC	Suspended Sediment Concentrations
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TRHs	Total Recoverable Hydrocarbons
TSS	Total Suspended Solids
VSCs	Voltage Source Converters
WQOs	Water Quality Objectives
W m ⁻² d ⁻¹	Watts per square metre per day
ZEU	Euphotic depth

Executive Summary

Sun Cable Pty Ltd is developing the Australia-Asia PowerLink (AAPowerLink), which will establish a high-voltage direct current transmission network, connecting Northern Territory and Singapore energy markets to a new solar farm in Northern Australia. A subsea fibre optic cable network will extend approximately 3,750 km from Murrumujuk in the Northern Territory to Singapore, via Indonesia. The environmental authorities decided that the proposed action in Australian waters requires formal assessment at the level of an Environmental Impact Statement (EIS).

In order to support the EIS, MetOcean Dynamic Solutions Pty Ltd was engaged to develop a baseline understanding of marine environmental parameters, including both water quality and sediment characteristics.

The Project study area lies within the geographical limits of Shoal Bay, which is categorised as part of the Outer Darwin Harbour, and extends offshore into Beagle Gulf and the Timor Sea. The study area was divided into two main sections: (1) the nearshore development area that extends for approximately 100 km along the submarine route from the land sea joint station near Murrumujuk in Shoal Bay into the Beagle Gulf, and (2) the offshore development area along the route (approximately 650 km) in the Timor Sea to the edge of Australia's Exclusive Economic Zone. The nearshore part of the Project includes protected areas such as the Shoal Bay Coastal Reserve and Tree Point Conservation Area, while the offshore part includes the Oceanic Shoals Marine Park.

The study involved a desktop literature review, analyses of available data and results of project-specific numerical modelling.

The Project area is located within the monsoonal tropics which have two distinct seasons: a hot, wet season from November to March, when river flows reach their maximum volumes, and a warm, dry season from May to September with little to no rainfall. April and October are transitional months between the wet and dry seasons. The heaviest rainfall in the area is associated with monsoonal troughs, and the passage of tropical cyclones, which occur periodically in the region typically between November and April.

The area is characterised by a macro-tidal regime, with a maximum range of 8.1 m in Darwin Harbour. Tides are predominantly semidiurnal (two highs and two lows per day), with a slight diurnal inequality. Waves below 1.0 m from the west to north-west sector under non-cyclone conditions appear to be typical for Shoal Bay. In the more open offshore part of the Project, wave conditions are more energetic, with wave heights frequently exceeding 2 m in both the wet and dry seasons. Wave conditions reflect the seasonal reversal of the dominant wind direction with higher incident wave energy during the wet season. Depending on location and intensity, tropical cyclones and low-pressure systems can cause extreme wave conditions in both the nearshore and offshore areas of the Project. During such events, coastal areas can also be affected by storm surge.

Water quality in the study area is highly variable both spatially and temporally. There is a natural spatial gradient in some water quality parameters that extends from the coastal area towards more open waters of Beagle Gulf and the Timor Sea. Generally, water in the coastal areas is more turbid than that of the more open sea. Water in the coastal areas also has lower salinity during the wet season, higher salinity during the dry season, and is higher in nutrients and chlorophyll α , indicating higher productivity.

Seasonal influences on water quality are driven by the climatic differences between the wet and dry seasons. During the dry season, dry south-easterly airstreams pass over the Top End and the Timor Sea resulting in very little or virtually no rain. In the wet season, monsoonal north-westerly winds produce waves that stir up sediments in shallow areas and impact on water quality, whilst runoff from the catchment introduces freshwater and dissolved and particulate material to the nearshore Project area which affects salinity and turbidity. Water quality in the offshore areas appears to be less sensitive to seasonal changes.

Tidal influences on water quality in the nearshore Project area are also significant. Turbidity and suspended particulate material are most affected by tides. Tidal impacts depend on location and are mediated, for example, by the proximity to mangroves, which usually act as sinks for suspended particulate material.

In the Project area within Shoal Bay, water quality was deemed to be excellent in the last three reported years (2017-2019) by the Department of Environment, Parks and Water Security (Northern Territory Government).

The sediments in the Project area generally comprise silt, clay and sand and occasional gravel and appear to be in relatively good condition. Although some localised high levels of arsenic and nickel concentrations were reported, they appear to be naturally occurring. Elevated acidity levels were detected in sediments of the Outer Darwin Harbour.

1.0 Introduction

Sun Cable Pty Ltd (Sun Cable) is developing the Australia-Asia PowerLink (AAPowerLink), a renewable energy transmission system that connects Northern Territory (NT) and Singapore to a new, large-scale solar precinct and battery systems located in the Barkly Region of the NT. The project proposal comprises six key components:

- Solar Precinct where electricity will be generated, near Elliott in the Barkly Region, NT
- Overhead Transmission Line (OHTL) to transmit electricity from the Solar Precinct to Darwin
- Darwin Converter Site including Voltage Source Converters (VSC), energy storage and network connection to supply electricity to the Darwin region
- Cable Transition Facilities to enable transition of power cables between land and sea
- Subsea Cable System extending between the Cable Transition Facilities and Singapore
- Singapore Converter Station to receive electricity and supply the Singapore electrical network.

The NT Environment Protection Authority (EPA) decided that the proposed action requires formal assessment under the *NT Environmental Protection Act 2019 (EP Act)* at the level of an Environmental Impact Statement (EIS). The proposal is also being assessed under the *Environment Protection and Biodiversity Conservation Act 1999*. The terms of reference (TOR) for the EIS set out the matters relating to the environment that are to be addressed. The TOR identified a number of key environmental factors that could be significantly impacted by the Proposal, these include the marine environmental quality factor with the following objective (NT EPA, 2021):

Protect the quality and productivity of water, sediment and biota so that environmental values are maintained.

MetOcean Dynamic Solutions (MetOcean) was engaged review and collate desktop information and data about environmental conditions and values within the marine area of impact and area of influence from Project activities associated with the installation and operation of the Subsea Cable System, to inform the environmental impact assessment undertaken for the Marine environmental quality factor.

The Subsea Cable System consists of up to six parallel High Voltage Direct Current (HVDC) cables that will extend approximately 4,200 km from the Cable Transition Facilities at Murrumbidgee in the NT to Singapore. The portion of the submarine cable route within the NT coastal waters (three nautical miles from the Territorial Sea Baseline) is approximately 100 km long, and the portion in the Commonwealth waters to the edge of Australia's Exclusive Economic Zone (AEEZ) is approximately 640 km (Figure 1). The remaining section outside the AEEZ falls within the jurisdictions of Indonesia and Singapore respectively and is therefore not assessed in this report.

This report describes the marine conditions of the Subsea Cable System component of the Project (Figure 1), including physical setting, climate, geomorphology and geology, bathymetry and topography, ambient oceanographic parameters, extreme conditions and marine water and sediment quality. Potential impacts of the Project activities on water quality are addressed in a separate report - the AAPowerLink Hydrodynamic, Wind Wave and Sediment Transport Modelling report. Marine ecology assessment is presented in the AAPowerLink Terrestrial Ecology and Marine Ecosystems reports. The information presented in this report has been provided by a range of data sources as acknowledged at the end of the report.

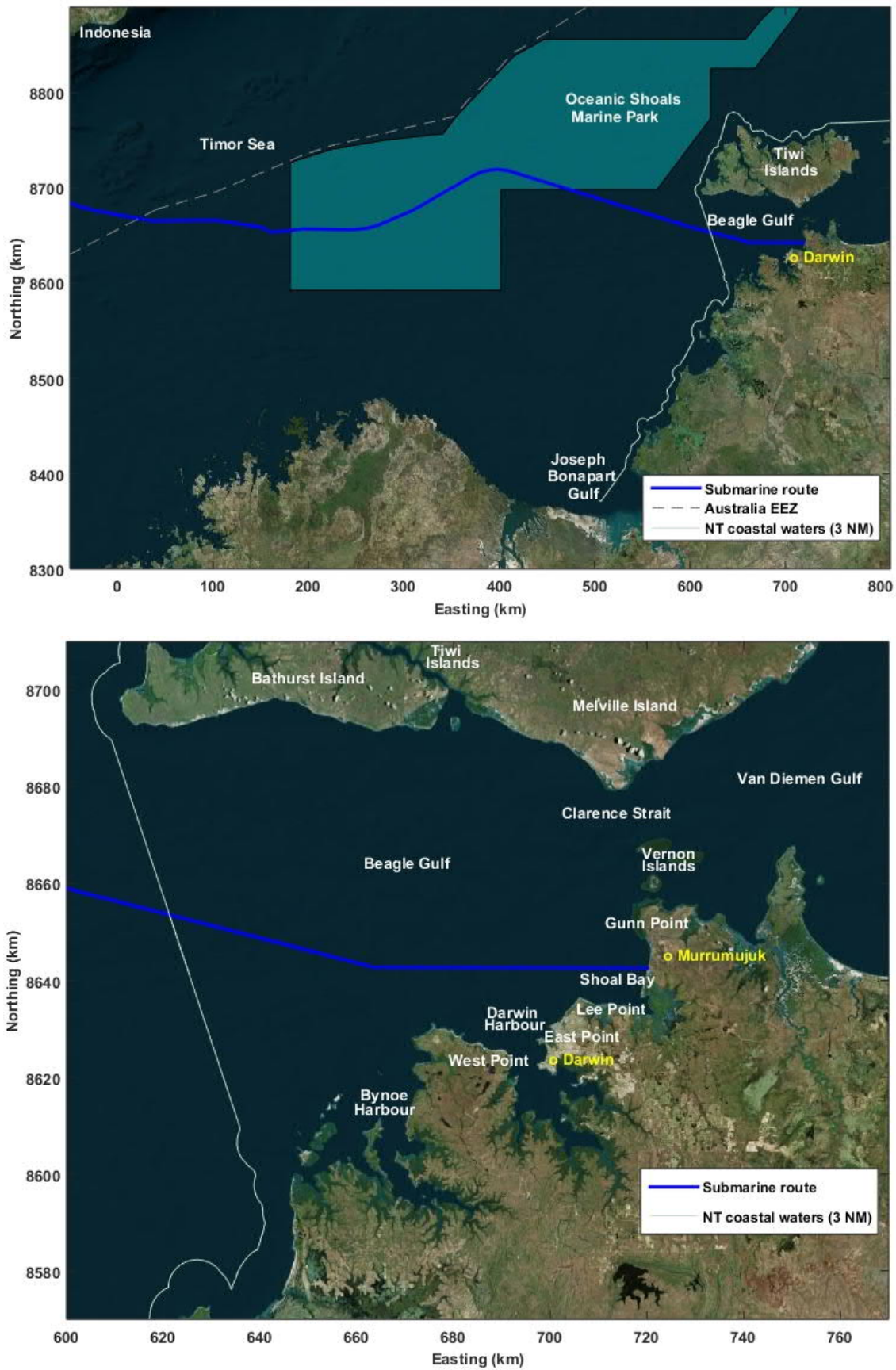


Figure 1 Project area in Australian waters (upper panel), zoom in into NT coastal waters (lower panel)

1.1 Study areas

The study area includes the portion of the submarine cable route within the NT coastal waters and another portion within the Commonwealth waters to the edge of the Australia's EEZ (Figure 1). Due to the complex nature of the environment, which can be affected by different marine processes in the nearshore and more offshore parts of the route, the study area was divided into two compartments:

- The nearshore area that extends along the submarine cable route for approximately 100 km from the land sea joint station near Murrumujuk in Shoal Bay into Beagle Gulf (Figure 1, lower panel). The area includes Shoal Bay Coastal Reserve and Tree Point Conservation Reserve protected by the NT government.
- The offshore area, which includes the submarine cable route (approximately 650 km) in the waters of the Timor Sea to the edge of Australia's EEZ (Figure 1, upper panel). The route traverses the western part of the Oceanic Shoals Marine Park protected by the Commonwealth.

1.2 Purpose

The purpose of this study was to develop a baseline understanding of marine environmental quality, including both water quality and sediment characteristics.

1.3 Method

A literature review of studies relating to both nearshore and offshore Project marine environments was undertaken. The review, where possible, was supported by analyses of field data obtained from a number of sources described below.

2.0 Numerical data sources

The closest Bureau of Meteorology (BoM) meteorological station to the nearshore part of the Project with comprehensive and uninterrupted climatic data is located at the Darwin Airport (see Figure 2 for location). The data from this station were used for the climate analysis.

The wind speed and direction data as well as sea levels (also used in project-specific modelling study (see the AAPOWERLINK EIS Hydrodynamic, Wind Wave and Sediment Transport Modelling report)) were obtained from the Darwin SEAFRAME station (see Figure 2 for location), which is a coastal station.

Data from the Beagle Gulf Surface Buoy (see Figure 2 for location) operated by Australian Institute of Marine Science (AIMS), designed to monitor oceanographic phenomena, were used in analyses of water quality and physical oceanographic parameters.

For the offshore part of the Project, outputs of gridded hindcast modelling by WaveWatch III (CSIRO, 2021; Durrant et al., 2014) and reanalyses by BRAN (Bluelink ReANalysis, Oke, et al., 2013) were used for analyses of waves, wind, currents, water temperature and salinity.

Water quality monitoring has been undertaken in Darwin Harbour, including Shoal Bay, by the Department of Environment, Parks and Water Security (DEPWS) and its predecessor organisations since 1987 (Wrigley et al., 1990). DEPWS data for 2004-2018 were used to describe water quality in Shoal Bay and the Outer Darwin Harbour.

A reconnaissance marine survey data by Sun Cable Marine were used to describe sediments along the submarine cable route.

Summary of data sources is presented in Table 1.

Table 1 Sources of data used in analyses

Parameter	Source name	Coordinates	Period
Air temperature, rainfall	Darwin Airport BoM station 01405	12.42°S, 130.89°E	1991-2020
Wind speed and direction, sea level, water temperature	Darwin SEAFRAME (Australian Baseline Sea Level Monitoring Project), BoM station 071014	12.47°S, 130.85°E	1991-2020

MetOcean Dynamic Solutions

Parameter	Source name	Coordinates	Period
Global current data, water temperature and salinity (daily averages)	BRAN (2021) global model reanalysis		January 2015-August 2016
Global wave and wind data (hourly averages)	Ocean wave hindcast generated by the WaveWatch III v4.18 model (CSIRO Australia, Durrant et al., 2014)		January 2015-August 2016
Water quality data in Shoal Bay and Outer Darwin Harbour	DEPWS, Northern Territory Government	Multiple locations	
Bathymetry (nearshore and offshore)	Geoscience Australia, AIMS, Saqab (2016), Water Technology (2017), Nicholas et al.(2019)	N/a	N/a
Particle size distribution data along the submarine route in the offshore part of the Project	Sun Cable survey		

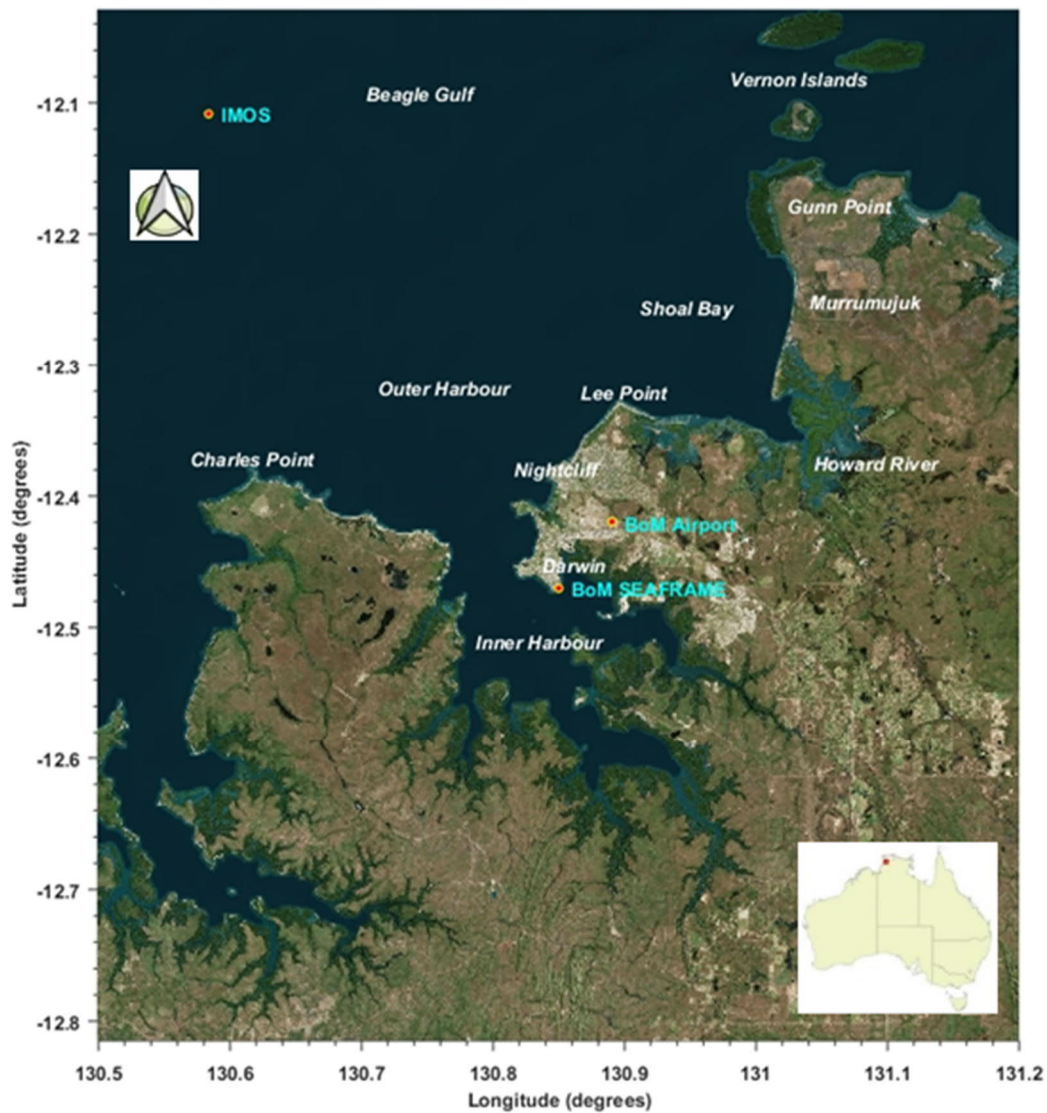


Figure 2 Location of monitoring stations (red circles)

3.0 Existing marine environment

3.1 Regional setting

The Project study area lies within the geographical limits of Shoal Bay, which is categorised as part of the Outer Darwin Harbour (ODH) (e. g. Fortune and Patterson, 2016; Makarynska, 2019a), and extends into Beagle Gulf and the Timor Sea (Figure 1). Most of the submarine cable route is distant from land, with the exception of the eastern end of the route that enters Shoal Bay and crosses land at Murumujuk, where the land sea joint station is proposed.

Project-related environmental values are addressed in in the AAPowerLink EIS Terrestrial Ecology and Marine Ecosystems reports.

3.1.1 Nearshore

The nearshore part of the Project is situated in Beagle Gulf and Shoal Bay, which are part of the NT coastal waters (three nautical miles from the Territorial Sea Baseline) (Figure 1, lower panel).

Beagle Gulf and Shoal Bay are bounded to the south by the mainland and to the north by Tiwi Islands (Figure 1). This area is approximately 100 km long and 50 km wide. Beagle Gulf opens on its west to the Timor Sea and is connected to Van Diemen Gulf in the east by Clarence Strait.

Shoal Bay is a shallow embayment lying northeast of the city of Darwin (Figure 1, lower panel). The bay comprises the lower reaches of the Howard River, which has a catchment size of 1,500 km² (Woodward et al., 2008). Buffalo, Mickett and King Creeks also feed into Shoal Bay. Much of Shoal Bay is exposed at low tide, with about 100 km² of tidal mud and sand flats. The maximum depth of the bay is approximately 15 m near Gunn Point. Sandy beaches are a prominent feature of the shoreline.

Shoal Bay is situated within the ODH, which includes the protected Shoal Bay Coastal Reserve (NTGOV, 2021) stretching from Howard River to Gunn Point (Figure 3). The Shoal Bay Coastal Reserve consists of large areas of rainforest, savannah woodlands, wetlands, mangroves, tidal habitats, and coral reefs. It also contains a large area of saline swamps that can be inundated during the wet season.

Tree Point Conservation Area is situated to the northwest of Shoal Bay Coastal Reserve and south of Murumujuk Drive, protecting a coastal strip of the bay on the Tree Point Peninsula (Figure 3). The conservation area is fringed by coastal vine thicket and a swampy flood plain.

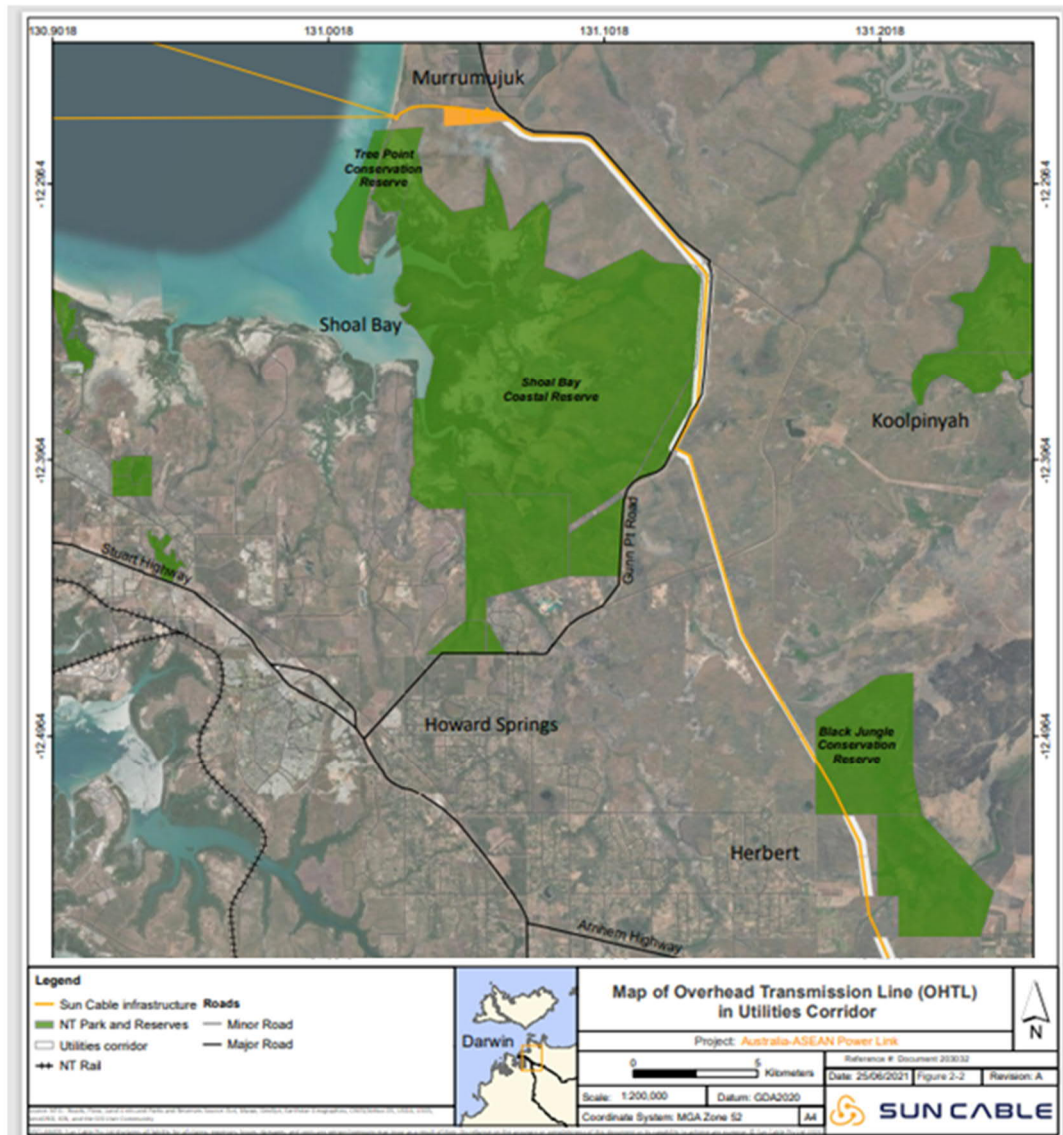


Figure 3 Reserves associated with Shoal Bay in proximity to the land sea joint station

3.1.2 Offshore

In the offshore part of the Project, the submarine cable travels through the Timor Sea to the edge of Australia's EEZ. The Timor Sea is relatively shallow (~50 – 120 m depth), with small areas deeper than 3000 m (Alongi et al., 2011). The region has complex bathymetry, climate, water circulation, and diverse shallow- and deep-water habitats.

The submarine cable route traverses a large portion (approximately 250 km) of the western part of the Oceanic Shoals Marine Park (former Commonwealth Marine Reserve (CMR)), which is located offshore of the NT, about 155 km northwest of Darwin. The marine park is protected by the Commonwealth (Parks Australia, 2021).

3.2 Regional climate

The climate of Northern Australia and the Timor Sea experiences two distinct seasons: a hot, wet season from November to March, when river flows reach their maximum volumes, and a warm, dry season from May to September with little to no rainfall. The yearly seasonal cycle however is more complex, and includes transitional periods with characteristic weather patterns between the main seasons.

Seasonal changes are a result of two major atmospheric pressure systems affecting the north of Australia: a broad tropical low-pressure region called the monsoon trough and the subtropical ridge of high-pressure cells (highs of anticyclones) (e.g. RPS, 2008).

During the wet season the prevailing winds are from the northwest, and during the dry season from the southeast (Figure 5). Strong seasonality in wind patterns in the Project offshore area can be seen from the wind fields presented in Figure 6.

A description of the seasonal climate presented in this section is based on 30-year records sourced from the BoM station (014015) at the Darwin Airport, BoM Darwin SEAFRAME station (071014) and data extracted from WaveWatch III hindcast (Durrant et al., 2014) (for more detail see Section 2.0).

3.2.1 Wet season

In general, the wet season weather is largely determined by the position of the monsoon trough, which can be in either “active” or “inactive” phase. The active phase is usually associated with broad areas of cloud and rain with sustained moderate to fresh north-westerly winds. The inactive phase is associated with light winds and isolated shower and thunderstorms with gusty squall lines.

Daytime air temperatures rise to the mid-thirties in coastal regions and are hotter inland. While the maximum air temperatures are defined as hot all year round, November is the hottest month with a temperature range from 25.4°C (mean minimum) to 33.7°C (mean maximum) (see Figure 4). Minimum air temperatures are around the mid-twenties at night, with the lowest wet season mean minimum of 24.9°C recorded for March (Figure 4). December is the rainiest month of the season with maximum mean monthly rainfall of 470.7 mm, while the total average seasonal rainfall is about 1680 mm. The heaviest rainfall is usually associated with the monsoonal troughs, and the passage of tropical cyclones, which occur periodically between November and April. In the Darwin region, coastal areas are exposed to flooding when sea level rises above normal heights during tropical cyclones or monsoonal activity (SEA, 2006).

Depending on rainfall during the wet season, waters in the coastal areas may become stratified with fresher surface waters, for a few days to a few weeks at a time (e. g. Williams et al., 2006, Drewry et al., 2010). At all other times, water is a vertically uniform and well mixed as a result of the tidal energy.

3.2.2 Dry season

During the dry season the prevailing south-easterlies (South East Trade Winds) bring predominantly fine conditions with occasional light showers over northern Australia.

Figure 4 shows air temperatures and rainfall based on data acquired for the Project from the Darwin Airport meteorological station (BoM, 014015) for 1991 to 2020. Air temperatures (Figure 4) remain warm to hot during the day and are usually between high twenties and low thirties (e. g. Swan et al., 1994). June and July are normally the coldest months, with air temperature ranging from approximately 20°C (see mean minimum, Figure 4) to 30°C (see mean maximum, Figure 4). September is recorded as having the highest mean maximum air temperature (33.1°C) for the season, and July the lowest mean minimum (19.3°C).

The average seasonal rainfall is about 44.3 mm, with maximum mean monthly rainfall of 20.7 mm recorded in May.

During the dry season, Darwin Harbour becomes an inverse estuary with hypersaline (exceeding open-ocean salinity) water formed in its landward arms as a result of evaporation.

3.2.3 Transitional seasons

During April, the North West Monsoon retreats northward and the subtropical ridge also moves northward (e. g. Parkinson, 1996). Thus, the winds can be south-easterly for a period, but brief returns of the north-west airflow are common. The October transition period is characterised by the development of a low-pressure system over central Australia and its displacement from time to time by anticyclones travelling over the southern regions of Australia. While the low is present, the winds tend to possess a westerly component. At other times, the synoptic easterlies may persist.

Transitional periods between the main seasons (wet and dry) are often longer in duration with quite distinct weather patterns. For instance, a period between October and December (known as “build up”), that brings high humidity and clouds but no rain, is characteristic of yearly weather cycle. Based on thousand years of observation of differences in the land and the sky the members of the aboriginal Gulumoerrgin (Larrakia) language group from the Darwin region recognise seven main seasons (CSIRO, 2018).

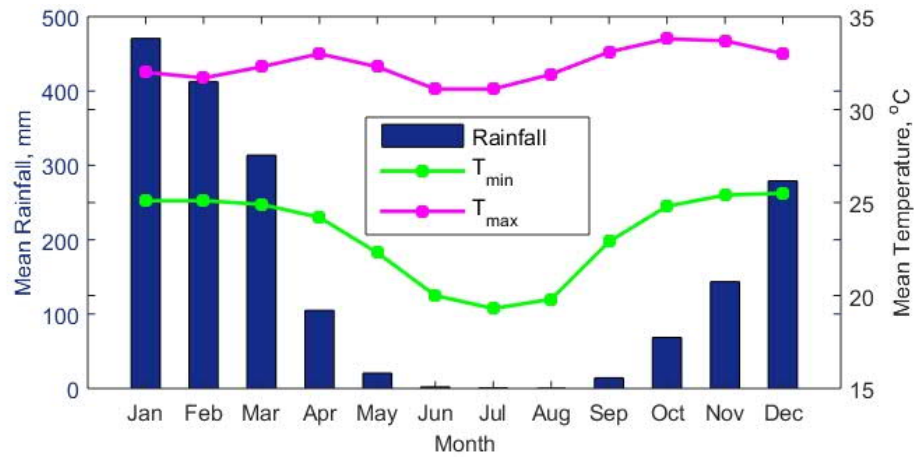


Figure 4 Monthly-average minimum and maximum air temperature and rainfall based on data for 1991 to 2020 from Darwin Airport (BoM, 014015)

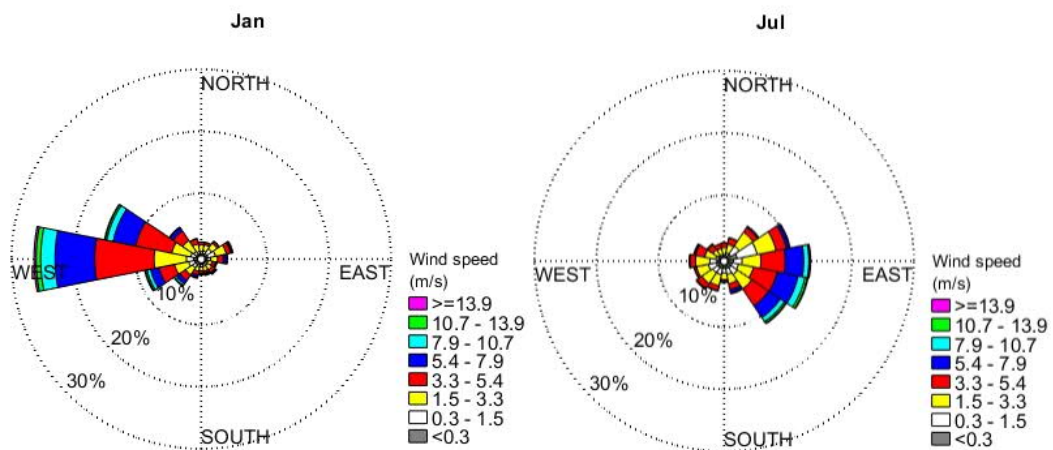


Figure 5 Wind roses for January representing wet season (left) and July representing dry season (right) based on 1991-2020 data from Darwin SEAFRAME station (BoM, 071014)

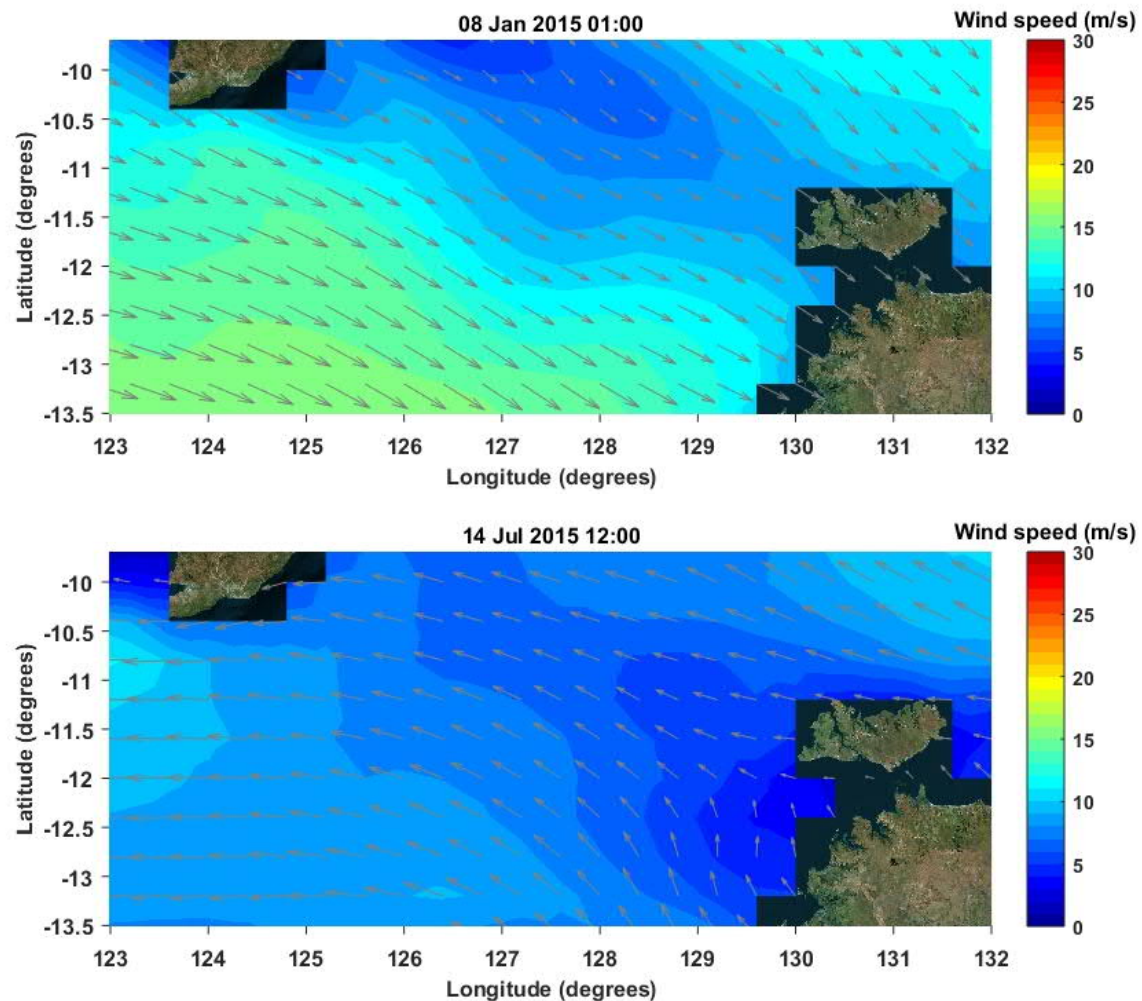


Figure 6 Examples of typical wind fields for wet (upper panel) and dry (lower panel) seasons in the Project offshore area based on data extracted from WaveWatch III hindcast

3.3 Geomorphology and geology

3.3.1 Nearshore

On the shallow continental shelf of Beagle Gulf, a large part of the seabed is dominated by sandy sediment and a range of simple to complex soft sediment bedforms; irregular hardgrounds are also present (Siwabessy et al., 2015; Nicholas et al., 2019) (Figure 7).

The seabed of the area is characterised by a series of shore-perpendicular depressions and channels that extend out into the Beagle Gulf and the greater Bonaparte Gulf (Figure 7). These depressions are internally characterised and flanked by a variety of other bedforms, ridges and partially or completely exposed bedrock.

In Shoal Bay the seabed is a low-lying, generally flat, sandy sediment plain, except at Foelsche Bank (9 km east of Gunn Point Peninsula), and the Howard River mouth where there are a number of low-profile sandbanks and shallow rocky outcrops that are exposed during spring low tides (Nicholas et al., 2019; Radke et al., 2020). Intertidal flats, saltmarshes and associated mud plains are characteristic of the area. A series of unstable cliffs lie behind the main beach of Murrumujuk (Calnan, 2006).

The geology of the Darwin to Gunn Point region is represented by the Palaeoproterozoic metamorphic rocks of the Welltree Formation overlain by Cretaceous marine claystones, siltstones and sandstones of the Darwin Formation (Nicholas et al., 2019). Palaeogene, Neogene and Quaternary sediments and soils of the Cainozoic Era overlay the Cretaceous units as lateritic, marine and non-marine deposits (Pietsch, 1983). The Quaternary period marine alluvium of sand, silt and clay is typically present in the flat, intertidal mangrove zone adjacent to Darwin Harbour and the nearby creeks. The Quaternary age colluvial sand, silt and clay are typically present on the fringe of the intertidal

zone and is an accumulation of run-off carrying soils from upslope. These sediments are generally underlain by lateric soil profiles then by rocks of the Burrell Creek Formation, which are several kilometres thick.

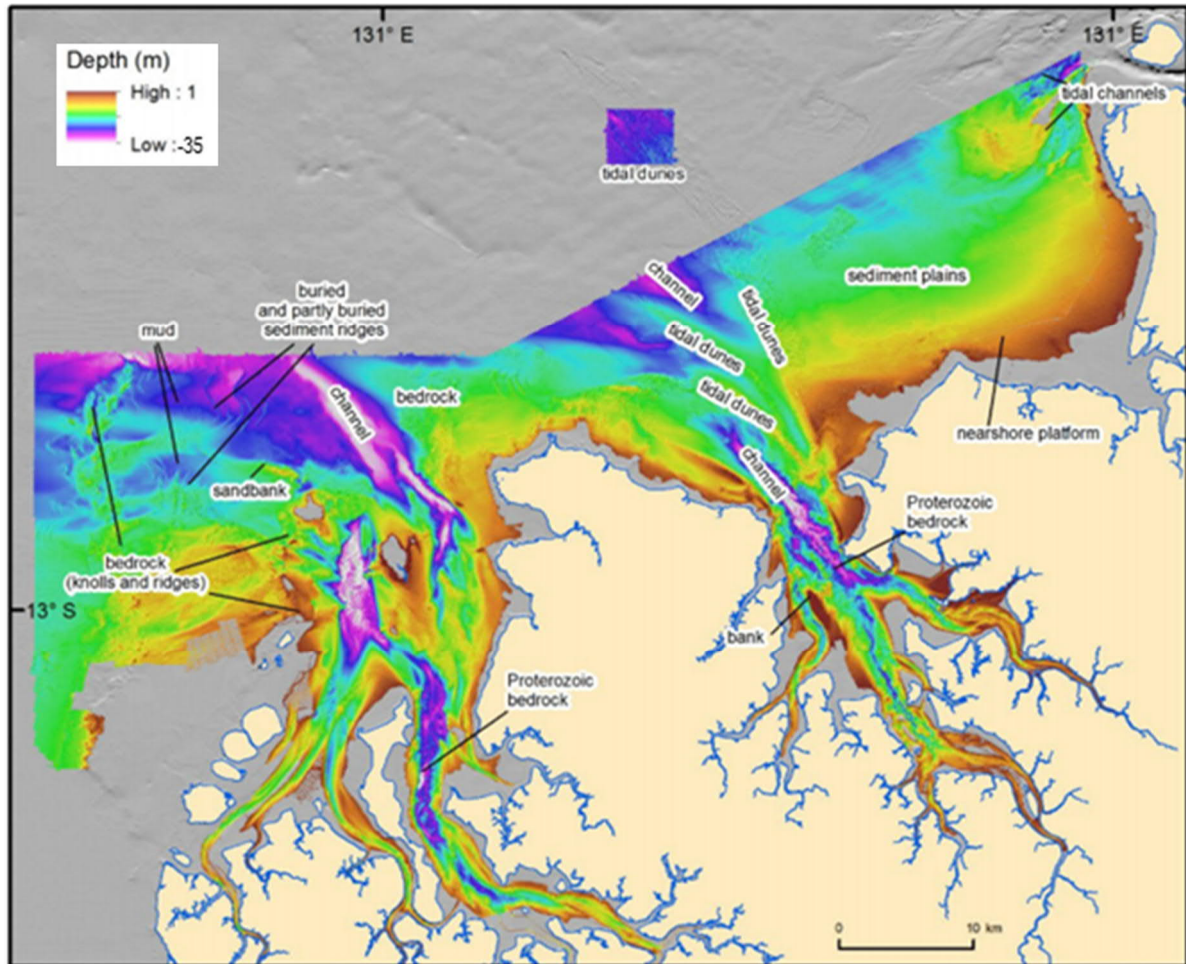


Figure 7 Mapped interpreted morphology features overlain on bathymetry (from Nicholas et al., 2019)

3.3.2 Offshore

The cable route traverses the south-western part of the Money Shoal Basin and Bonaparte Basin. The route crosses an area containing valleys, terraces, banks before reaching the continental shelf break of Northern Australia (Figure 8). The continental shelf is characterised by active growth of carbonate platforms in the shallow areas around the Malita intra-shelf basin (Saqab, 2016) (Figure 9). Extensive areas of carbonate banks, terraces and isolated pinnacles represent key ecological features of the area (Przeslawski et al., 2014).

In the Money Shoal Basin, the base of the sedimentary succession is Middle Jurassic in the western part. Sediments were deposited in marine environments, with occasional incursions of deltaic and fluvial sediments and are up to 4500 m thick in the northwest (GA, 2021).

The Bonaparte Basin adjoins the Money Basin to the northeast. The Bonaparte Basin contains several distinct structural elements that includes the Vulcan Sub-basin, Ashmore Platform, Londonderry High, and Laminaria and Flamingo Highs (Saqab, 2016). The Malita Graben is a prominent depocenter within the Bonaparte Basin and contains up to 10 km of Mesozoic to Cenozoic sediments. The basin developed during two phases of Palaeozoic extension and Late Triassic compression prior to the onset of Mesozoic extension. The Jurassic depocentres contain thick marine mudstones flanked by fan delta sandstones. A thick post-rift Cretaceous-Tertiary succession is dominated by fine-grained clastic and carbonate facies (Nicholas et al., 2015).

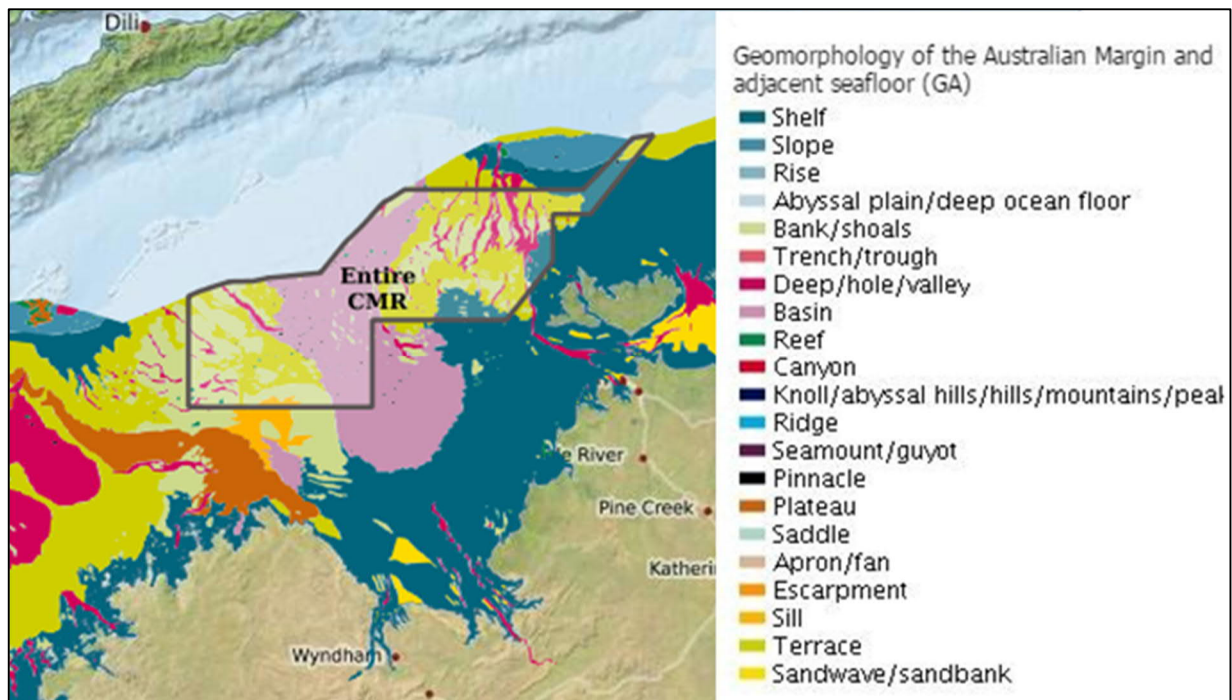


Figure 8 Geomorphology of the Project offshore area (from CARS)

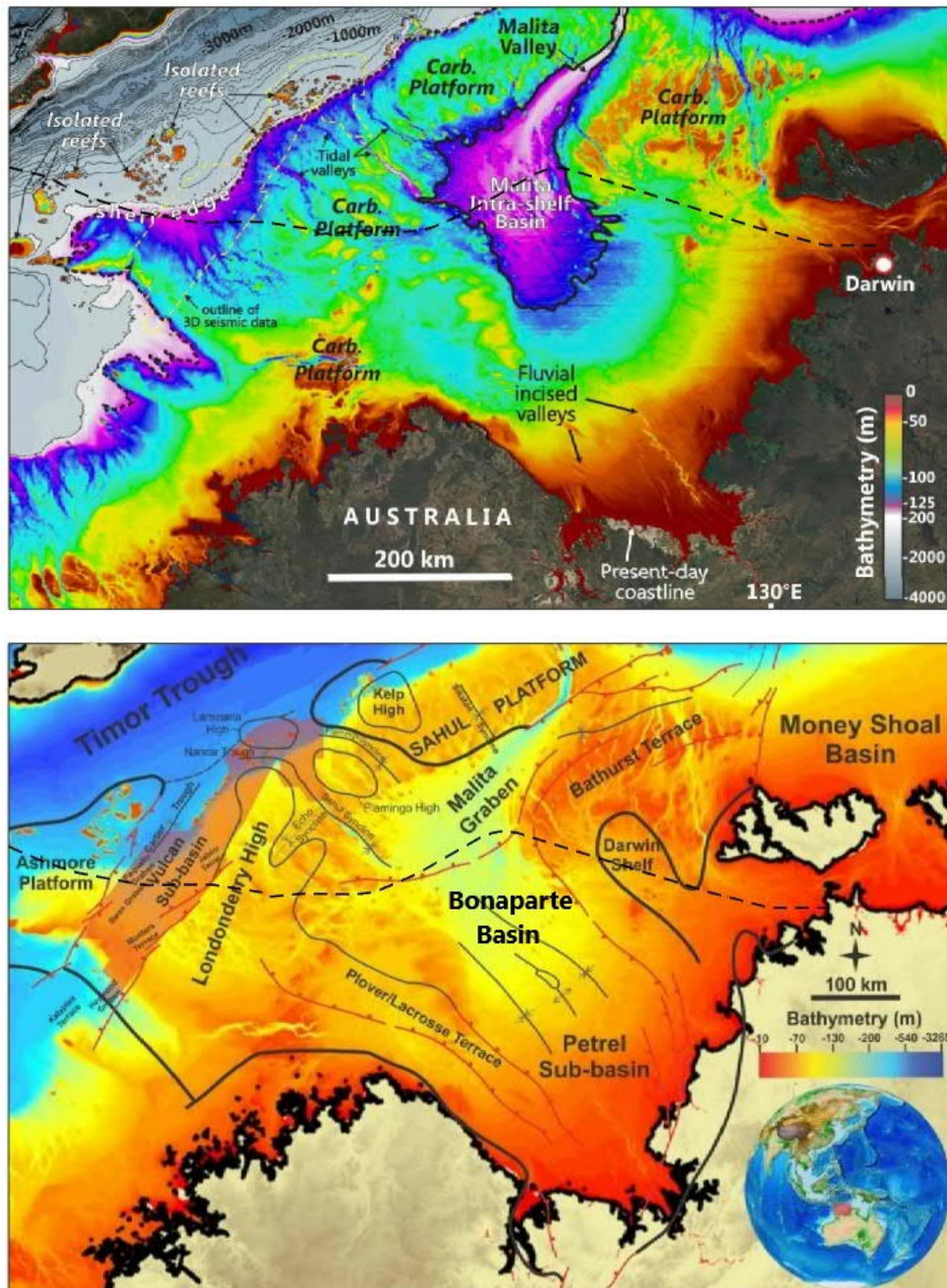


Figure 9 Mapped sedimentary environment (upper panel) (after Bourget et al., 2013) and regional structural elements (lower panel) overlain on bathymetry of the Project offshore area (from Saqab, 2016). Dashed line indicates Project submarine route

3.4 Bathymetry

3.4.1 Nearshore

Bathymetric data for the nearshore study area are incomplete, with mapping products available for subtidal areas only (e. g. Siwabessy et al., 2019). At the time of preparation of this report, project-specific hydrographic surveys of the nearshore Project area have not been completed.

AIMS regularly updates bathymetry from the most recent available data sets for their Darwin Harbour and Beagle Gulf model (Nicholas et al., 2019). Figure 10 shows AIMS model bathymetry covering the nearshore Project area.

As can be seen from Figure 7 and Figure 10, the seafloor of the study area is complex and irregular with water depths varying between 0 and 60 m MSL. Most areas adjoining the coast are typically shallow at approximately 1 m below the sea surface. Approximately 96% of the mapped area shown in Figure 7 is represented by plain surfaces with gradients $< 3^\circ$ (Nicholas et al., 2019).

Results of a 2017 hydrographic survey of the area near Murrumujuk in Shoal Bay reported by Water Technology (2017) indicated that depth reduces slowly offshore below mean low water spring tides at a slope of over 1:700. Figure 11 shows that the water depth drops to 4.0 m at approximately 800-900 m offshore from the vegetation line (elevation > 4.5 m AHD) before becoming deeper.

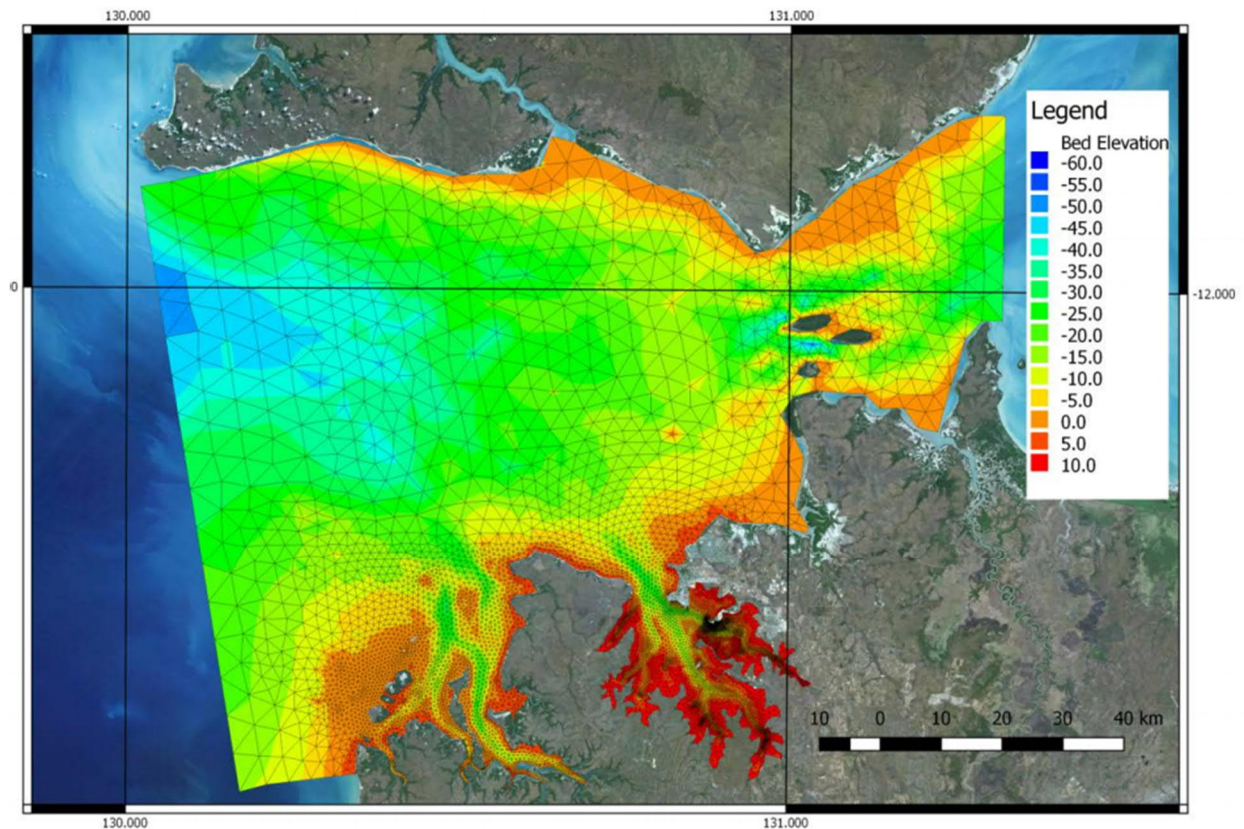


Figure 10 Model mesh and bathymetry in nearshore Project area (adopted from Nicholas et al., 2019) based on AIMS model (e. g. Williams et al., 2006)

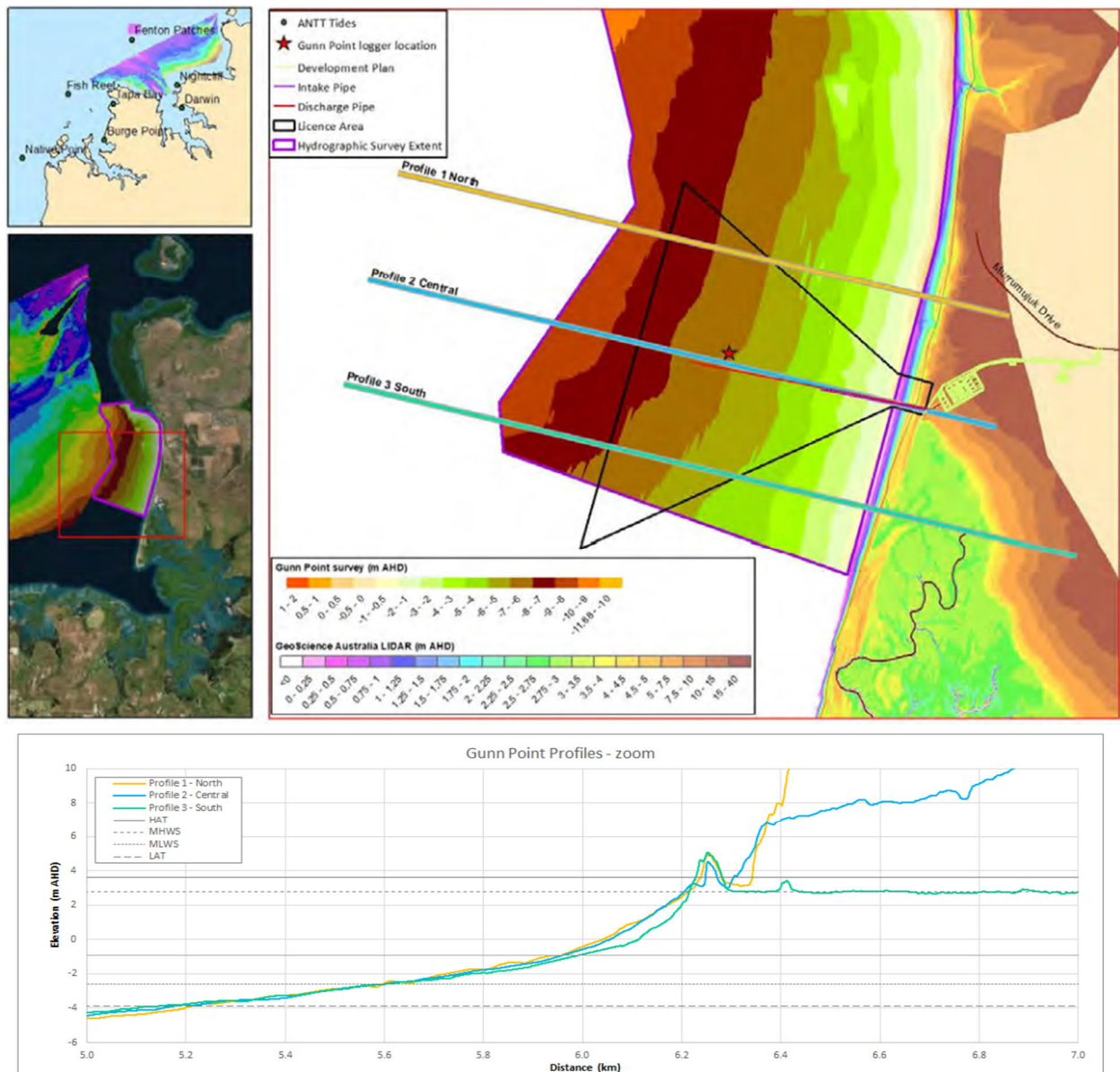


Figure 11 Local bathymetry (upper panel) and depth profile (lower panel) near Murrumujuk in Shoal Bay (from Water Technology, 2017)

3.4.2 Offshore

The submarine cable route in the Timor Sea crosses large area, with water depth ranging from approximately 60 m to 140 m near the route (Figure 9). The offshore part of the route was surveyed by Sun Cable, however due to a limited area being surveyed on both sides of the route these data were not presented in this report.

There are some local seabed features in the area of Oceanic Shoals Marine Park as shallow as approximately 20-30 m. The deepest area in the Timor Sea is the Timor Trough located in the northern part of the sea, which reaches a depth of 3,300 m (Figure 9). The remainder of the Timor sea is shallower, much of it averaging less than 200 m deep, as it overlies the Sahul Shelf which is part of the Australian continental shelf.

3.5 Sediment characteristics

3.5.1 Nearshore

The seabed sediments of the ODH area were documented based on extensive survey data as part of the Darwin Harbour Mapping Project (Nicholas et al., 2019; Siwabessy et al., 2019). Figure 12 shows spatial variation of the

dominant sediment classes, such as gravel (>2000 μm diameter), sand (>63 μm and <2000 μm) and mud (<63 μm diameter), with mud representing a combination of silt and clay particles. The sediments of the ODH are generally muddy sands with varying amounts of gravel, although moderate to large proportions of mud were identified in shallow water on the eastern side of Shoal Bay and at various locations in deeper parts of the study area. High sand percentages were also located over shallower parts of the nearshore region between Darwin and Gunn Point. The nearshore sediments in Shoal Bay are well sorted, potentially due to wave energy in the nearshore environment (Siwabessy et al., 2019). Similar sediment classes were found in Beagle Gulf based on survey data by Sun Cable (Figure 13).

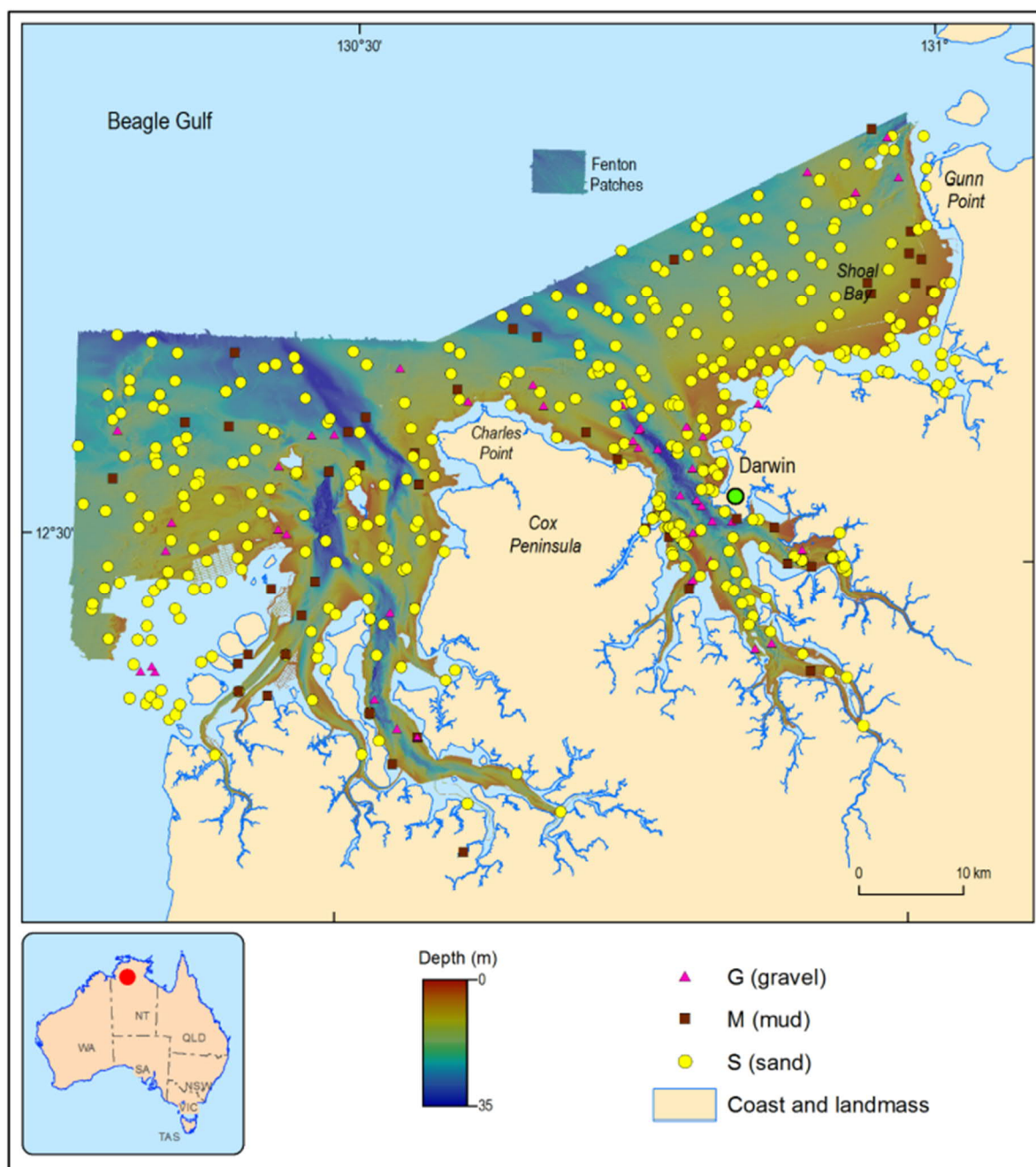


Figure 12 Spatial variation in the dominant sediment textural classes, mud (M), sand (S) and gravel (G) (adopted from Nicholas et al., 2019)

3.5.2 Offshore

Marine sediments along the submarine cable route were characterised by a reconnaissance marine survey by Sun Cable. Figure 13 based on particle size distribution (PSD) of collected samples during the survey shows that the seabed sediments along the route vary and include clay, silt, sand and gravel. The PSD data were averaged for each site based on samples at different depths.

The grainsize analysis indicated that the sediments at the majority of sites (15 out of total 16) contained more than 30% of mud (clay and silt). The proportion of sand greater than 30% was present at 10 sites, whereas only 2 sites had gravel in excess of 30%. The average percentage of mud, sand and gravel was 48%, 39% and 13%, respectively. The average percentage of clay and silt was 24% and 25%, respectively.

This suggests that muddy sands with varying amounts of gravel dominate the seabed along the offshore part of the Project submarine cable route.

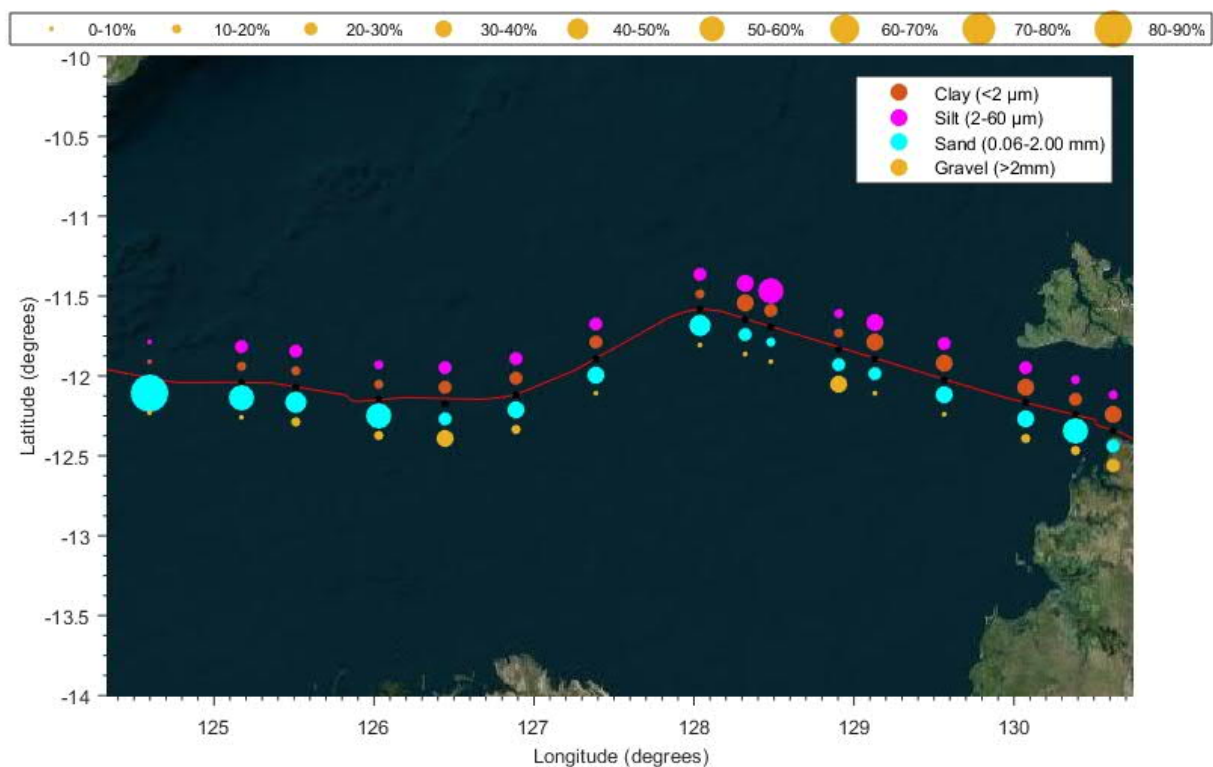


Figure 13 Spatial distribution of clay, silt, sand and gravel along submarine route based on Sun Cable survey data shown by coloured circles. Circle size is proportional to percentage of sediment constituent in seabed material. Red line indicates submarine cable route, black dots show sampling locations

3.6 Oceanographic processes

3.6.1 Tides

3.6.1.1 Nearshore

Water level variations within the nearshore study area are characterised by a macro-tidal regime. Tides are predominantly semidiurnal (two highs and two lows per day), with a slight inequality between the successive tides during a single day. Nearly diurnal tides occur for a two-day period during the neaps. The lowest spring tides of the year occur during October, November and December, while the highest spring tides take place in June and July.

Water Technology (2017) noted the consistency of the tidal pattern and range in measured water levels offshore from Gunn Point, Darwin Harbour and within the Beagle Gulf. This suggests that water level variations recorded in Darwin Harbour can be applicable to Shoal Bay.

Darwin Harbour has a maximum tidal range of around 8.1 m (e. g. Harper, 2010). Figure 14 illustrates the indicated range with sea level records collected over a 10-year period at Darwin SEAFRAME, which is an Australian Baseline Sea Level Monitoring Project site. An example of tidal variation modelled for the nearshore Project part (see the AAPowerLink EIS Hydrodynamic, Wind Wave and Sediment Transport Modelling report for more details) is shown in Figure 15 (magenta line).

According to Landbridge (2020) the average tidal range (LAT) in the Darwin Harbour area is:

- Mean spring tide: 6.9 m (high) and 1.3 m (low)
- Mean neap tide: 5.0 m (high) and 3.2 m (low).

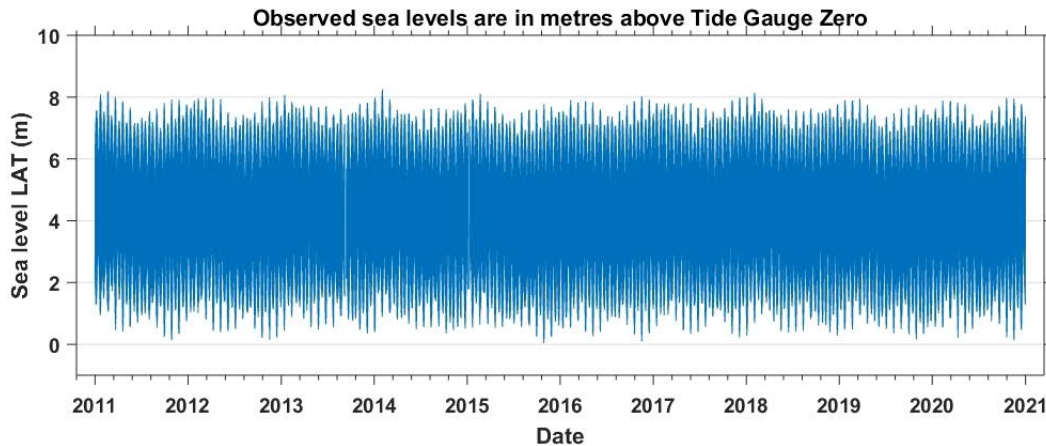


Figure 14 Darwin Harbour sea level records from January 2011 to December 2020 (BoM, 071014)

3.6.1.2 Offshore

Semidiurnal tides dominate the North Western Shelf of Australia. In the Timor Sea, the tidal wave advances faster over the deep Timor Trench than over the Australian continental shelf, which causes wave refraction. Over the shelf the wave proceeds slowly but on a broad front.

No monitoring data were available from sites near the subsea cable route. Estimated tidal levels for the Sunrise pipeline in the Timor Sea based on SKM (2002) were 3.1 m (HAT), 1.7 m (MSL) and 0 m (LAT).

Locally along the coasts an essential increase of the amplitudes occurs, caused by the seabed morphology (Wyrski, 1961). This can be seen from Figure 15 based on project-specific modelling results (for more detail see the AAPOWERLINK EIS Hydrodynamic, Wind Wave and Sediment Transport Modelling report). The tidal range is lower in the open offshore waters compared to the coastal areas, such as Shoal Bay and Darwin Harbour.

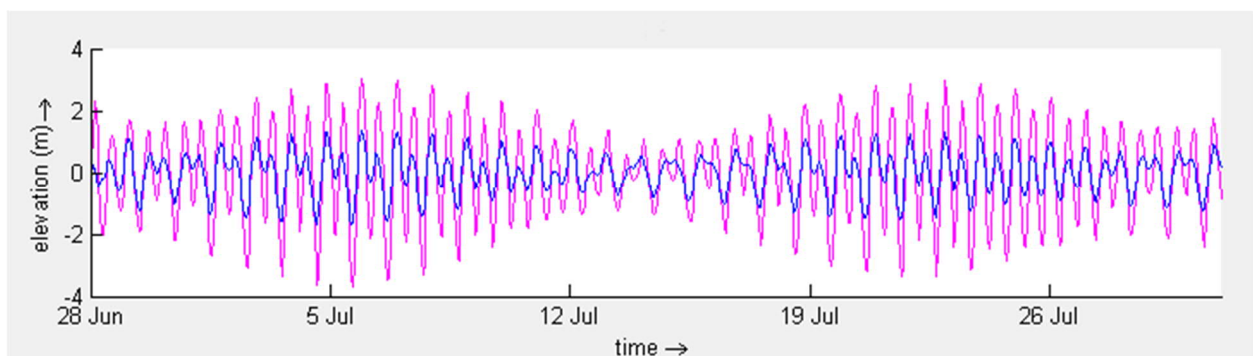


Figure 15 Sea level (MSL) predicted at the nearshore (magenta line) and offshore (blue line) Project locations

3.6.2 Currents

3.6.2.1 Nearshore

Due to the macro-tidal regime of Beagle Gulf and surrounding waters, prevailing currents are of tidal origin (Williams et al., 2006; Siwabessy, 2015). Tidal currents occur in conjunction with the rise and fall of the tide.

The current records collected near the entrance to Darwin Harbour indicate that the maximum flood current speeds may vary from 0.3 m/s (neaps) to 1 m/s (springs), while the maximum ebb speeds may vary from 0.5 m/s (neaps) to 1.6 m/s (springs) (Williams et al., 2006). A current rose based on data from IMOS buoy in Beagle Gulf (Figure 16) demonstrates reversing character of the currents as a result of directional change due to flood/ebb tidal fluctuations,

with strong bi-directionality (east-west) of the currents and a “slack water” period of very low speed (<0.1 m/s) as they move from the flooding stage to the ebbing stage. The results suggest that the recorded current speed was less than 0.5 m/s in almost 65% of times, with the maximum magnitude of 1.4 m/s recorded on 18 October 2016.

Figure 17 presents examples of modelled typical flood (rising) and ebb (falling) current fields within the nearshore area of the Project (for more details see the AAPowerLink EIS Hydrodynamic, Wind Wave and Sediment Transport Modelling report). The complex bathymetry and strong tidal currents create complex circulating patterns, with tidal sand flats and mangrove ecosystems as features of the lower energy regions.

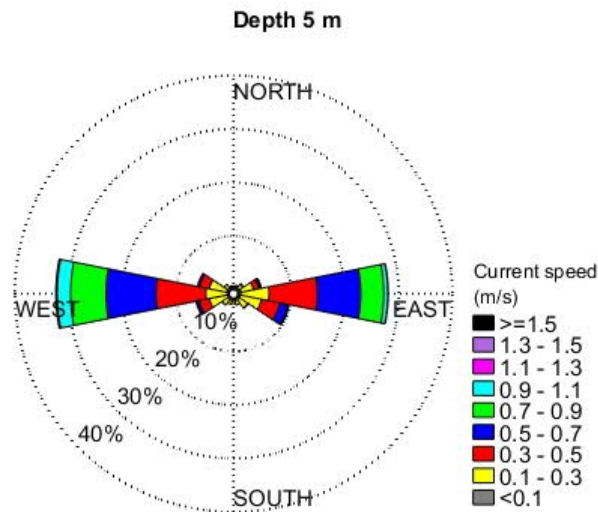


Figure 16 Current rose based on data from IMOS buoy deployed in Beagle Gulf from May 2015 to July 2017

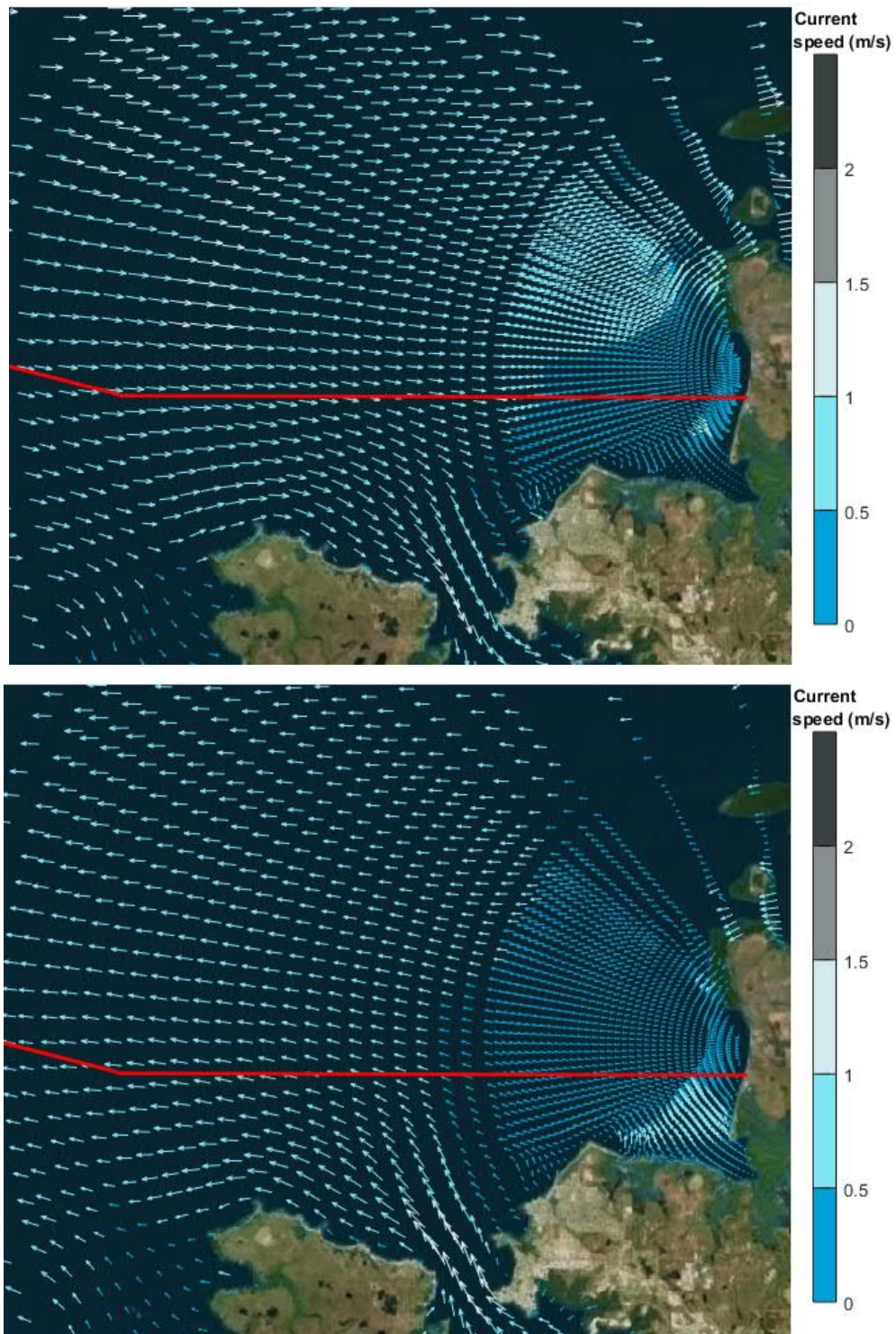


Figure 17 Example of Delft3D modelled current velocities for flood (incoming) tide (upper panel) and ebb (outgoing) tide (lower panel) in nearshore Project part. Red line indicates submarine route. Arrow size is proportional to current speed

3.6.2.2 Offshore

Due to the absence of current observations in the offshore Project area, daily average current speed and directions were extracted from global model reanalysis (BRAN, 2021) to investigate circulation patterns.

Current regime of the offshore Project area in the Timor Sea is complex, with the large-scale currents dominated by the Indonesian Throughflow (Collins, 2010). The Indonesian Throughflow is a system of currents that carries water

westward from the Pacific to the Indian Ocean through the deep passages and straits of the Indonesian Archipelago. This is the only place in the world where warm, equatorial waters flow from one ocean to another.

A major contributor to the Indonesian Throughflow is the Timor Current that runs south-west in the Timor Sea between the Malay Archipelago and Australia, with average speed of 0.2-0.4 m/s. From April to September the current reaches to the Australian coast, although its velocity decreases in that direction (Figure 18, lower panel). From October to March a weak current towards the northeast is formed off the Australian coast under the influence of winds from the southwest (Figure 18, upper panel; Wyrski, 1961).

Tidal currents can also play an important role in the open sea, especially over the shelves, but they normally remain below 0.6 m/s (SKM, 2002; Rothlisberg, 2005; Makarynskyy and Makarynska, 2019). In general, they tend to the south-southeast during flooding and to the north-northwest during ebbing as indicated in Figure 19 based on project-specific modelling results (for more details see the AAPOWERLINK EIS Hydrodynamic, Wind Wave and Sediment Transport Modelling report). These flows are augmented by wind- and wave-generated currents that have strong seasonality in strength and direction. Such currents, with speeds below 0.5 m/s (SKM, 2002), are expected to reflect seasonal wind patterns, flowing to the east or north-east during the wet season and to the west or south-west during the dry season.

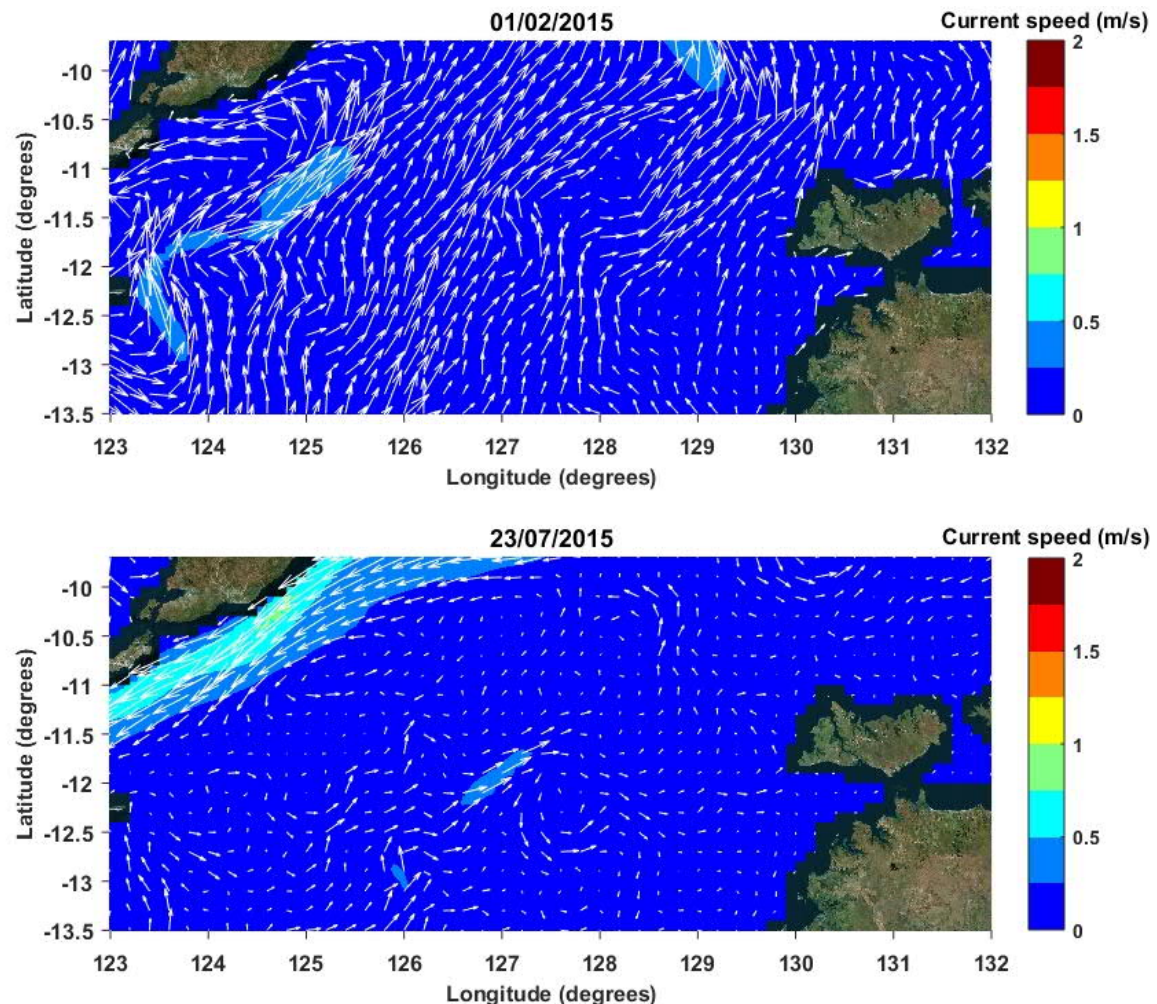


Figure 18 Examples of typical current field for wet (upper panel) and dry (lower panel) seasons in the Project offshore area based on daily averaged current speed from BRAN hindcast. Arrow size is proportional to current speed

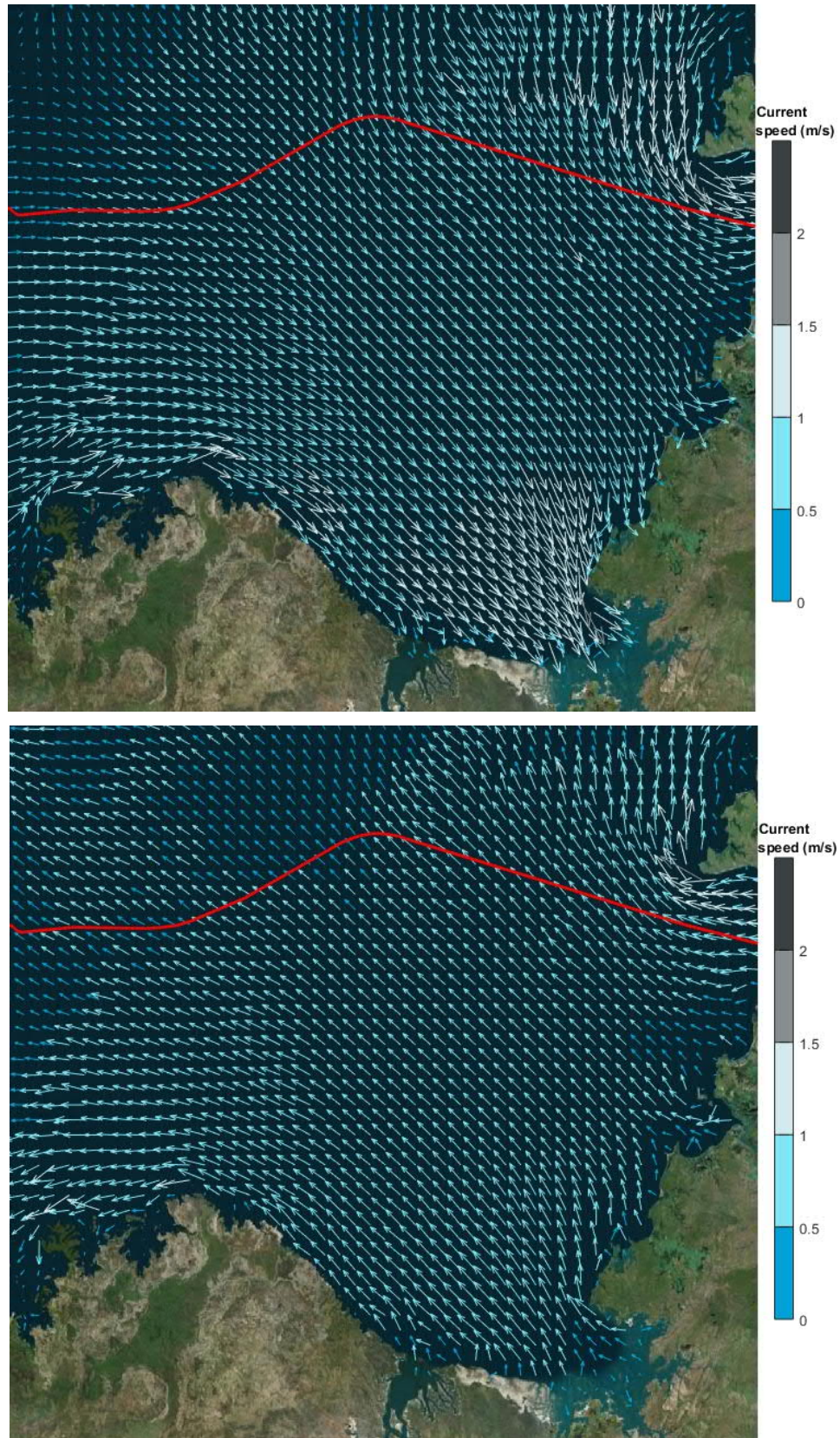


Figure 19 Example of Delft3D modelled current velocities for flood (incoming) tide (upper panel) and for ebb (outgoing) tide (lower panel) in offshore Project part. Red line indicates submarine route. Arrow size is proportional to current speed

3.6.3 Waves

3.6.3.1 Nearshore

The nearshore Project area is well sheltered from long period tsunami and ocean swell waves by the Tiwi (Melville and Bathurst) Islands (Figure 1). Due to the local bathymetry and coastline configuration, energy of long period waves entering Shoal Bay quickly dissipates and thus wave heights decrease dramatically (Figure 20; for modelling details see the AAPOWERLINK EIS Hydrodynamic, Wind Wave and Sediment Transport Modelling report).

Wave rose based on measurements in Beagle Gulf for the period from May 2015 to July 2017 (Figure 21, left panel) shows that waves were coming mostly from the west to north-west sector, with significant wave height (H_s) of less than 0.5 m in approximately 70% of cases. The data suggest that long period waves (peak period >13 s) would have lower than 0.5 m heights (Figure 21, right panel). The highest waves (H_s around 3 m) would have peak periods of around 8 s.

To investigate seasonal effects on wave patterns wave roses were constructed based on the Beagle Gulf buoy measurements for the wet and dry seasons (Figure 22). Due to some missing records the wet season was represented by December, January and February, while the dry season was represented by June, July and August.

In general, wave conditions reflect the seasonal reversal of the dominant wind direction. During the wet season north-westerly winds blow over the uninterrupted fetch of the Timor Sea (Figure 6, upper panel), increasing incident wave energy in Beagle Gulf and Shoal Bay. Waves tend to be mostly westerly and north-westerly with up to 3 m H_s . However, 50% of the record indicate H_s less than 0.5 m.

During the dry season, the region experiences south-easterly Trade Winds (Figure 6, lower panel), which due to the limited fetch result in a low energy local wave climate (Rigby et al, 2014). The dry season waves are typically (around 85% of record) less than 0.5 m high. The dominant wave direction is west-northwest, with 65% of the waves coming from the 225° to 300° sector. This might be the case of attenuated swell projecting in from the deeper offshore waters.

The Darwin region is exposed to low pressure systems and tropical cyclones, which can generate large waves as a result of energy transfer from wind to the ocean surface. The growth of ocean waves is a function of the fetch (the unobstructed distance the wind acts over), wind speed, wind duration, the depth of water and the intensity and location of the cyclone. Although Shoal Bay is well protected from northerly waves by the Tiwi Islands, wind fetch and water depth increase to the northwest and west and therefore extreme wave conditions are likely to propagate into Shoal Bay from these directions.

While waves are important for turbulent mixing processes, they do not contribute significantly to the net horizontal movement of water. Waves contribute to resuspension and seasonal turbidity variation in the study area, especially in nearshore locations (Yang et al., 2018; Buckee et al., 2014).

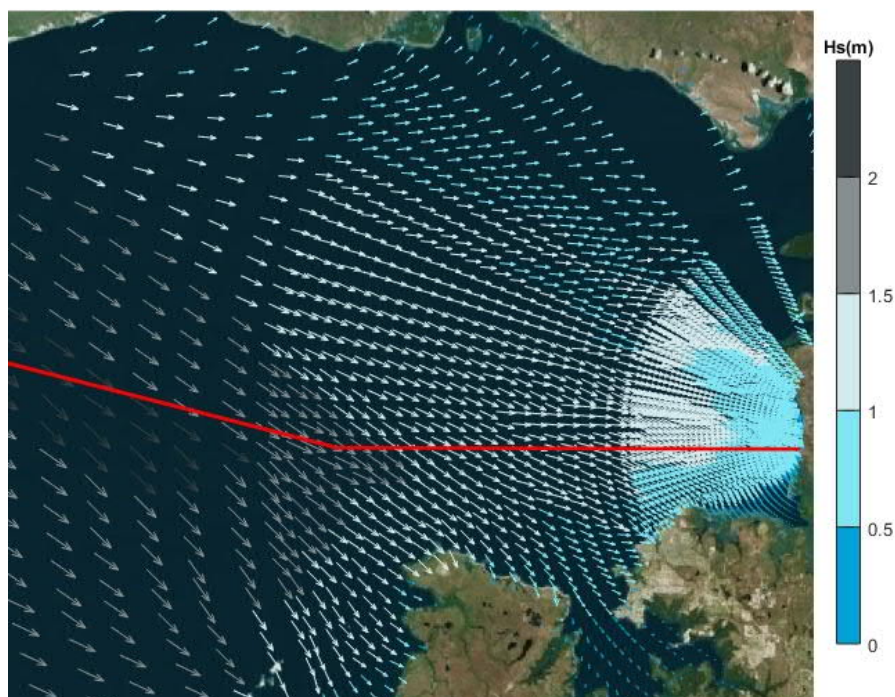


Figure 20 Example of Delft3D modelled significant wave height (H_s), vectors show peak wave direction in Project nearshore area. Red line indicates submarine route. Arrow size is proportional to H_s

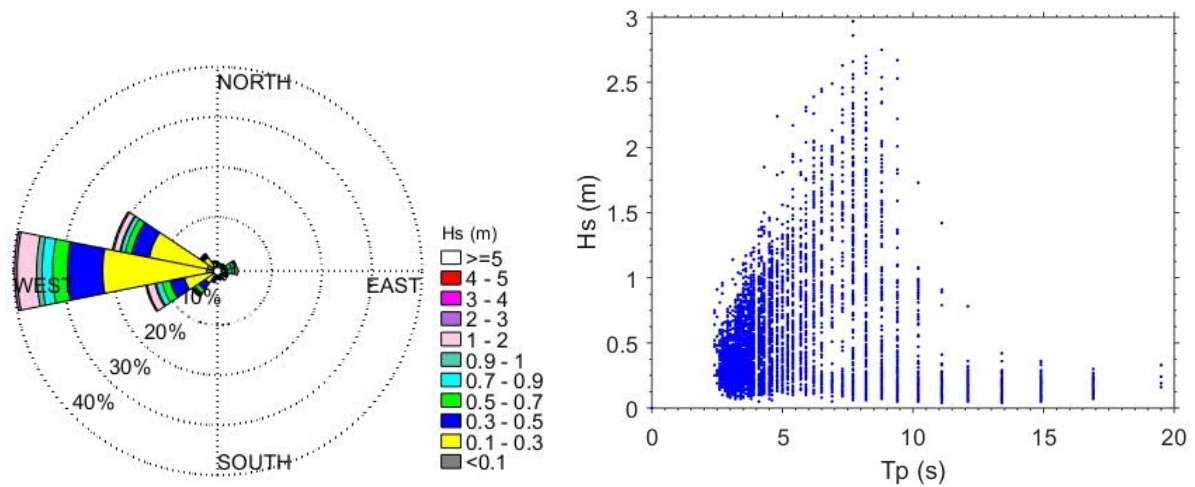


Figure 21 Wave rose (left panel) and scatter plot (right panel) based on data from IMOS buoy deployed in Beagle Gulf from May 2015 to July 2017

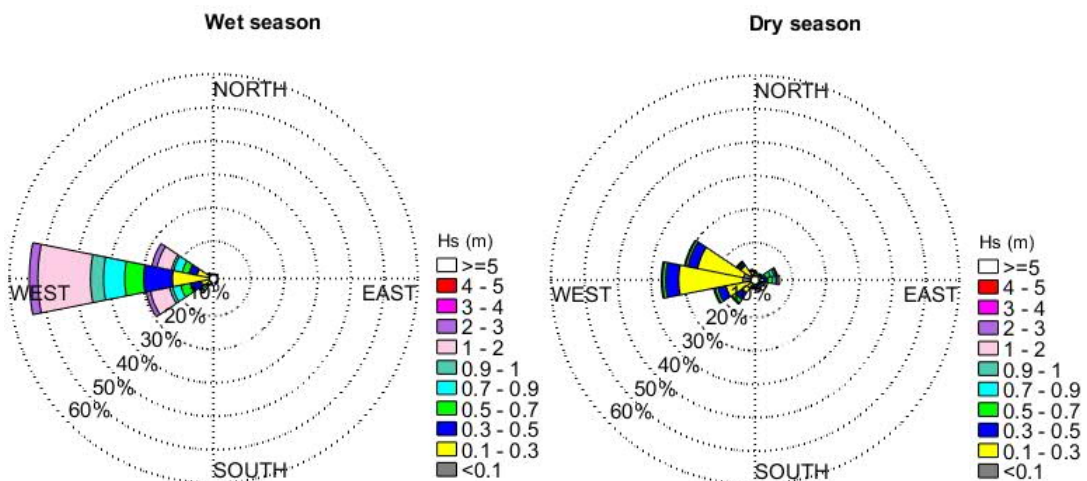


Figure 22 Seasonal wave roses based on data from IMOS buoy deployed in Beagle Gulf from May 2015 to July 2017; nearshore Project area

3.6.3.2 Offshore

Due to the absence of wind wave observations in the offshore Project area, hourly wave parameters for 2015-2016 were extracted from the CSIRO WaveWatch III model (Durrant et al., 2014) to investigate wind wave patterns. Wave fields and wave roses based on these data for the wet and dry seasons are presented in Figure 23 and Figure 24, respectively. Wave roses were constructed for the most northern part of the submarine cable route in the offshore part of the Project (Figure 1). For consistency with the wind roses for the nearshore part of the Project (Figure 22) the wet season was represented by December, January and February, while the dry season was represented by June, July and August.

Figure 23 and Figure 24 demonstrate strong seasonality in the wind wave patterns in the Project offshore area in accord with seasonal winds (Figure 6), with westerly and south-westerly seas prevailing in the wet season, shifting to predominantly north-easterly seas in the dry season. Wave conditions appear to be more energetic in the wet season, with maximum Hs of 4.6 m registered in December. During the wet season waves with Hs above 2 m contribute to almost 12% of records, while during the dry season to 3% of records. However, in both seasons Hs of more than 55% of recorded waves was lower than 1 m and the mean wave period was around 6 s.

It is important to note that wave parameters can vary from year to year, with strongest wave heights recorded during La Nina years in the wet season. This can be associated with an increase in monsoon wind speeds.

The most severe noncyclonic 50-year return period waves with H_s of up to 6.5 m were estimated by RPS (2016) for the area of the Bonaparte Basin in the Timor Sea. However, the most energetic waves in the Timor Sea are associated with tropical cyclones, reaching down up to 115 m water depth (James et al., 2004). During cyclonic events, extreme winds can generate waves with H_s up to 11 m (50-year return period) and affect wave patterns over a large area (RPS, 2016). Some waves will move in the same direction as the storm, and these will likely grow bigger. Others will move in the opposite direction, and these will likely lose energy over time.

Internal waves can develop during the wet season, which result in thermocline shift (up to 100 m) at the shelf break (James et al., 2004).

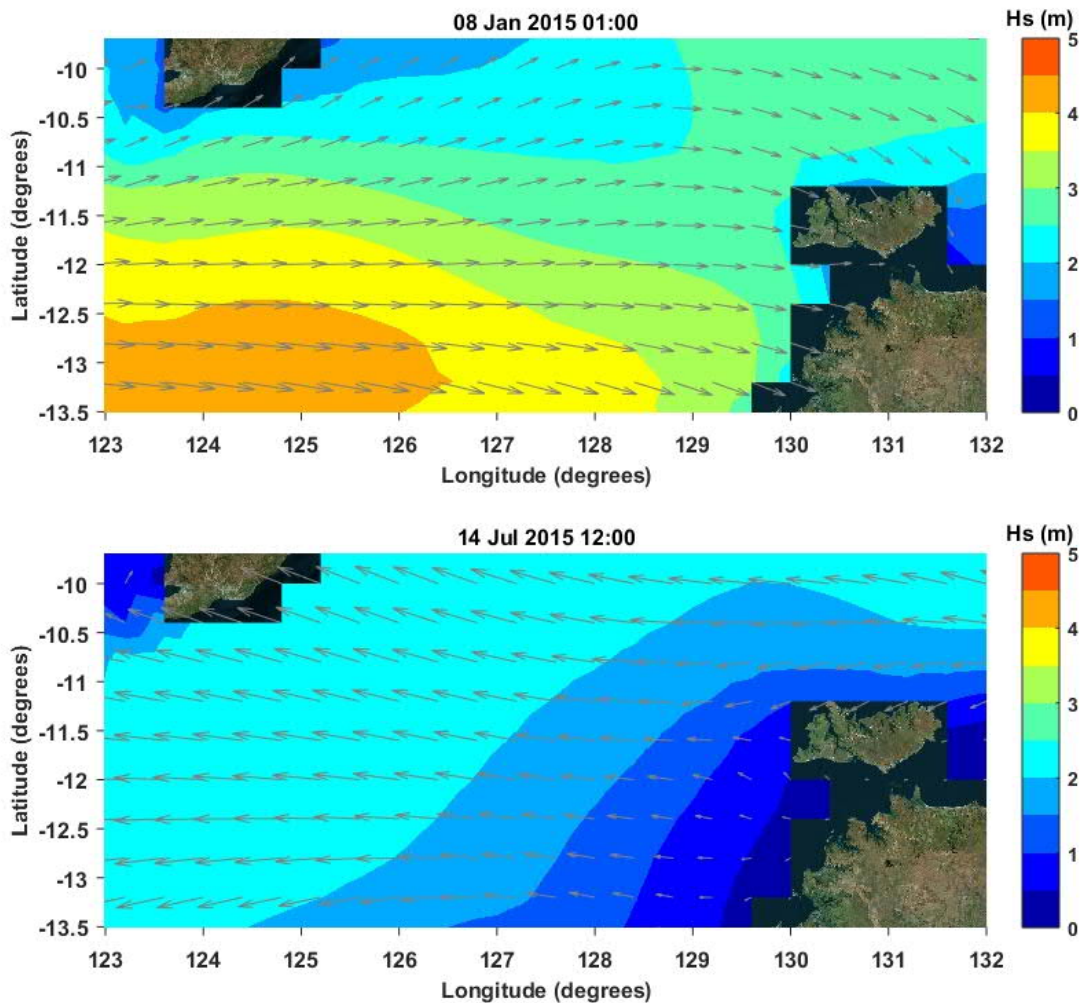


Figure 23 Example of typical wave field for wet (upper panel) and dry (lower panel) seasons in the Project offshore area based on hourly significant wave heights and directions from WaveWatch III hindcast

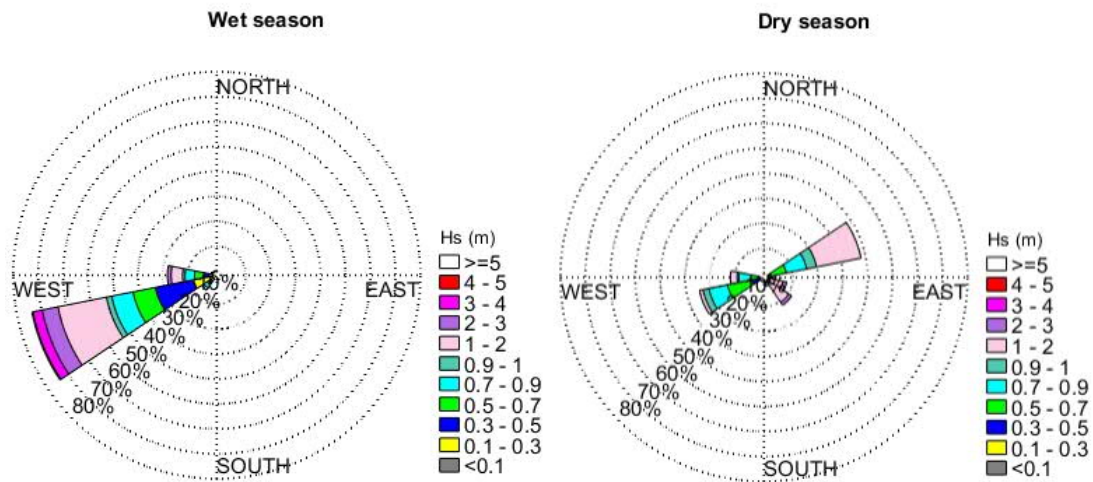


Figure 24 Seasonal wave roses based on hourly significant wave heights and peak direction derived from WaveWatch III hindcast for 2015-2016; offshore Project area

3.7 Extreme conditions

3.7.1 Tropical cyclones

The cyclone season in Northern Australia begins on 1 November and extends until April. During this time many cyclones will form, though few will cause much destruction. Darwin and the north of Australia have felt the force of a cyclone on a number of occasions (Figure 25) – the worst being in 1897, 1937 and 1974 (NAA, 2021). The data presented in Figure 25 suggest that 50 tropical cyclones were registered within 200 km radius from Darwin in 1969-2018, that is equivalent to one cyclone per year on average (BoM, 2021a). Tropical cyclones are usually associated with extreme winds (from 65 km/h to more than 220 km/h), intense rainfall, extreme waves and storm surge. Extreme wave conditions are discussed in Section 3.6.3.

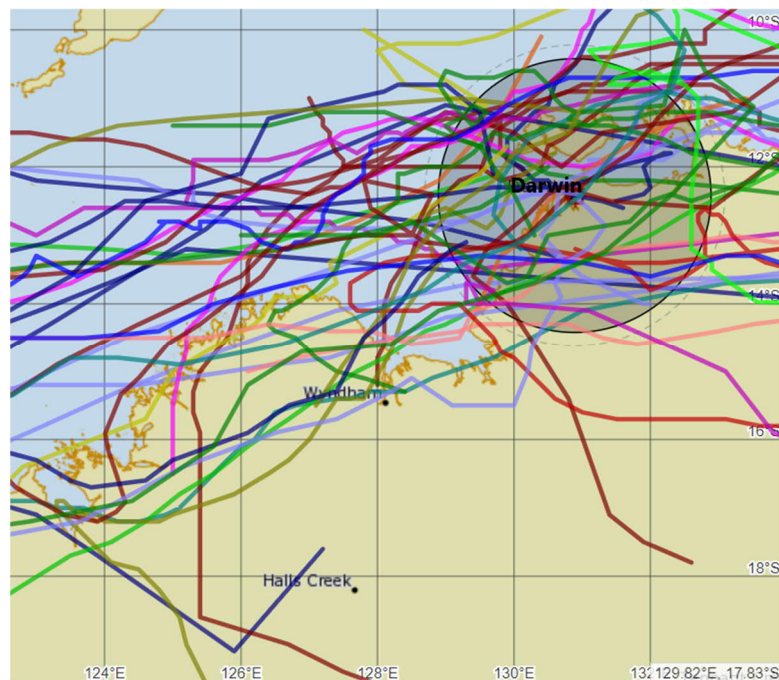


Figure 25 Tropical cyclones in study area based on 1969-2018 data from BoM. Black circle indicates radius of 200 km from Darwin

3.7.2 Storm surge

Storm surge is a raised mass of water, generally several meters higher than normal tide levels, which results from strong onshore winds and reduced atmospheric pressure. An individual storm surge is measured relative to the tide level at the time. The combination of storm surge and normal (astronomical) tide is known as a “storm tide”. The worst impacts occur when the storm surge arrives on top of a high tide. When this happens, the storm tide can reach areas that might otherwise have been safe.

Storm surge is often associated with cyclones and can cause flooding and damage through raised tides and waves. The height of storm surge is influenced by many factors, including the intensity and speed of an associated cyclone, the angle at which the cyclone crosses the coast and the topography of the affected area.

Storm surge inundation maps have been produced by NT government for areas in Greater Darwin and for communities in the Gulf and Top End regions. These maps are based on the projected mean sea level by year 2100 for hazard Return Periods (or Average Recurrence Intervals, ARIs).

Figure 26 shows storm surge map zoomed in for the Shoal Bay area, with the blue line indicating estimated Highest Astronomical Tide (HAT), light blue shaded areas indicating primary storm surge zone (100 ARI), dark blue shaded areas indicating secondary storm surge zone (1,000 year ARI), and magenta line indicating extreme storm surge extent (10,000 Year ARI). For instance, the 100 ARI line shows how far up the coast water would reach with a primary storm surge being a one-in-100-year inundation event. That does not mean that every 100 years one of those events will occur, but a 1 per cent chance that an event of that size will be equalled or exceeded in any year, while a secondary storm surge event is a one-in-1000 chance of inundation at that level.

Estimates of total storm tide levels for locations within Darwin region were produced by System Engineering Australia Pty Ltd (SEA, 2006; SEA, 2010). These estimates were based on statistical model simulations, which used parametric wind, storm surge and wave models to generate 50,000 years of artificial storm events, each combined with astronomical tide. As a result of the assumed increases in tropical cyclone peak intensities due to projected climate change, estimated 2050 total storm tide levels at Gunn Point for 100 and 1,000 year return periods were 3.7 m and 4.2 m AHD, respectively (Table 2).

Table 2 Estimated 2050 total storm tide levels (m AHD) for selected locations within Darwin Harbour (SEA, 2010)

Site	Return period (ARI), years				
	50	100	500	1000	10,000
Gunn Point	3.6 m	3.7 m	4.0 m	4.2 m	4.9 m
Lee Point	4.9 m	5.1 m	5.6 m	5.8 m	7.1 m
Mickett Creek	4.0 m	4.0 m	4.6 m	5.0 m	6.9 m

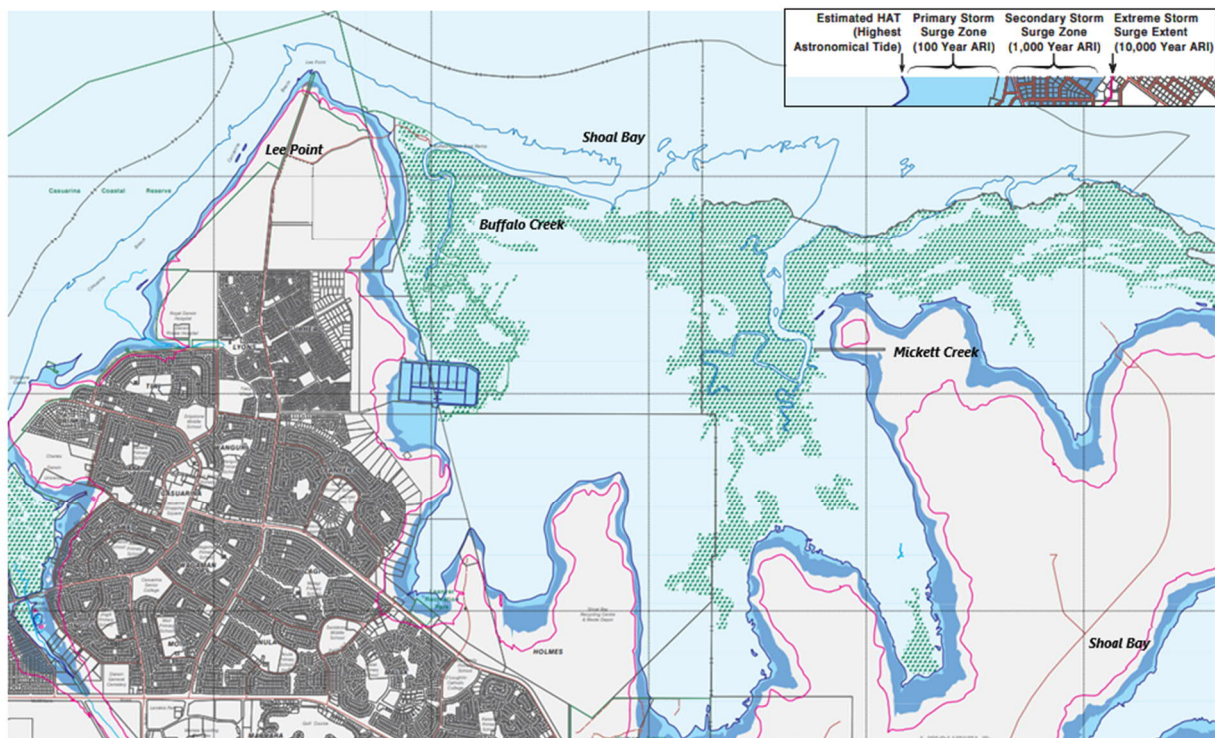


Figure 26 Storm surge map for Shoal Bay area (Darwin Storm Surge, 2020)

3.7.3 Tsunami

A tsunami is a series of ocean waves generated by a sudden disturbance of a large volume of water, which can have significant effect on the coastline. Even with relatively small tsunami, there could be strong waves, rips and currents and unusual sea levels that can be dangerous. The NT has a low-to-moderate risk of being hit by a tsunami. Historically, tsunamis are rare along the NT coastline, with only one being cited in history: on January 29, 1899 the shock of an earthquake was felt at Port Darwin and Port Charles, where a “tidal wave” of 6 ft (approximately 2 m) was observed (McCue, 2013).

Due to the long, wide continental shelf between the Top End and the fault lines to the north, tsunami waves would reduce in speed and take some time to travel across the water. The Joint Australian Tsunami Warning Centre, which uses the BOM and Geoscience Australia to detect and monitor tsunami threats, is at the forefront of tsunami detection in the Pacific and Indian Oceans. Geoscience Australia can detect earthquakes anywhere in the world within about 10 minutes of one occurring. That information is passed onto the BOM, which uses computer models to assess and issue tsunami warnings.

4.0 Marine water quality

4.1 Overview

Marine water quality of Darwin Harbour varies with tides, season and location (Padovan, 2003; Makarynska, 2019a). It is affected by tidal range (notably the neap-spring cycle; Wilson et al., 2004), tidal stage (Frieden and Darnell, 2012), whether mid-tide or at the turn of the tides, and whether ebb (outflow) or flood (inflow) tides. Turbidity and suspended particulate material are most affected by tides, whilst chlorophyll α is least affected (Padovan, 1997; Buckee et al., 2014). Tidal impacts depend on location and are mediated, for example, by the proximity to mangroves, which usually act as sinks for suspended particulate material (Cardno, 2014).

Seasonal influences on water quality are driven by the climatic differences between the wet and dry seasons. During the dry season there is very little or virtually no freshwater discharge to the Darwin region waters. In the wet season, monsoonal north-westerly winds produce waves that stir up sediments and impact water quality, whilst runoff from the catchment introduces freshwater and dissolved and particulate material to the nearshore area that affects salinity and turbidity (Water Monitoring Group, 2005; McKinnon et al., 2006; Skinner et al., 2009).

The greatest variability is found in the upper estuarine reaches and tidal creeks during the wet season when tidal exchange results in changes in water quality on hourly basis (Makarynska, 2019b).

4.2 Darwin Harbour Report Cards

The NT government and science providers routinely monitor and assess the quality of Northern Territory waters. Water quality monitoring has been undertaken in Darwin Harbour, including Shoal Bay, by DEPWS (and its predecessor organisations) since 1987 (Wrigley et al., 1990).

The Harbour's water quality has been graded annually against the Darwin Harbour WQOs and presented in the form of a Report Card since 2009. Four key water quality indicators, such as water clarity (turbidity), dissolved oxygen (saturation), nutrients and algae (chlorophyll α concentration), are assessed for the Darwin Harbour report cards. The near-surface data for the cards are usually collected during the dry season's neap tidal events. Water quality grades are calculated based on the median value of all the data within a zone for each indicator and compared against the Darwin Harbour water quality objectives.

The Report Card for 2019 (Fortune, 2019) indicated that the Harbour's water quality was good to excellent. In the Project area within Shoal Bay, water quality was deemed to be excellent in the last three reported years (2017-2019), meaning that all key water quality indicators met their corresponding WQOs.

4.3 Water quality objectives

The Darwin Harbour WQOs provide locally derived guideline values for water quality indicators in Darwin Harbour to protect and sustain the identified environmental values and beneficial uses (Fortune, 2010). These include:

- To maintain and protect the ecological condition of marine, estuarine and freshwater ecosystems of the Darwin Harbour Region
- To maintain marine, estuarine and fresh water quality so that it is suitable for activities such as swimming and other direct water contact sports
- To maintain water quality for the production and consumption of aquatic foods derived from aquaculture, recreational, commercial or indigenous food gathering.

Table 3 shows WQOs as reported by DEPWS (Fortune, 2019).

Table 3 Water Quality Objectives for Outer Estuary (from Fortune, 2019)

Indicators	Sub-indicators	Water quality guideline value
Dissolved Oxygen	Dissolved oxygen (% saturation)	80 to 100
Water clarity	Turbidity (NTU) or Suspended solids (mg/L)	<4 <10
Algae	Chlorophyll α ($\mu\text{g/L}$)	<1
Nutrients	NO $_x$ ($\mu\text{g/L}$)	<10
	Ammonia ($\mu\text{g/L}$)	<20
	Filterable Reactive Phosphorus ($\mu\text{g/L}$)	<10
	Total nitrogen*	<440
	Total phosphorus*	<20

*As reported in Fortune (2015)

WQOs for the offshore part of the Project are discussed in the AAPOWERLINK EIS Hydrodynamic, Wind Wave and Sediment Transport Modelling report.

4.4 Physical properties

4.4.1 Water temperature

Temperature impacts both the chemical and biological characteristics of surface water. It affects the dissolved oxygen level in the water, photosynthesis of aquatic plants, metabolic rates of aquatic organisms, and the sensitivity of these organisms to pollution, parasites and disease (Vernier, 2018; Harvey et al., 2013).

4.4.1.1 Nearshore

With its tropical location, water temperature in Darwin Harbour and Shoal Bay is very high and shows distinct seasonal variations (e. g. Michie et al., 1991; Padovan, 1997; Makarynska, 2019b). This can also be seen from Figure 27 (upper panel, left) based on 30 years of observations at Fort Hill Wharf in Darwin Harbour (BoM station 071014). The dry season is typically cooler, contributing to lower water temperatures. During December-February there is a decline in temperature by up to 4°C associated with wet season cloud cover and monsoonal activities. However, median monthly temperatures stay above 25°C throughout a year. Over the entire 30-year period the lowest temperature (21.6°C) was recorded in July and the highest (34.5°C) in November.

Figure 27 (lower panel) shows a consistent trend in water temperature between the sites in Beagle Gulf, Darwin Harbour and Shoal Bay (Gunn Point) throughout the reported period, with no significant variation with depth. However, daily variation of temperature appears to be higher on the surface, as would be expected. Little temperature stratification in Darwin Harbour during the wet season was reported by Hanley and Caswell (1995). Water temperature appears to be lower after significant rain events which can also be associated with lower air temperature. A cool change in air temperature with rain in early April results in a notable drop in water temperature, particularly closer to shore at the Gunn Point and Darwin Harbour stations (Water Technology, 2017).

Makarynska (2019a) reported intra-seasonal variation in surface water temperature, which is likely to be dictated by the extent of solar insolation, evaporation and sensible heat transfer across the water surface. As the dry season progresses the average water temperature rises by several degrees and peaks in September (Figure 27, upper panel, right). Consistent with this study, Padovan (2003) found that temperature in Darwin Harbour is lowest in June-July, after which it increases steadily during the dry season. Tidal range and presence of freshwater inflow could also have significant effect on temperature patterns, especially at shallow sites.

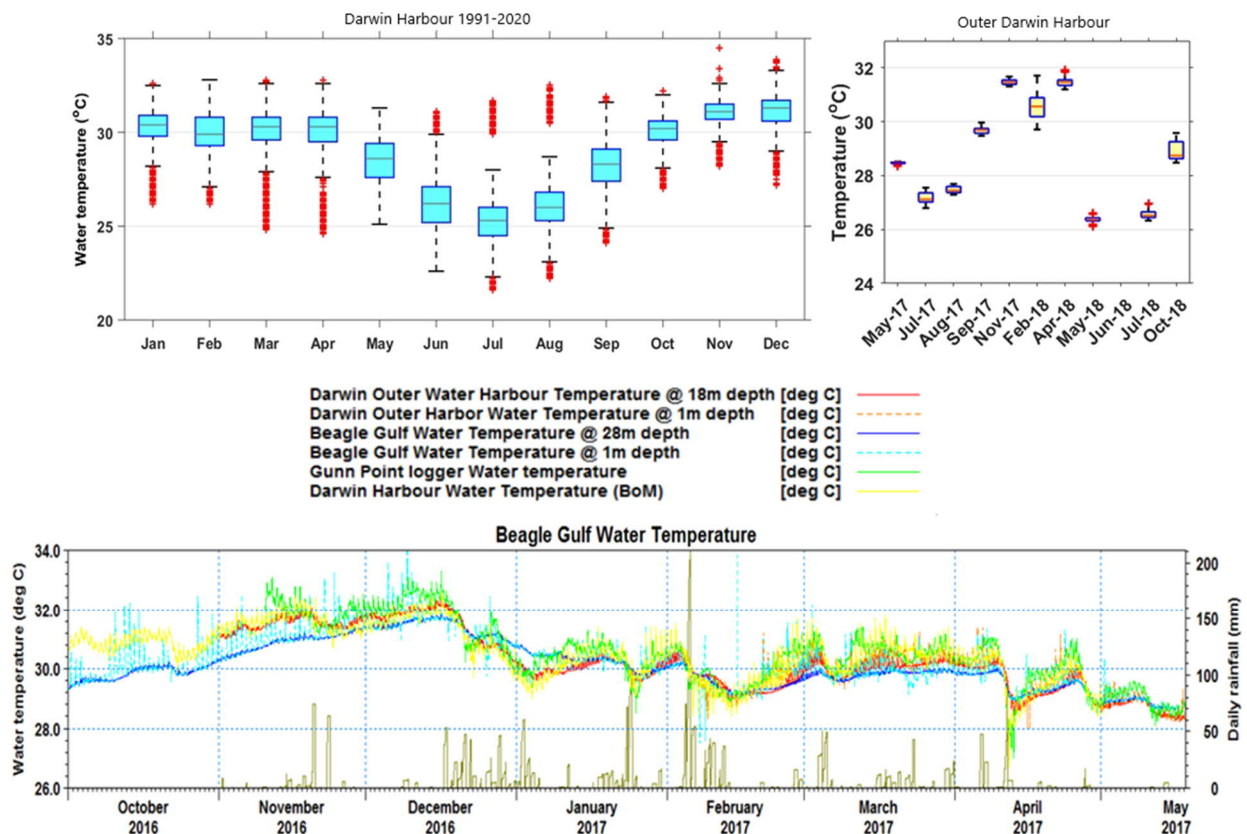


Figure 27 Monthly box plot of near-surface water temperature based on long-term data in Darwin Harbour (BoM, 071014) (upper panel, left) and based on seasonal data in Outer Darwin Harbour (upper panel, right) (from Makarynska, 2019b) and water temperature and daily rainfall (brown line) timeseries based on data from IMOS buoys in Darwin Harbour and Beagle Gulf and loggers at Gunn Point in Shoal Bay (from Water Technology, 2017) (lower panel)

4.4.1.2 Offshore

The surface layer of the tropical ocean is warm and the annual variation of temperature is normally small. But relatively high daily variations of temperature are very common. The average annual variation of water temperature of about 3-4°C occurs in the Timor Sea (Wyrki, 1961). This can be seen from Figure 28 which shows examples of spatial distribution of typical daily average water temperature for the wet and dry seasons based on data from BRAN hindcast (BRAN, 2021; for more details see Section 2.0). No monitoring data were available for the offshore Project part.

Figure 28 (upper panel) indicates that water temperature ranges from 31°C in the open sea to 35°C in the coastal areas on a “typical” wet season day. On a “typical” dry season day (Figure 28, lower panel), water temperature is generally lower, with cooler coastal areas (25°C) and warmer open sea (up to 28°C).

Offshore waters in general are temperature stratified, with a linear gradient in the interior of the water column, a surface wind-mixed layer of typically around 20 m depth, and a similar bottom tide-mixed layer also of around 20 m depth (RPS, 2016).

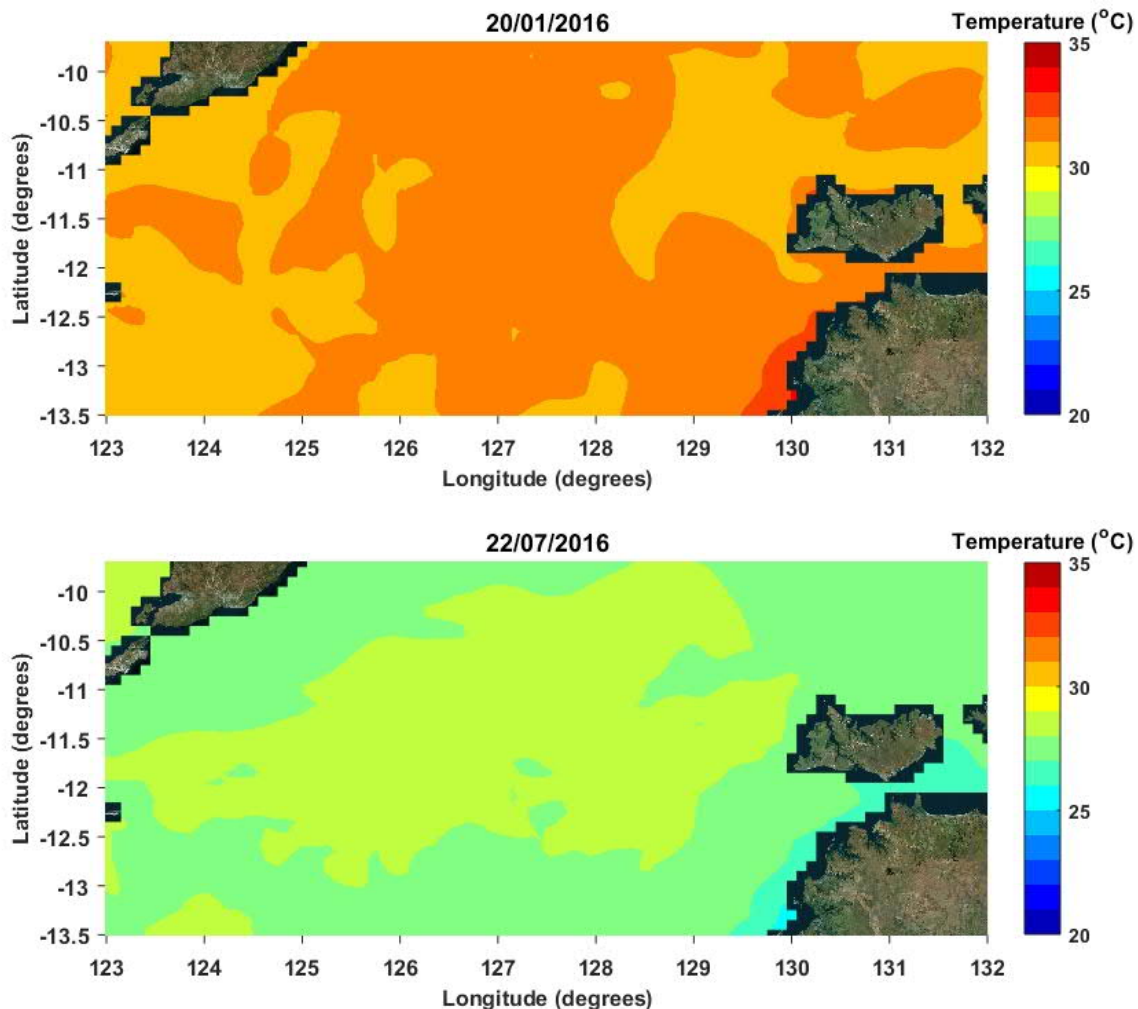


Figure 28 Example of typical water temperature field for wet (upper panel) and dry (lower panel) seasons in the Project offshore area based on daily averaged temperature from BRAN hindcast

4.4.2 Turbidity and suspended sediments

Turbidity is a measure of the light scattering property of water due to material suspended in the water, and is correlated with suspended solids (suspended sediments). High turbidity can harm organisms dependent on light required for photosynthesis.

4.4.2.1 Nearshore

Natural variations in turbidity in Darwin Harbour typically occur depending on the season and the tidal cycle (e. g. Buckee et al., 2014; Makarynska, 2019b). Higher turbidity in the wet season compared to the dry is due to the influx of terrigenous sediments to the Darwin region waters through the rivers and surface water sheet flow. Waves are also

a key driver of resuspension and seasonal turbidity variation in the local waters (Yang et al., 2018), especially in nearshore areas and when winds drive north-westerly waves during monsoons (Buckee et al., 2014; Radke et al., 2020). As a result, sediment plumes can extend over wide areas of Darwin Harbour and turbidity values can range from 5 NTU (Nephelometric Turbidity Units) in the dry season to in excess of 400 NTU during the wet season (Nicholas et al., 2019). For instance, turbidity variation from 0 NTU to 145 NTU over 11-months monitoring campaign, with corresponding suspended sediment concentrations (SSC) range from 6 mg/L up to 140 mg/L, was reported by URS (2011).

Turbidity and SSC vary with the spring-neap tidal cycle (Padovan, 1997; Li et al., 2012; Buckee et al., 2014), with higher turbidity during the spring tides compared to the neap tides due to the stronger tidal currents suspending fine seafloor sediments.

Timeseries of daily average turbidity for the near-surface and near-bed water levels recorded by the IMOS buoy in Beagle Gulf in 2015-2017 (for more detail see Section 2) are presented in Figure 29. The near-bed turbidity variation appears to be much higher compared to the near-surface one, with values reaching 350 NTU at the end of November 2016 (wet season). This is due to the tidal/wave action stirring up sediments from the seabed. No data for the same period in 2015 were available for analyses due to missing records. The near-surface turbidity was generally low ranging from approximately 4 NTU to 6 NTU, which is slightly above the WQO of 4 NTU (Table 3).

Box and whisker plots of monthly variation in turbidity and total suspended solids (TSS) in the near-surface level based on DEPWS data collected over 2004-2018 in Shoal Bay are shown in Figure 30. No data for November, January and February were available. The presented turbidity and TSS may not be synchronised in time due to limited data collected in different years at different sites. TSS and SSC both measure the solid-phase material within the water column, with difference in the analysis method (Caltest, 2021). Despite the fact that the DEPWS data were collected over a long period, they generally represent discrete sampling events over several hours at particular dates usually coinciding with neap tides. Limited data were collected over the wet season periods.

The results indicate that turbidity was relatively stable from month to month with median values below 5 NTU. Variation in TSS shows the highest spread in data for September with TSS concentrations above 50 mg/L, which may be due to an early rainfall onset and/or more intense wave action preceding discrete sampling results. Over the months, the median TSS concentrations varied from 2 mg/L to 35 mg/L.

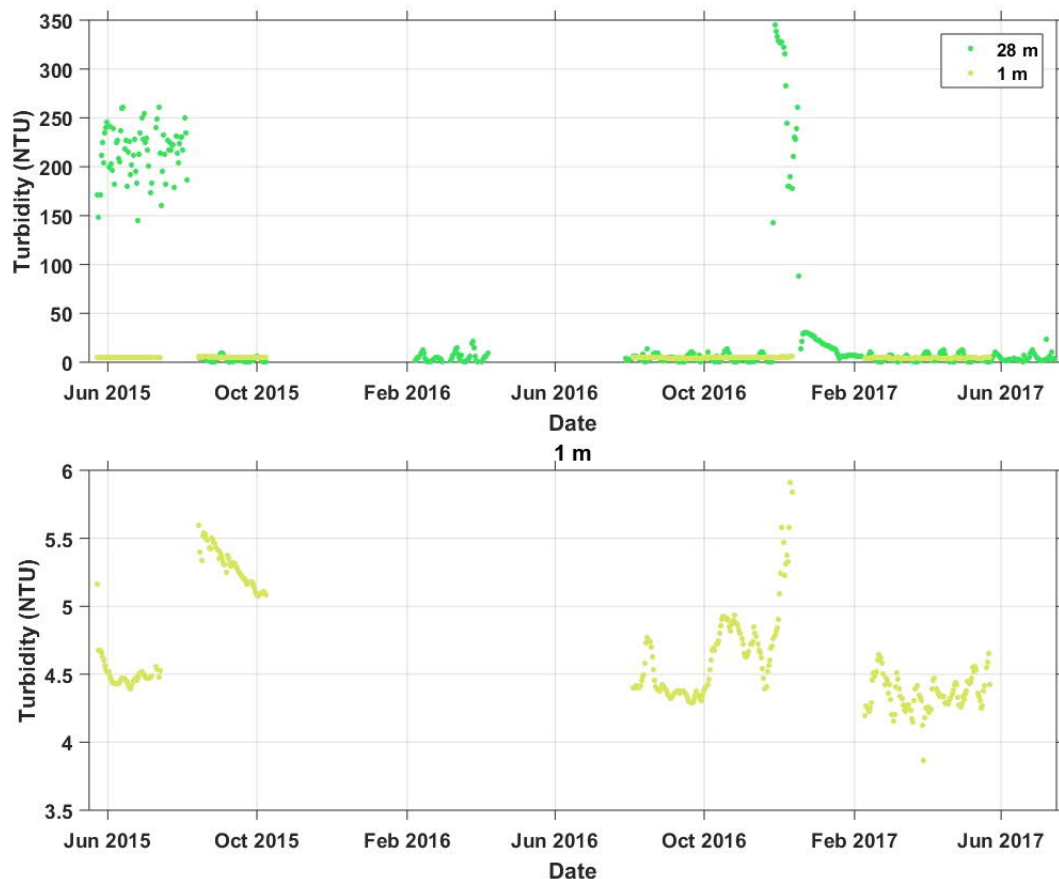


Figure 29 Daily average turbidity at 1 m (near-surface) and 28 m (near-seabed) depth (upper panel) and zoom in 1 m depth (lower panel) based on data from IMOS buoy deployed in Beagle Gulf from May 2015 to July, 2017

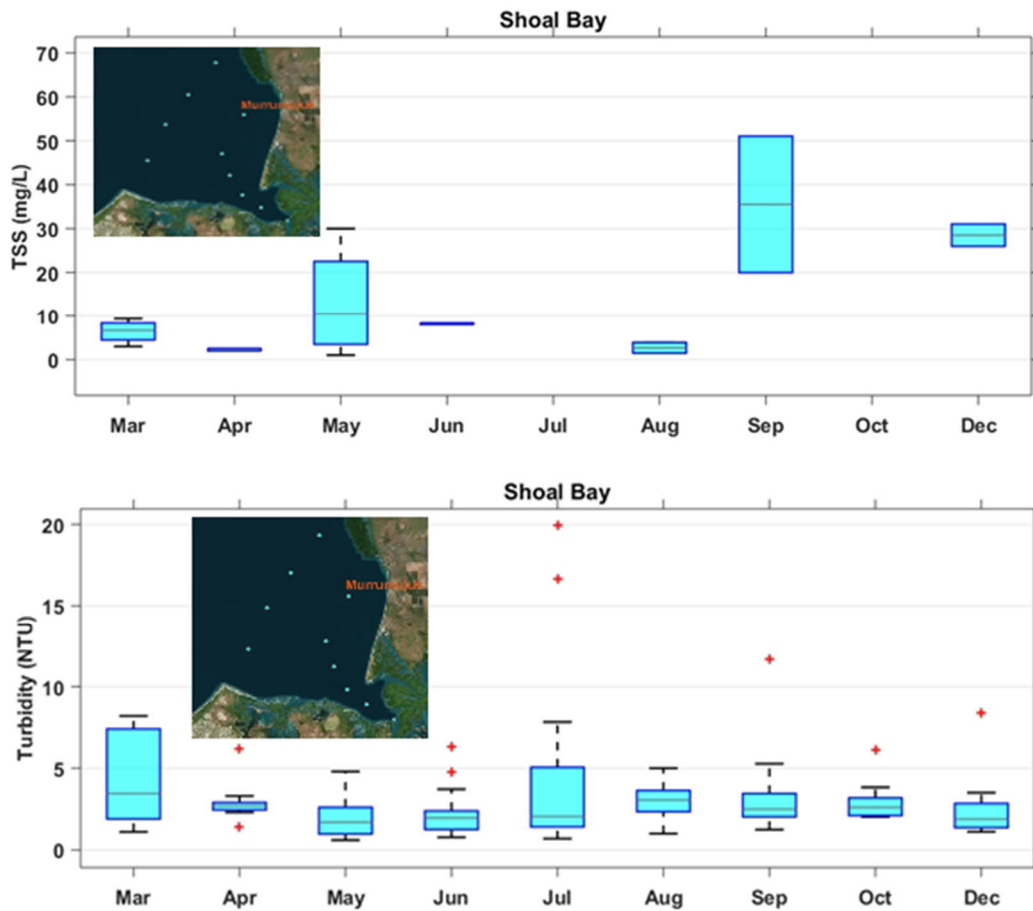


Figure 30 Box and whisker plots of near-surface TSS (upper panel) and turbidity (lower panel) grouped by months based on 2004-2018 DEPWS data from a number of sites in Shoal Bay. Red line indicates median values, red crosses indicate outliers

4.4.2.1 Offshore

The shelf waters of Northern Australia are recognised as a region of relatively high turbidity (Przeslawski, 2014). Natural levels of suspended sediment (turbidity) appear higher in the western part of the Oceanic Shoals Marine Park (NERP, 2021), which will be intersected by the Project subsea cable route. The eastern part of the park features pinnacles partly buried by sediment indicating ongoing dynamic sedimentary processes. Although no particular turbidity values were reported, this high turbidity precluded the analysis of video collected during the survey (Przeslawski, 2014). Nichol (2013) reported possible spatial gradients in turbidity levels along the decreasing depth transition from bank to terrace to plain, with tidal currents regulating levels of suspended sediment (turbidity) and redistribution of sediment across the area.

Turbidity levels in the area of Barossa Gas Export Pipeline, which is located to the west and then north of Tiwi Islands, appeared to be dependent on the location of the site (ConocoPhillips, 2019). Relatively high turbidity (5.7 – 36.7 NTU) for bottom water samples were reported from sites in proximity to Bathurst Island, which is within approximately 40 km from the Project subsea cable route.

4.5 Chemical properties

4.5.1 Salinity

Salinity is a measure of the amount of salts in the water. Significant change in salinity due to anthropogenic factors can be detrimental to water quality and aquatic life.

4.5.1.1 Nearshore

Salinities in waters of the Darwin region exhibit considerable temporal (intra- and inter-seasonal) and spatial (between different parts of the area) variation. In the months following the cessation of freshwater flows, higher temperatures and evaporation rates cause salinity to gradually increase, with rates of increase depending on site location.

Figure 31 based on transect data collected in the ODH (Makarynska, 2019b) shows an increase in salinity of about 3 PSU from May 2017 to September 2017. The shallowest inner Harbour sites are more affected by these changes, with a 43% increase in the median values of salinity from June to September (31 PSU to 44.4 PSU) (Makarynska, 2019b). In general, dry season salinities throughout the Harbour are greater than 34 PSU with the surface and bottom depths having similar values (e. g. McKinnon et al., 2006).

At the height of monsoonal inflow during February-March, salinity over the areas that are largely influenced by freshwater inflow can fall as low as 17 ppt. Significant drop in salinity values observed on 09/02/2018 in the ODH (Figure 31) was a result of substantial rainfall at the beginning of February 2018. The water column at such times can be highly stratified, with freshwater input from the surrounding catchments flooding the Harbour and overlying the intrusion of more dense, higher salinity water from outside of the Harbour, forming a classical “salt wedge”, characteristic of estuarine systems. Salinities at the bottom of the Harbour can be as much as 12 ppt higher than at the surface. This can last for a few days to a few weeks (e. g. Williams et al., 2006, Drewry et al., 2010) before water becomes vertically uniform and well mixed due to the tidal action.

For instance, during the wet season of 2016-2017 the near-surface salinity at Gunn Point generally ranged from 23 PSU to 31 PSU (Figure 32). A significant decrease in salinities for both surface and bottom layers correlated well with the recorded heavy rainfall registered at the Shoal Bay BoM station (Water Technology, 2017). Recovery to the average salinity level took around one week. As the rains cease and runoff decreases salinities return to their higher dry season levels (e. g. Parry and Munksgaard, 1995).

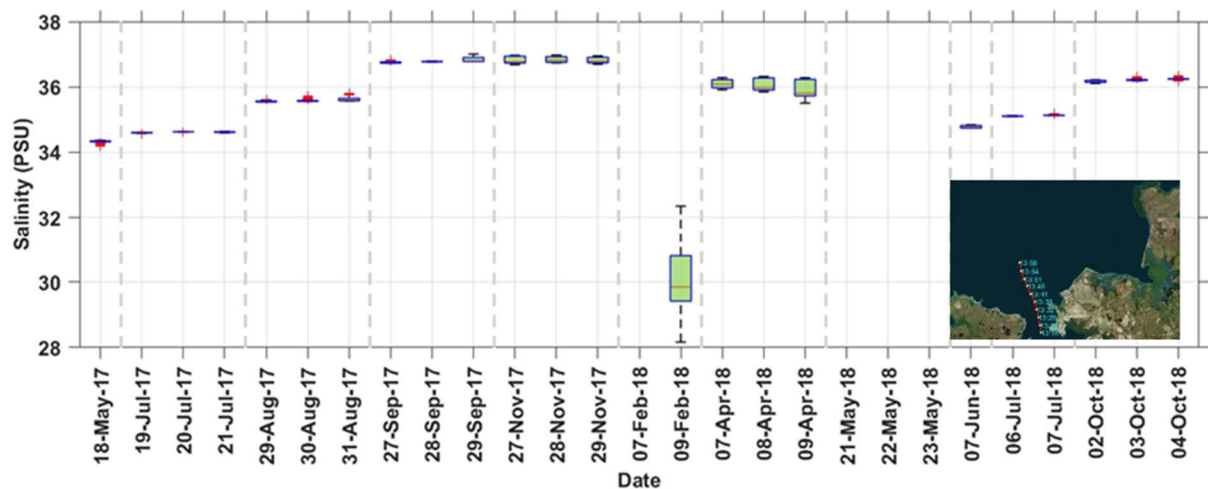


Figure 31 Box and whisker plots of near-surface salinity in Outer Darwin Harbour; dashed line separates different months (from Makarynska, 2019b)

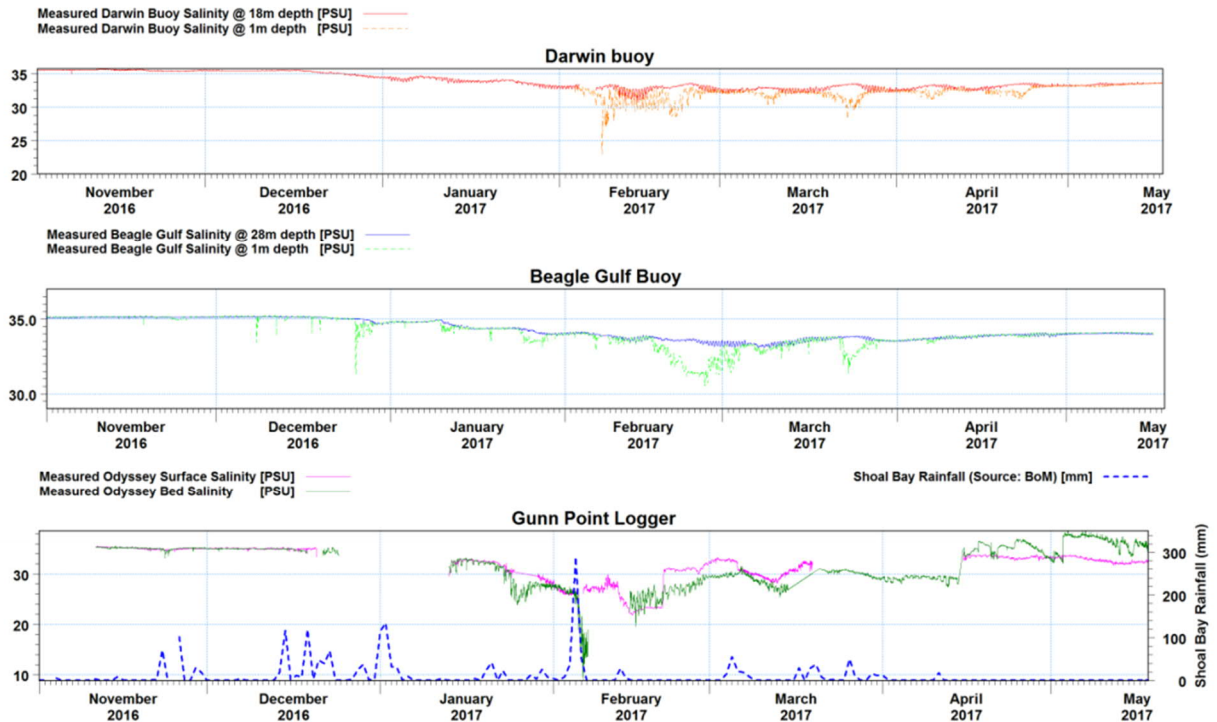


Figure 32 Timeseries of daily average salinity at 1m and 28 m depth based on data from IMOS buoy deployed in Darwin Harbour (upper panel), Beagle Gulf (lower panel) and loggers at Gunn Point (lower panel) (from Water Technology, 2017)

4.5.1.2 Offshore

Off the south coast of Timor, the Timor Current flows towards the southwest throughout the year and extends during the southeast monsoon to the Australian coast (Wyrki, 1961). This makes the Timor Sea a passage of water masses which are altered in salinity while passing, but this does not necessarily cause strong variations of salinity over a large area. Figure 33 shows examples of typical spatial daily average salinity distributions for the wet and dry seasons based on data from BRAN hindcast (BRAN, 2021; for more details see Section 2.0). No monitoring data were available for the offshore Project part.

Figure 33 indicates that the salinity range (~33-36 PSU) in the area on a “typical” wet season day is not significantly different from a “typical” dry season day. However, the hindcast “snapshot” for the wet season (Figure 33, upper panel) shows the lowest values of salinity in this range near the coast of Australia and the “snapshot” for the dry season (Figure 33, lower panel) near the coast of Timor and Indonesia. A similar range of salinity (34.5-35.7 PSU) over the continental shelf and margin was reported by Collins (2011).

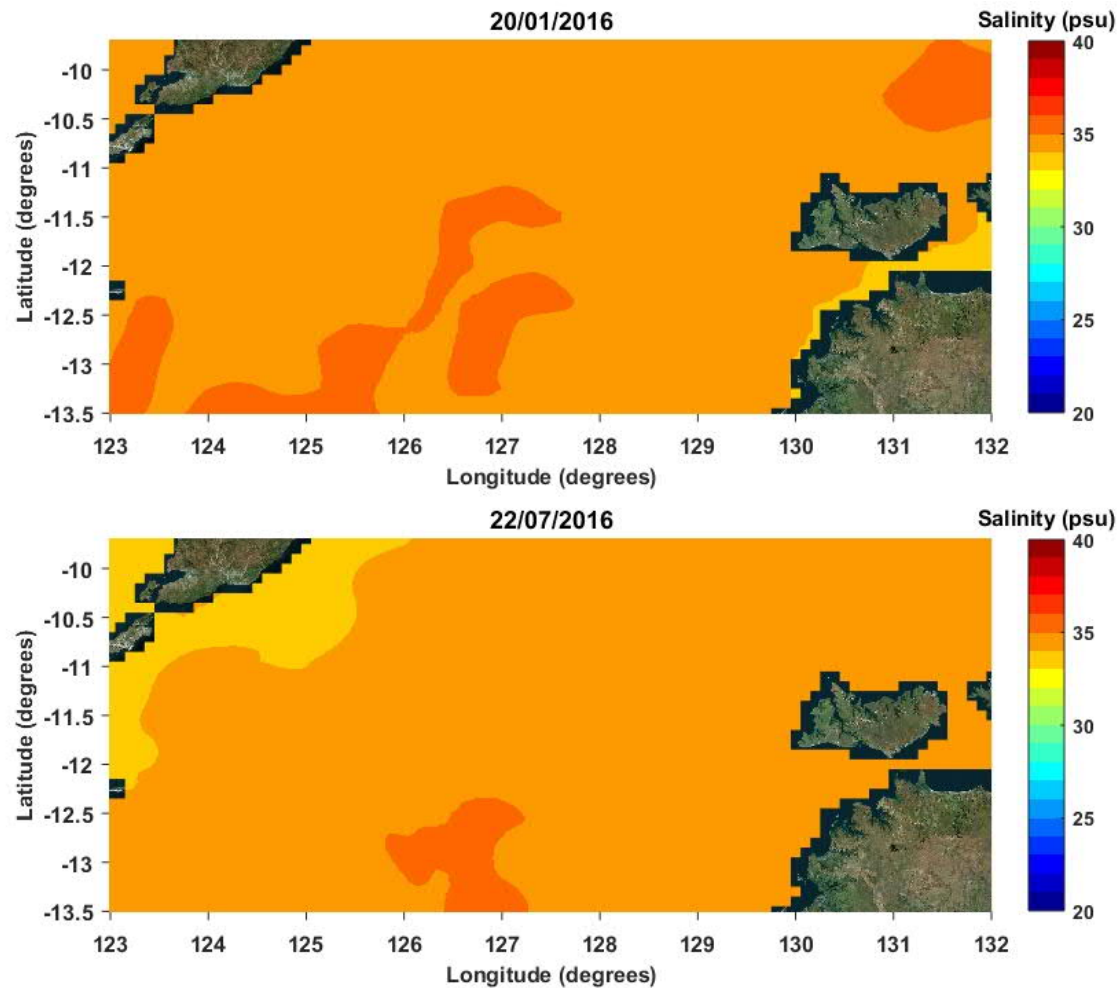


Figure 33 Example of typical salinity field for wet (upper panel) and dry (lower panel) seasons in the offshore Project area based on daily averaged salinity from BRAN hindcast

4.5.2 Dissolved oxygen

Dissolved oxygen (DO) is essential for all biological processes associated with marine organisms and can serve as an indicator of organic pollution. Oxygen content is highest at the surface and usually declines with depth reaching oxygen minimum layer.

4.5.2.1 Nearshore

Box and whisker plots of DO monthly variation presented in Figure 34 (upper panel) indicate that Shoal Bay waters are well oxygenated, with DO saturation above 80% in all periods except May. In May, DO levels show higher spread from approximately 70% (25th percentile) to 107% (75th percentile) saturation. Median values of DO varied between the months from 92% (March) to 115% (September) saturation, which is consistent with WQO (Table 3).

Variation in DO grouped by days for the ODH (Figure 34, lower panel) shows that DO was above 90% saturation in all reported periods. Significant changes in DO levels during the wet season (see 07/02/2018 in Figure 34, lower panel) can be caused by varying combination of factors controlling DO balance, such as differing rates of turbulent monsoon water discharges leading to abrupt changes in water temperature and salinity, water clarity, light attenuation, productivity and oxygen demand. It is well-known that rapid temperature changes can also create DO readings greater than 100%. This could also explain high variation in DO saturation levels in Shoal Bay observed in May (Figure 34, upper panel).

In general, the values above 100% may be a result of intense photosynthesis which could contribute to supersaturation. During the process of photosynthesis, oxygen is produced as a waste product. This adds to the dissolved oxygen concentration in the water, potentially bringing it above 100% saturation (YSI, 2005).

DO levels can also fluctuate with tides. DO was reported to be slightly lower at the rising (flood) tide than at the falling (ebb) tide, indicating high oxygenation of Harbour waters (Makarynska, 2019a). There is a trend in DO values

between different parts of the Harbour, with the lowest average values of DO at the shallow upper reaches and the highest in the more open ODH waters. This complex behaviour of DO was reported by Butler and Padovan (2005).

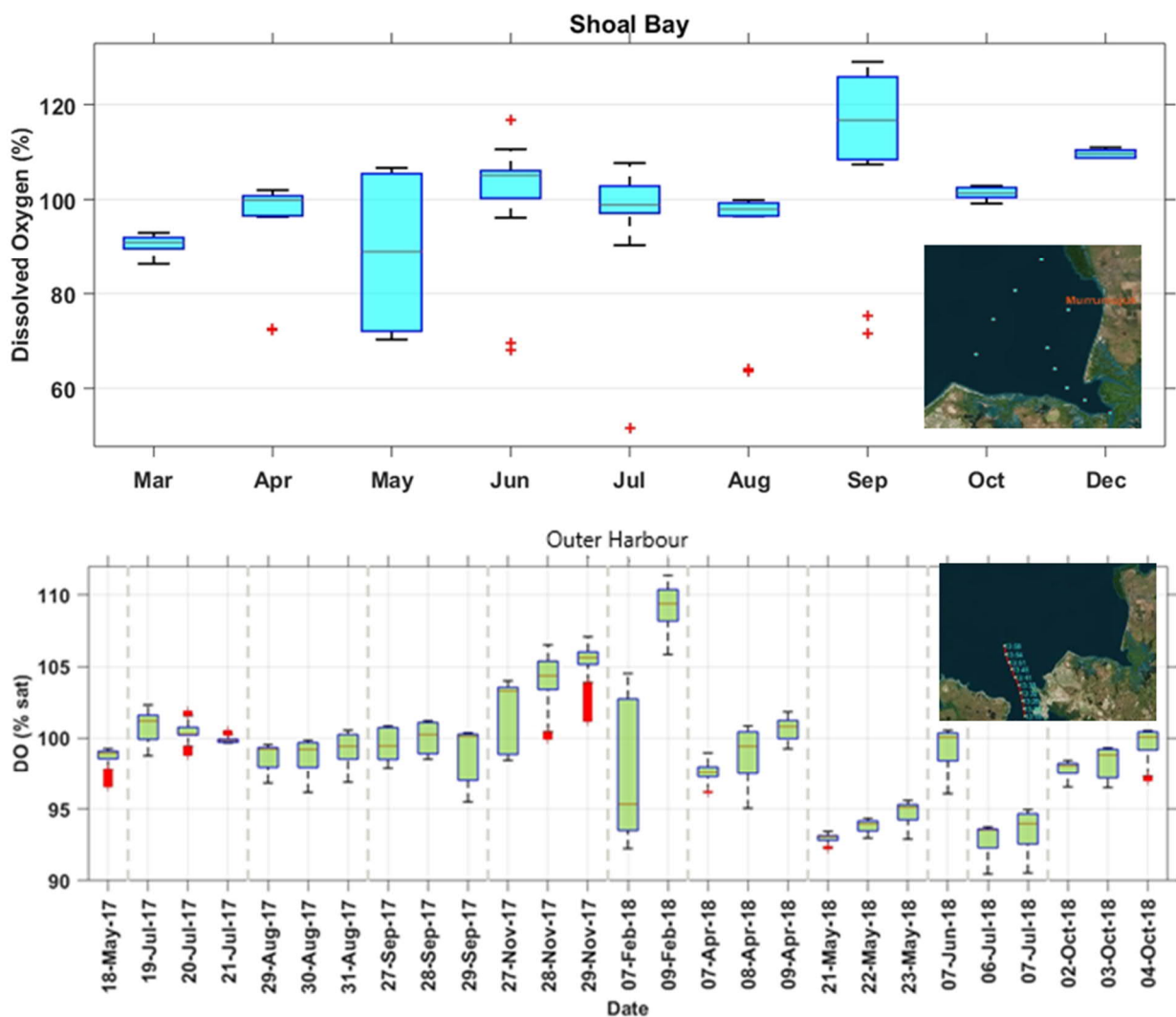


Figure 34 Box and whisker plots of near-surface dissolved oxygen (% saturation) grouped by months based on 2004-2018 DEPWS data from a number of sites in Shoal Bay (upper panel) and based on 2017-2018 transect data from Outer Darwin Harbour grouped by days (lower panel) (from Makarynska, 2019b). Red line indicates median values

4.5.2.2 Offshore

Figure 35 shows spatial distribution of annual mean DO adopted from CSIRO Atlas of Regional Seas (CARS) (Rothlisberg et al., 2005). The DO distribution near the surface remains near equilibrium with the atmosphere. The oxygen levels are therefore mainly a function of temperature, however, the temperature differences are relatively small and oxygen patterns may also be influenced by ocean transport patterns and vertical mixing with deeper waters depleted in oxygen (Rothlisberg et al., 2005). In the offshore part of the Project the annual mean DO is around 4.7-5.0 ml/L.

DO in the Barossa Gas Export Pipeline area (ConocoPhillips, 2019), which lies at its southern part within several kilometers from the Project subsea cable route and extends to the north from Bathurst Island for over 100 km, was high in the surface water (90%-100% saturation at all sites for each season) decreasing to approximately 35% saturation in the bottom water of the deepest sites.

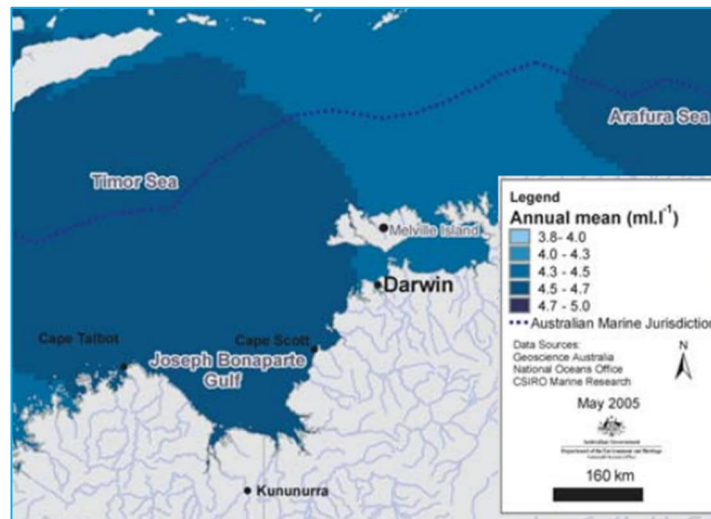


Figure 35 Annual mean near-surface dissolved oxygen from CARS (Rothlisberg et al., 2005)

4.6 Biological properties

4.6.1 Nutrients

Nutrients, such as nitrogen (N) and phosphorus (P), are substances that are required for growth and reproduction of aquatic plants and algae. However, significant increases in nutrient concentrations can result in problematic growths of algae, and in turn may have undesirable effects on the marine ecosystem (Padovan, 2003). Nutrients can be present in soluble, particulate, organic and inorganic forms. The bioavailability of different forms varies; transformation of one form to another depends on the physical and chemical condition of waters and sediments, and is often mediated by biological processes.

In general, nutrients appear to be weakly variable with seasons in the nearshore part of the Project. Variability of nutrients is complex and can be influenced by combination of tidal dynamics with biological activity (changes in primary production) and re-suspension of organic material from the seafloor, freshwater discharge and nutrient loads, and flushing rates.

The majority of nutrients that enter the nearshore part of the Project are imported from the ocean and are typically in the particulate or organic form (Burford et al., 2008). These nutrients are not considered to be bioavailable, that is, able to be used by biological organisms. Nutrients also enter the area from the surrounding catchment and are derived from both diffuse sources, such as urban and rural runoff, as well as point sources such as treated sewage effluent.

The waters of the offshore area are primarily oligotrophic (i.e. nutrient poor and oxygen rich) with low levels of nitrates in surface waters (Condie et al., 2003). However, nutrients may be transported into the Bonaparte Basin through storm and cyclone events. Enhanced productivity was reported in the area of the limestone pinnacles (Condie et al., 2003).

4.6.1.1 Nitrogen

Ammonia (NH_3) is one of several forms of inorganic dissolved nitrogen in aquatic environments and is highly toxic to fish and other aquatic life. Oxides of nitrogen (NO_x) are also part of inorganic dissolved nitrogen. When in excess NO_x can stimulate excessive growth leading to eutrophication, which can result in oxygen depletion and the formation of toxic reduced compounds.

Total nitrogen (TN) includes all forms of dissolved (organic and inorganic) and particulate nitrogen present in water. Elevated particulate nitrogen levels could further exacerbate water quality and eutrophication problems in sensitive aquatic ecosystems already subjected to excess dissolved nitrogen loads. Particulate nitrogen can be found in suspension or in sediments.

4.6.1.1.1 Nearshore

Box and whisker plots of nitrogen concentrations grouped by months in near-surface level based on DEPWS data collected over 2004-2018 in Shoal Bay are shown in Figure 36.

Over the reported period, NH_3 concentrations (Figure 36, upper panel) ranged from approximately 1 $\mu\text{g/L}$ to 40 $\mu\text{g/L}$, with October and December showing highest values in the range with greater spread in data. The median values of NH_3 in October and December were above WQO of 20 $\mu\text{g/L}$ (Table 3).

Concentrations of NO_x (Figure 36, middle panel) were lower than those of ammonia, with the values below 20 $\mu\text{g/L}$. The median values of NO_x for September and December were above WQO of 10 $\mu\text{g/L}$ (Table 3).

TN concentrations (Figure 36, lower panel) fluctuated from approximately 60 $\mu\text{g/L}$ to more than 350 $\mu\text{g/L}$ with highest variation recorded in October, which can reflect an increase in ammonia concentrations during this period. Data for January, February, April and November were not available.

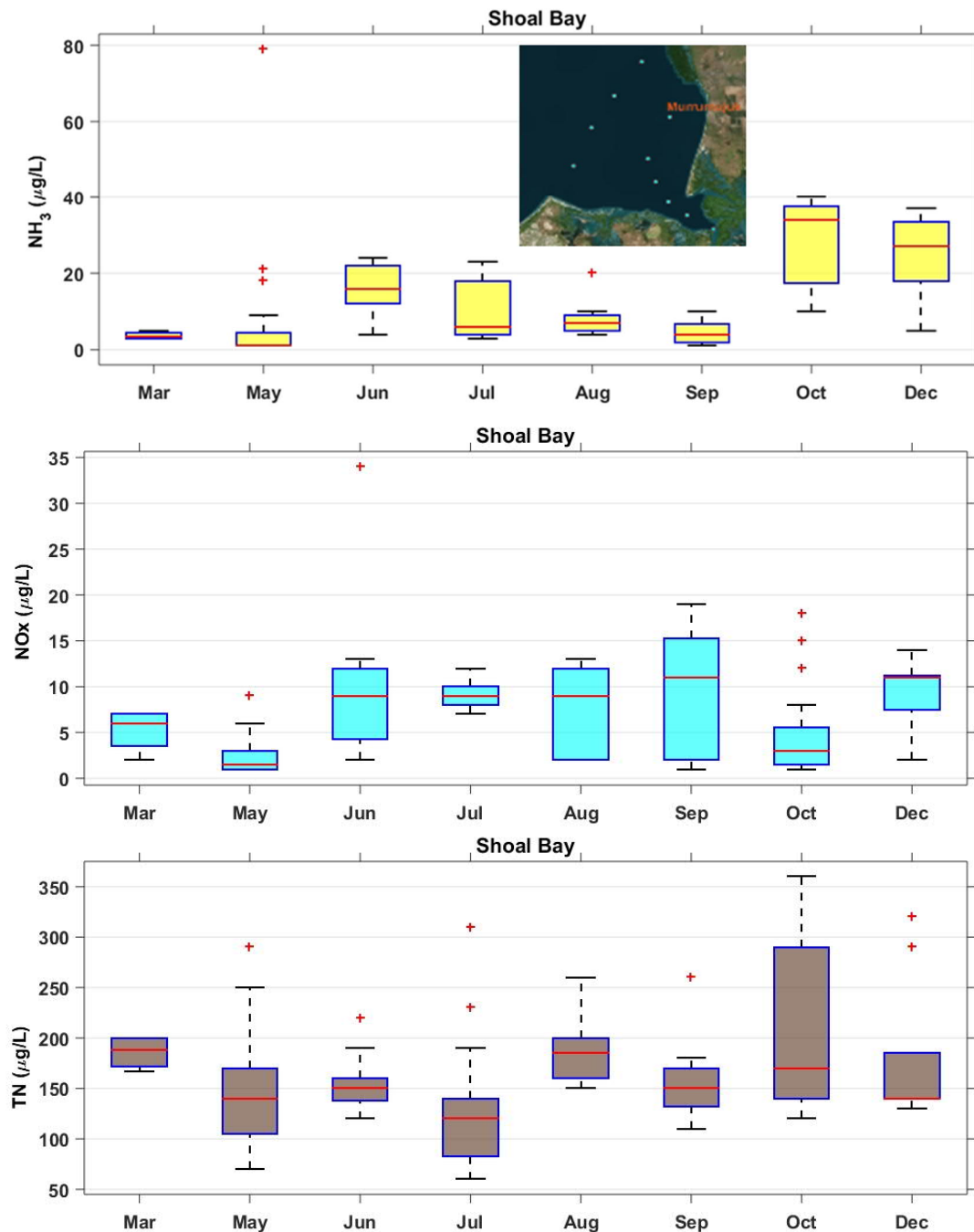


Figure 36 Box and whisker plots of near-surface ammonia (NH_3) (upper panel), oxides of nitrogen (NO_x) (middle panel) and total nitrogen (TN) (lower panel) concentrations grouped by months based on 2004-2018 DEPWS data from nine sites in Shoal Bay. Red line indicates median values

Based on a combination of published DEPWS data and results of limited sample collection in Shoal Bay during 2016-17 period, Water Technology (2017) derived median values of background concentrations for TN, which appear to be consistent with the median values presented in Figure 36 (lower panel) and below WQO.

Table 4 Median background nutrient concentrations derived from Water Technology (2017), and the Outer Darwin Harbour water quality Objectives

Parameter	Background Concentration (µg/L)	Outer Darwin Harbour WQO (µg/L)
Total Nitrogen (TN)	160	440
Total Phosphorus (TP)	8	20

4.6.1.1.1 Offshore

The spatial distribution of annual mean dissolved nitrate (NO_3) (Figure 37) tends to be relatively low (0.05-0.30 µM) in the surface waters of the offshore Project area, reflecting possible rapid consumption by phytoplankton that is typical of most tropical systems. No monitoring data were available for the Project.

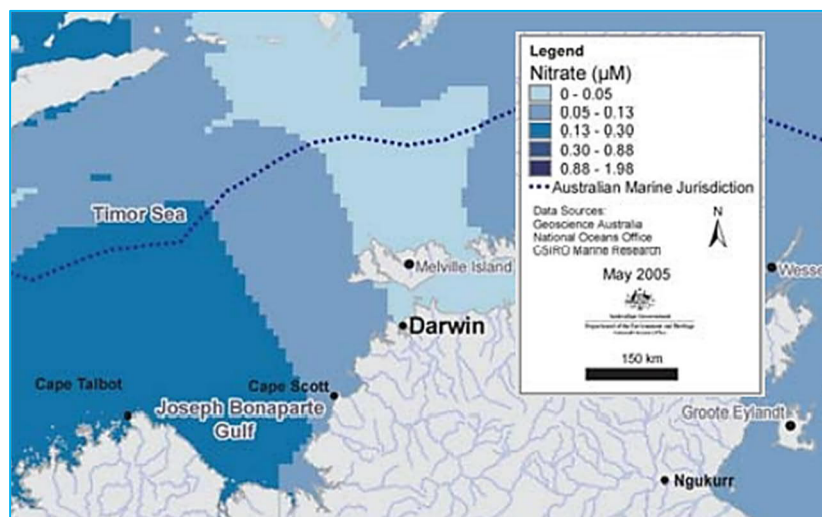


Figure 37 Annual mean near-surface dissolved nitrate from CARS (Rothlisberg et al., 2005)

4.6.1.2 Phosphorus

Orthophosphates (inorganic forms of phosphate), also known as soluble (dissolved) reactive phosphate (SRP), are a main constituent in fertilizers used for agriculture and residential purposes. SRP are readily available for consumption by bacteria, algae and plants and is an essential nutrient for biomass growth.

Total phosphorus (TP) is a measure of all forms of phosphorus (dissolved organic and inorganic and particulate). Particulate phosphorus can be found in suspension or in sediments.

4.6.1.2.1 Nearshore

Over the reported period, SRP concentrations (Figure 38, upper panel) were generally below 8 µg/L while TP concentrations (Figure 38, upper panel) were below 25 µg/L, except for some outliers indicated by red crosses.

SRP median concentrations were below WQO (Table 3). TP median concentrations (Figure 38, lower panel) were around 8-10 µg/L, which is consistent with values for Shoal Bay estimated by Water Technology (2017) and below WQO (Table 3).

In general, distributions of P are determined by coastal circulation patterns, temporal and spatial variability in biological activity and the rate of nutrient recycling (Louanchi and Najjar, 2000). Balls (1994) showed that conservative mixing of nutrients, particularly phosphate, is a function of estuarine flushing time, as related to the particle-water interaction and chemical speciation. Némery and Garnier (2007) showed that salinity gradient, can

contribute to phosphorus desorption (release) with low salinity leading to an increase in phosphorus concentration, which is the case for Darwin Harbour in the wet season. Sediments can also play a critical role in the nutrient recycling and net removal of P (Slomp et al., 1998), with large intertidal areas and mudflats in Darwin Harbour, including Shoal Bay, greatly increasing sediment-water exchanges, and the alternating wetting and drying phases enhancing nutrient processing within the sediments (Padovan, 2003).

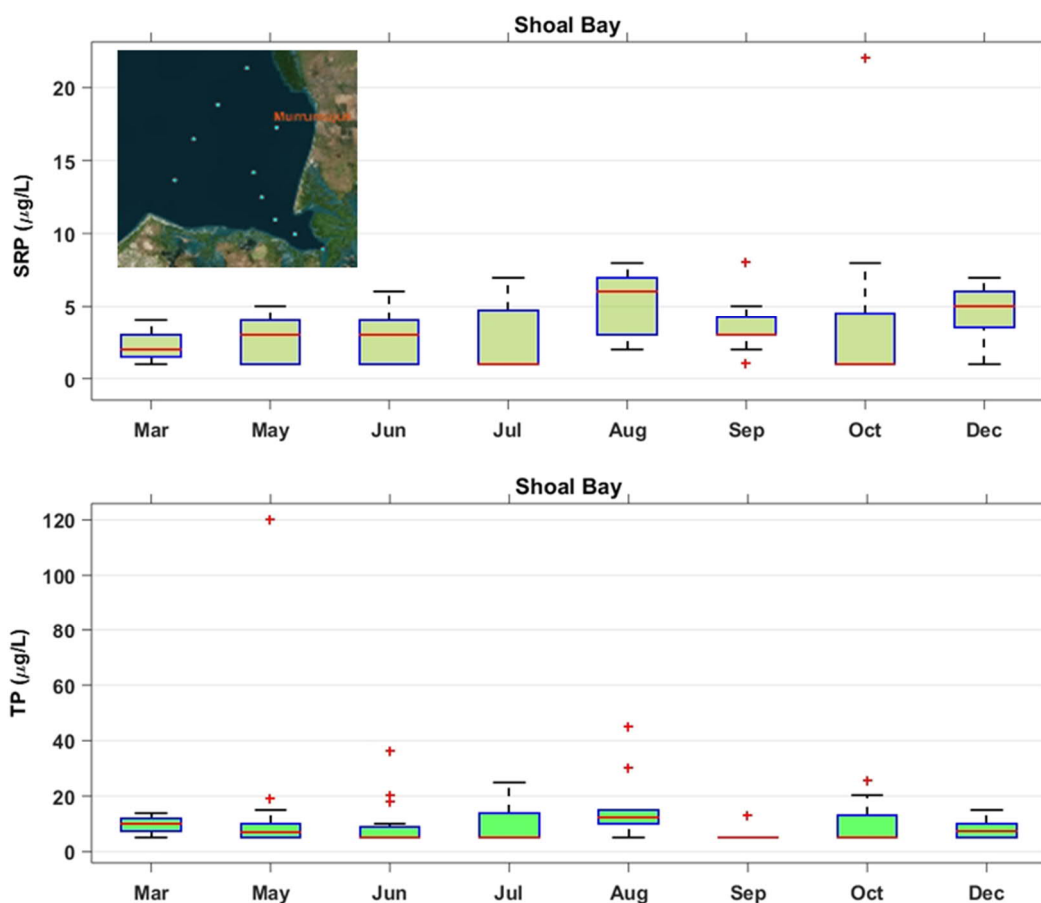


Figure 38 Box and whisker plots of near-surface soluble reactive phosphorus (SRP) (upper panel), and total phosphorus (TP) (lower panel) concentrations grouped by months based on 2004-2018 DEPWS data from a number of sites in Shoal Bay. Red line indicates median values

4.6.1.2.2 Offshore

The spatial distribution of annual mean dissolved phosphate (SRP) levels in the surface waters (Figure 39) are relatively low throughout the offshore area (0.02-0.13 µM) with higher values only encountered to the north in Indonesian waters. No monitoring data were available for the Project.

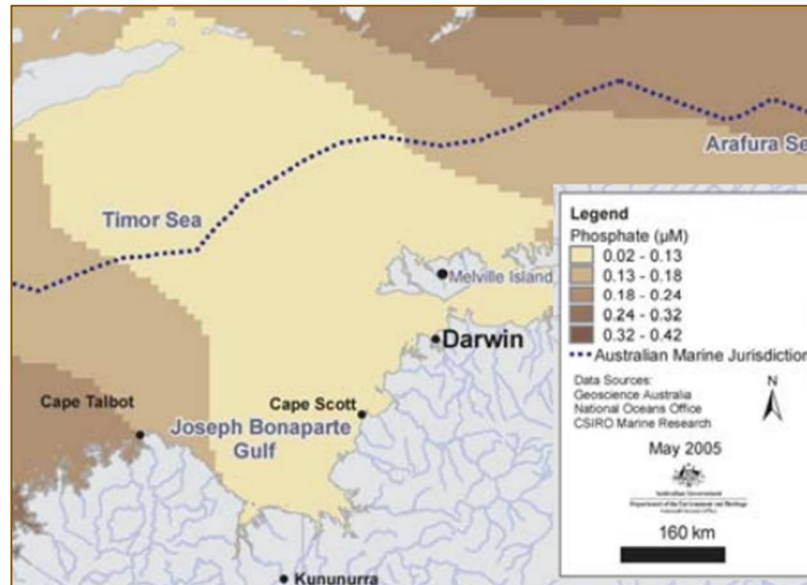


Figure 39 Annual mean near-surface dissolved phosphate from CARS (Rothlisberg et al., 2005)

4.6.2 Phytoplankton biomass

Phytoplankton are responsible for photosynthesis and primary production, and are responsive to changes in water quality, especially the addition of nutrients (Padovan, 2003). Chlorophyll is the major photosynthetic pigment produced by plants (including algae). Despite the fact that the relationship between chlorophyll and algal biomass is complex it provides a good indication of the amount of algae in the water. In this report, algal biomass was represented by chlorophyll measurements.

Chlorophyll concentrations generally depend on both the loads and bioavailability of nutrients, and the extent to which hydrodynamic features (e. g. residence times and mixing) and turbidity levels buffer nutrient loads (ANZECC and ARMCANZ, 2000).

4.6.2.1 Nearshore

The data presented in Figure 40 (upper panel) indicate that chlorophyll α levels in Shoal Bay were relatively stable from month to month and not exceeded 2 $\mu\text{g/L}$, except for some outliers. The monthly median values of chlorophyll α concentrations ranged from approximately 0.3 $\mu\text{g/L}$ to 0.9 $\mu\text{g/L}$ which is below WQO of 1.0 $\mu\text{g/L}$ (Table 3). Such low values are consistent with pristine mangrove systems with relatively narrow range of chlorophyll α concentrations (0.1-5.07 $\mu\text{g/L}$) (Padovan, 1997).

The timeseries of chlorophyll α concentrations based on IMOS data collected in the Beagle Gulf (Figure 40, lower panel) show variation of chlorophyll α with depth. The near-surface chlorophyll α appears to be consistent with monthly DEPWS data (Figure 40, upper panel) with values generally below 2 $\mu\text{g/L}$. However, the near-bed chlorophyll α exhibited much higher variation with concentrations reaching 12 $\mu\text{g/L}$ in March 2016 (wet season), which indicated possible formation of the subsurface chlorophyll α maximum (SCM). In March 2016, a weak monsoon trough developed over the Top End, which generated significant rainfall across much of the area (BOM, 2021b). During such rain events high sediment and nutrient loads enter the Harbour waters from urbanised areas. SCM generally exists at the same depth as nutricline (greatest change in nutrient concentrations) and depends on light availability and composition of phytoplankton. SCM can also be associated with water stratification.

Makarynska (2019b) reported that chlorophyll α concentrations in near-surface waters tend to decrease from the Upper Harbour to the Outer Harbour, with a more pronounced trend in the wet season periods. Higher concentrations of chlorophyll α were reported in the wet season compared to the dry season at the upper reaches of Darwin Harbour, which can be attributed to the fresh water discharge from rivers with higher concentrations of nutrients.

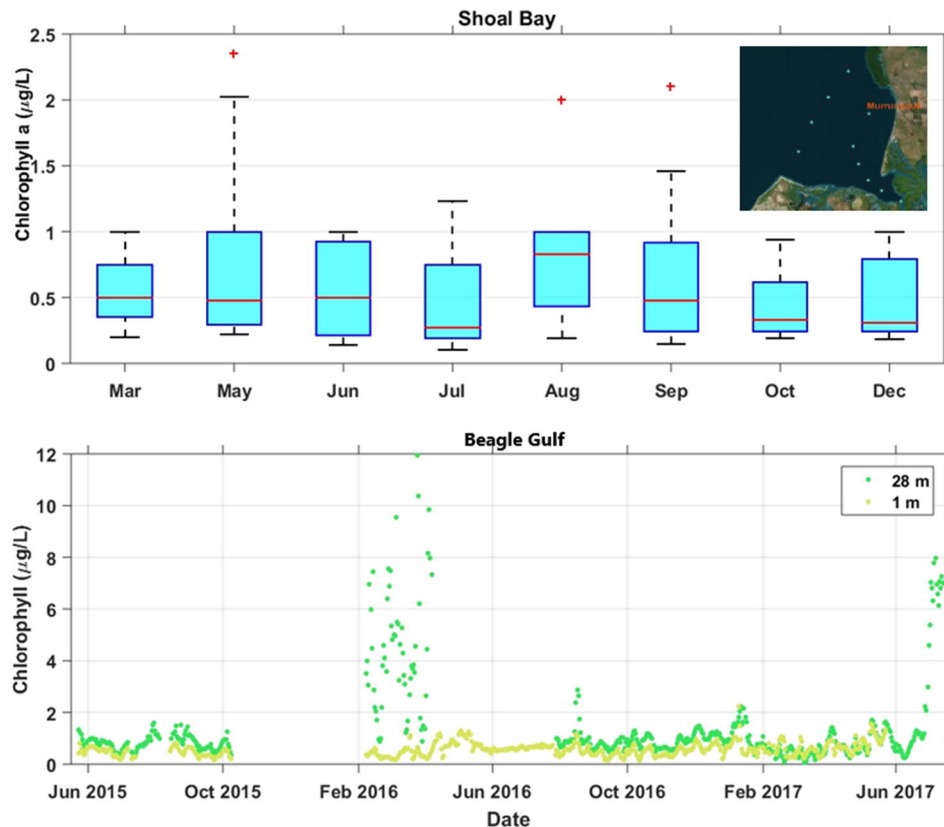


Figure 40 Box and whisker plots of near-surface chlorophyll concentrations grouped by months based on 2004-2018 DEPWS data from a number of sites in Shoal Bay (upper panel) and daily average chlorophyll concentrations at 1m and 28 m depth based on data from IMOS buoy deployed in Beagle Gulf from May 2015 to July 2017 (lower panel)

4.6.2.1 Offshore

Satellites, specifically MODIS (Moderate Resolution Imaging Spectroradiometer) can detect the concentration of chlorophyll in the oceans because the presence of chlorophyll changes the colour of the water, however their detection ability can be limited (Rothlisberg et al., 2005).

Near-surface spatial distributions of monthly mean chlorophyll estimated from MODIS ocean colour satellite data for January (wet season) and July (dry season) are presented in Figure 41.

During the wet season (Figure 41, upper panel) monthly mean surface chlorophyll is typically around 0.25 mg/m^3 , although values range from approximately 0.15 mg/m^3 to 0.75 mg/m^3 in the Timor Sea. Values in part of the coastal zone greater than 2.0 mg/m^3 may be over-estimated due to the presence of coloured dissolved organic matter (Rothlisberg et al., 2005).

Spatial trends are similar during the dry season (Figure 41, lower panel), but values are typically 0.25 mg/m^3 to 0.5 mg/m^3 higher than during the wet season. Hayes et al. (2005) reported that chlorophyll increases in surface waters of the Timor Sea in July–August, originating on the coast of both Indonesia and Australia and moving south and north to cover the surface waters. By November (wet season), there is a marked decline in surface chlorophyll in the centre of the Timor Sea, but there is evidence of subsurface chlorophyll maxima near the nutricline both on the shelf and offshore. This condition persists until about April.

For the Barossa Gas Export Pipeline area (ConocoPhillips, 2019) chlorophyll α concentrations were reported to be low ($<0.9 \text{ µg/L}$) throughout the water column at all sites and during each season. During the wet season the zone of maximum productivity lied some distance below the surface, most likely due to optimising the requirement for light and nutrients.

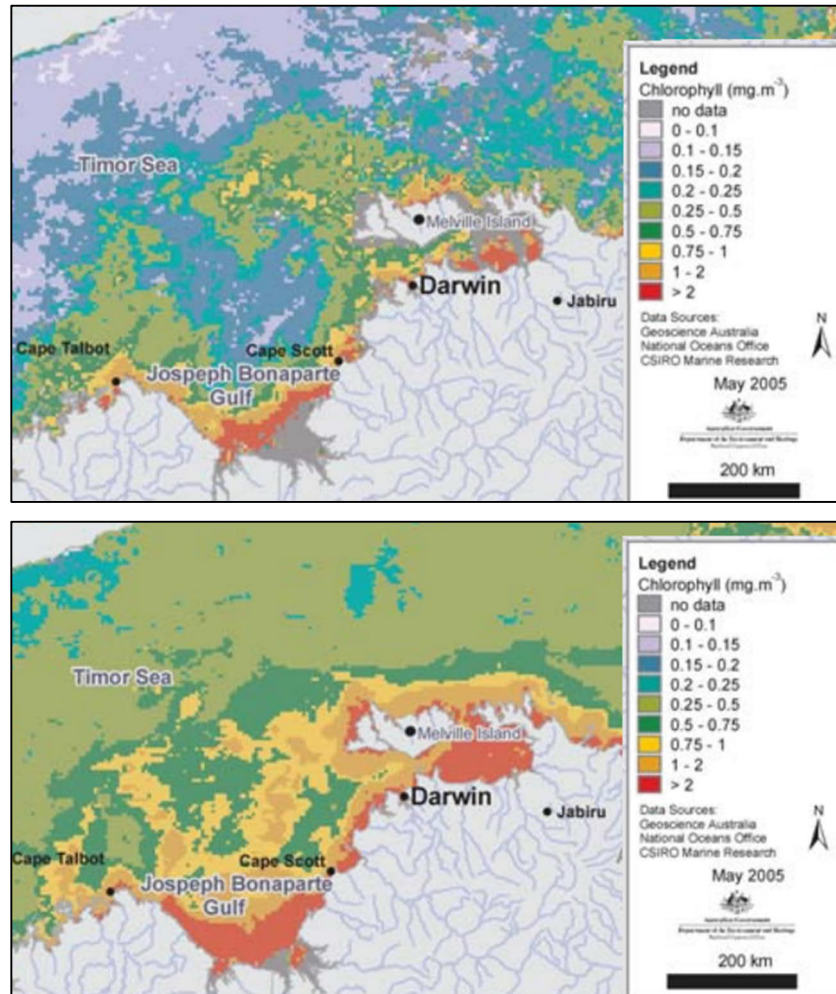


Figure 41 MODIS remotely sensed monthly mean near-surface chlorophyll: January (upper panel) and July (lower panel) (from Rothlisberg et al., 2005)

4.6.3 Euphotic depth

Photosynthetically active radiation (PAR) is defined as the light energy required for photosynthesis, and is restricted to wavelengths between 400 nm and 700 nm. Day length plus sun altitude determine the daily amount of PAR per unit area, and the amount of PAR available for photosynthesis and primary production at depth. PAR measurements can be used to calculate the euphotic depth (ZEU).

ZEU (99% light extinction coefficient) is a measure of water clarity and is the depth at which light intensity is 1% of the surface value. Since the euphotic zone is where almost all of the photosynthesis occurs, the depth of it (ZEU) is generally proportional to the level of primary production that occurs in that area of the ocean. About 90% of all marine life lives in the euphotic zone (Falkowski and Knoll, 2007).

4.6.3.1 Nearshore

Light levels reaching the sea surface in the Darwin region are generally very high. However, even within the space of a few metres the light levels can become very low, particularly during the wet season when turbidity levels are high. At a depth of only 3 m below the surface light levels can be just 7% of surface levels, while near the bottom they can be as low as 1% of surface levels during the wet season (Hanley and Caswell, 1995).

Figure 42 shows monthly variability in ZEU values based on DEPWS 2004-2018 data for Shoal Bay, with median monthly values ranging from 10 m to 16 m. The reported data represent mostly dry season months, except December. No significant change in the median ZEU values observed in December. The data indicate that the highest variation in ZEU (from 4 m to 27 m) occurred in September.

ZEU appears to be more dependent upon the tidal magnitude or range rather than stage of the tidal cycle (Padovan, 1997).

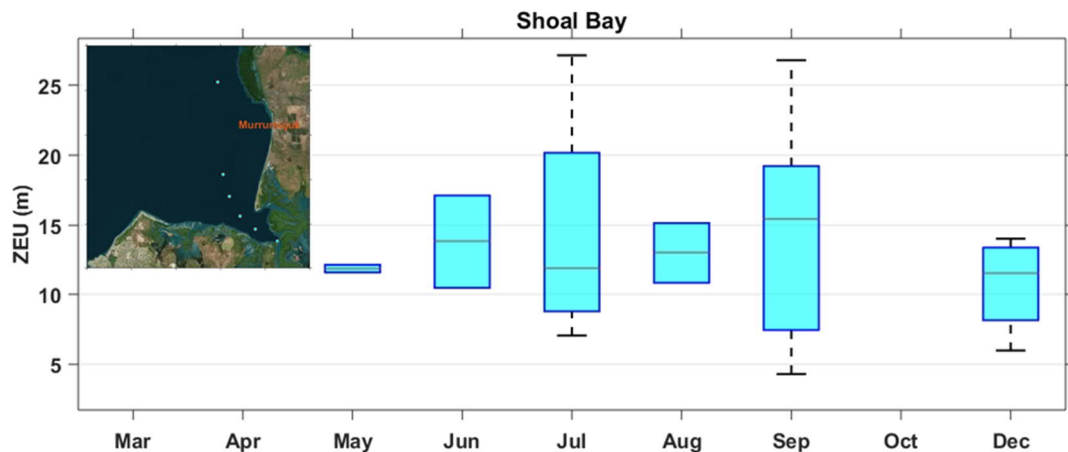


Figure 42 Box and whisker plots of euphotic depth (ZEU) grouped by months based on 2004-2018 DEPWS data from six sites in Shoal Bay

4.6.3.2 Offshore

Day lengths in the offshore Project area do not vary greatly between seasons, however, there is some reduction in PAR due to seasonal changes in cloud cover, particularly during the wet season.

Figure 43 shows that during the wet season, light intensities are in the range of $225 \text{ W m}^{-2} \text{ d}^{-1}$ to $250 \text{ W m}^{-2} \text{ d}^{-1}$, some $25 \text{ W m}^{-2} \text{ d}^{-1}$ higher than during the dry season, despite the impact of clouds during the wet season. This difference is due to the higher sun angle, and longer day length seen during January compared to July. This difference is not large, and probably does not impact substantially on any changes in primary production that may occur in different seasons. In general, the offshore waters are very clear and the euphotic zone can extend to 100 m across the shelf (DEWHA, 2007).

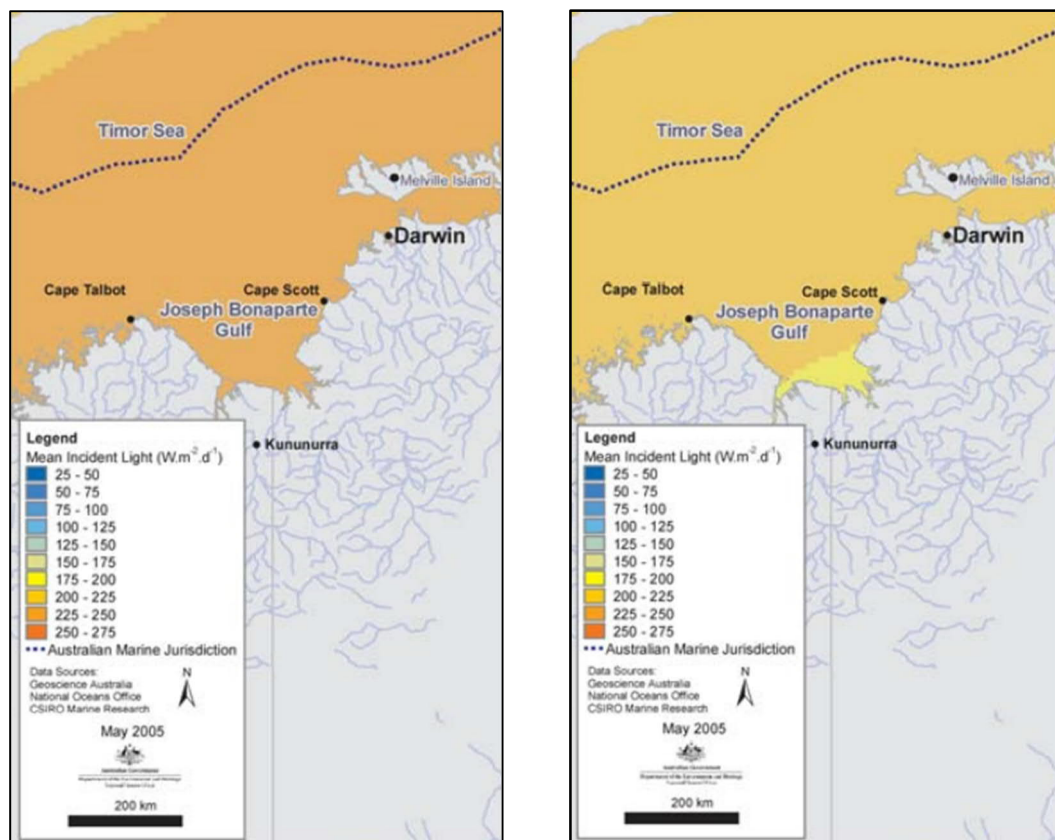


Figure 43 Mean incident light for wet season (left panel) and for dry season (right panel) from CARS (Rothlisberg et al., 2005)

5.0 Quality of marine sediments

5.1 Nearshore

A benthic sediment sampling survey was undertaken in the ODH, which includes Shoal Bay, in the period from 05 February 2020 to 22 April 2020 by DEPWS. Benthic sediment samples were collected at 91 sites in the region. The dataset comprised the first baseline dataset for metals and hydrocarbons and pesticides that is a suitable scale for surveillance monitoring in the ODH (Radke et al., 2020). Analytical results of the collected sediment samples were discussed in relation to exceedances over Default Guideline Values (DGVs) and upper guideline values (and GV-high's) for sediment toxicants in ANZECC and ARMCANZ (2000).

Figure 44 shows the locations of metal(loid) exceedances over DGVs in the reported area. Sediment arsenic (As) concentrations exceeded default guideline values at 38 sites, and nickel (Ni) exceeded the guideline values at 3 sites. Arsenic was generally most abundant in the sediments of Hope Inlet in Shoal Bay. Most of the As exceedances and all of the Ni exceedances were due to the naturally high background concentrations (Radke et al., 2020). However, As exceedances reported at three sites in the highly urbanised catchments of Ludmilla Creek and Rapid Creek were likely due to anthropogenic causes.

Polycyclic aromatic hydrocarbons (PAH) were detected in six samples from mangroves or mangrove-lined tidal creek sediments within the heavily populated and highly urbanised sub-catchments of Ludmilla Creek, Rapid Creek and Buffalo Creek (Figure 45), where stormwater and wastewater discharge points are present. However, the total organic carbon (TOC)-normalised PAH concentrations were below DGVs (default guideline values) at all of these sites. Dieldrin was detected in one sample from Rapid Creek but also had a TOC-normalised concentration that was lower than the guideline value. Total recoverable hydrocarbons (TRH) were detected at 88 sites, including Shoal Bay, with highest concentrations in the sediments of the urbanised catchments. Total TRH concentrations exceeded default guideline values at one site in Buffalo Creek and two sites in Rapid Creek (Figure 45).

With the exception of four sites, potential acidity of the Outer Harbour sediments exceeded the "Acid Sulfate Soil Action Criteria" of 18 moles H⁺/tonne (Dear et al., 2014), and the criteria was far exceeded at four sites.

Other potential pollutants were generally below DGVs or detection limits (DL).

Butler et al. (2013) indicated that the assimilative capacity of the sediments of Buffalo Creek, which receives elevated levels of nutrients in effluent from the Leanyer Sanderson Waste Stabilisation Ponds, is overwhelmed and relatively more nitrogen is recycled to the water column in bioavailable forms that can be exported to other areas.

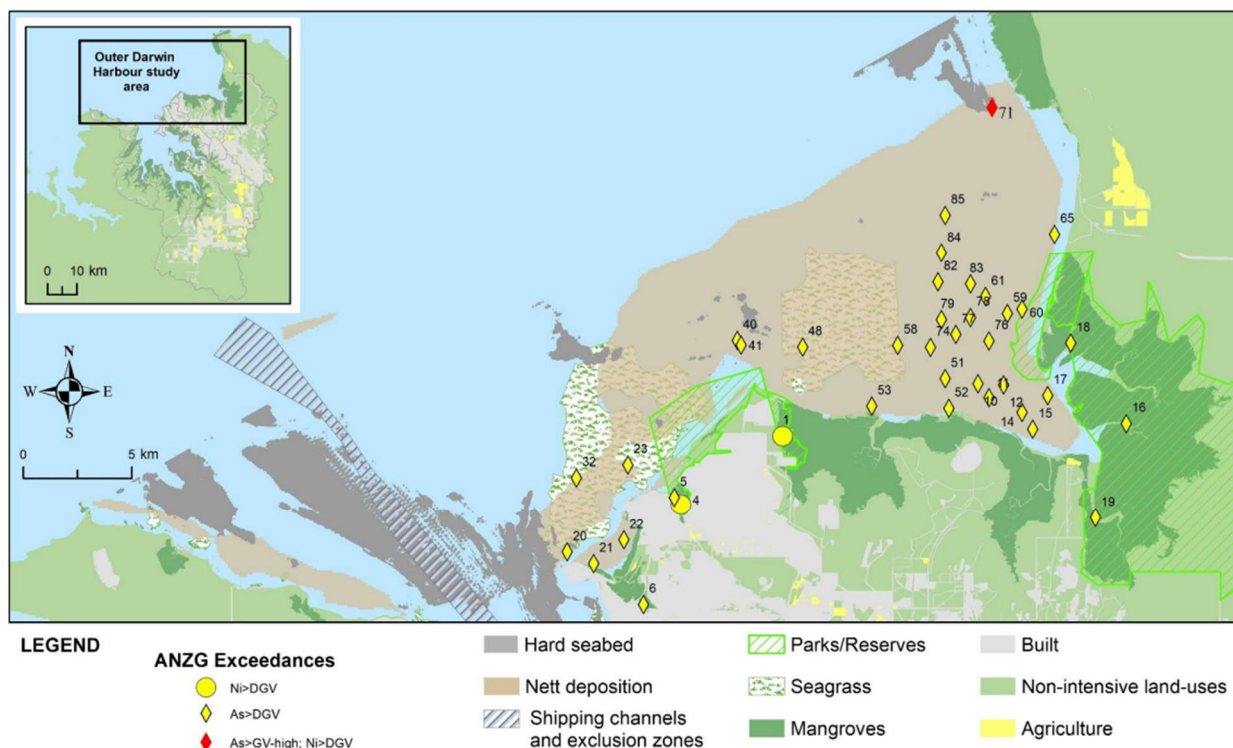


Figure 44 Locations of Ni (nickel) and As (arsenic) exceedances of DGVs and GV-high values (from Radke et al., 2020)

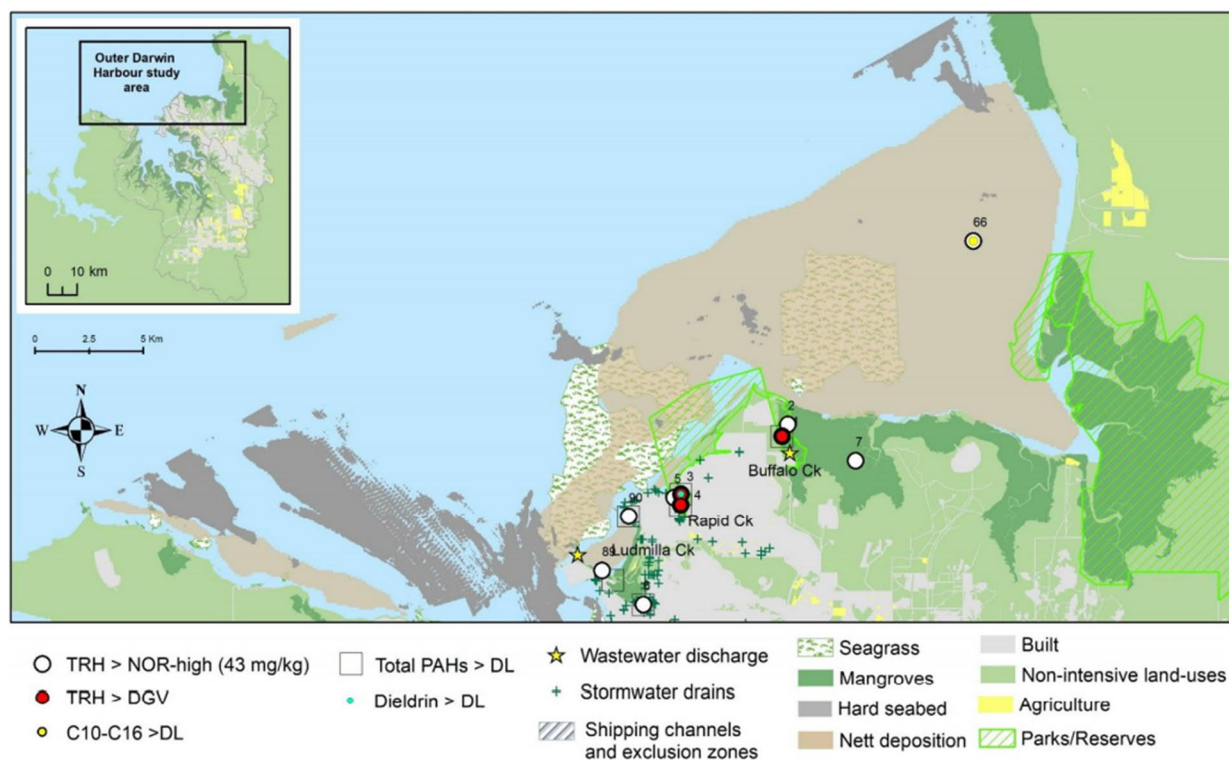


Figure 45 Comparison of hydrocarbon parameters with DGVs. NOR-high refers to high value of non-outlier range, and DL refers to detection limit (from Radke et al., 2020)

5.2 Offshore

Radke et al. (2014) and Radke et al. (2015) characterised sediments based on a large geochemistry data set from surveys in the eastern Timor Sea. Calcareous quartz sands and coarse quartzose calcarenites that formed plains on the inner shelf were characteristic sediments. Elevated levels of arsenic (above ANZECC and ARM CANZ (2000) default guideline value of 20 mg/kg) were reported for the inner-shelf area to the south-west from Bathurst Island, with 10.1-15.9 mg/kg median concentrations. The authors also suggested that *Trichodesmium* blooms (toxic cyanobacteria or blue-green algae) may be a significant source of organic matter to seabed in the area.

Sediment types observed during the Barossa marine studies program (ConocoPhillips, 2019) were comparable with those found in local and broader regional seabed habitat mapping studies undertaken in the Eastern Joseph Bonaparte Gulf and Timor Sea (e. g. Anderson et al., 2011). Whilst the majority of metal concentrations were below the ANZECC and ARM CANZ (2000) guidelines, cobalt and nickel were recorded above the trigger values. TRH and BTEXN were below the laboratory reporting limits at all sites. The highest concentrations of nitrogen and organic carbon were associated with deepest and the finest sediments.

6.0 References

- AIMS, 2021. The Beagle Gulf Surface Buoy deployed from May 2015 to July, 2017. Data Centre Australian Institute of Marine Science. <https://doi.org/10.25845/5c09bf93f315d> Accessed March 2021.
- Alongi, D. M., Edyvane, K., do Ceu Guterres, M. O., Pranowo, W. S., Wirasantosa, S., Wasson, R., 2011. Biophysical Profile of the Arafura and Timor Seas. Report prepared for the Arafura Timor Seas Ecosystem Action (ATSEA) Program.
- Anderson, T. J., Nichol, S., Radke L., Heap, A. D., Battershill, C., Hughes, M., Siwabessy, P. J., Barrie, V., Alvarez de Glasby, B., Tran, M., Daniell, J., Shipboard Party, 2011. Seabed Environments of the Eastern Joseph Bonaparte Gulf, Northern Australia. GeoScience Australia, Canberra, Australia.
- ANZECC and ARMCANZ, 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra, Revised in 2018.
- Balls, P. W., 1994. Nutrient inputs to estuaries from nine Scottish east coast rivers; influence of estuarine processes on inputs to the North Sea. *Estuarine Coastal and Shelf Science*, 39, 329–352.
- Bourget, J., Ainsworth, R. B., Nanson, R., 2013. Origin of mixed carbonate and siliciclastic sequences at the margin of a “giant” platform during the Quaternary (Bonaparte Basin, NW Australia). In Verwer, K., PLayton, T. E., Harris, P. M. (Eds.), *Deposits, Architecture, and Controls of Carbonate Margin, Slope, and Basinal Settings*. SEPM (Society of Sedimentary Geology) Special Publication 105, 157-177.
- Bourke, P. M., 2004. Three Aboriginal shell mounds at Hope Inlet: Evidence for coastal, not maritime Late Holocene economies on the Beagle Gulf mainland, northern Australia, *Australian Archaeology*, 59, 2004.
- BRAN, 2021. The Bluelink ReANalysis (BRAN) is a multi-year integration of OFAM that assimilates observations using an Ensemble Optimal Interpolation (EnOI) data assimilation system called BODAS (Bluelink Ocean Data Assimilation System). <https://research.csiro.au/bluelink/global/reanalysis/> Accessed March 2021.
- Buckee, J., Jimenez, I., Blount, C., Roberts, C., Hughes, M., van Senden, D., Reeds, K., O'Donnell, P., Macbeth, W., Barnes, L., Blewitt, M., Beadle, C., Lamb, J., Holloway, C., Harrison, S., 2014. Darwin Harbour: A summary of the Ichthys LNG project Nearshore environmental monitoring program / INPEX. INPEX Operations Australia Pty Ltd, 2014, Perth Australia.
- BOM, 2021a. Tropical Cyclone Knowledge Centre, Australian Government, Bureau of Meteorology, <http://www.bom.gov.au/cyclone/tropical-cyclone-knowledge-centre/> Accessed May 2021.
- BOM, 2021b. Australia in March 2016, Australian Government, Bureau of Meteorology, <http://www.bom.gov.au/climate/current/month/aus/archive/201603.summary.shtml> Accessed June 2021.
- Burford, M. A., Alongi, D. M., McKinnon, A. D., Trott, L. A., 2008. Primary production and nutrients in a tropical macrotidal estuary, Darwin Harbour, Australia. *Estuarine, Coastal and Shelf Science*, 79: 440–448.
- Butler, J. and Padovan, A., 2005. The water quality of Jones Creek, a tidal creek in Darwin Harbour. Technical Report: 14/2005D, Department of Natural Resources, Environment and the Arts, NT.
- Butler, E. C. V., Streten-Joyce, C., Tsang, J. J., Williams, D. K., Alongi, D. M., Furnas, M. J., McKinnon, A. D., 2013. A procedure for evaluating the nutrient assimilative capacity of Darwin Harbour. Report for Aquatic Health Unit, NT Department of Land Resource Management. Australian Institute of Marine Science, Darwin.
- Calnan, T., 2006. Rainforest to Reef just 40km from Darwin. An assessment of the conservation values of the Gunn Peninsula/Vernon Islands area and the impacts of the propose Glyde Point heavy industry and residential estate. Environment Centre of the Northern Territory and Australian Marine Conservation Society Australia.
- Caltest, 2021. Total Suspended Solids Analysis (TSS) and Suspended Sediment Concentration Analysis (SSC). Caltest Analytical Laboratory Environmental Analyses. <http://www.caltestlabs.com>, Accessed 15/08/2021.
- Collins, L. B., 2010. Controls on Morphology and Growth History of Coral Reefs of Australia's Western Margin. In: Morgan, W. A., George, A. D., Harris, P. M., Kupecz, J. A., Sarg, J.F. (Eds.), *Cenozoic Carbonate Systems of Australasia*. Society for Sedimentology Special Publication 195, 195-217.
- Collins, L. B., 2011. Geological Setting, Marine Geomorphology, Sediments and Oceanic Shoals Growth History of the Kimberley Region. *Journal of the Royal Society of Western Australia*, 94: 89–105, 2011.

Condie, S., Ridgway, K., Griffiths, B., Rintoul, S., Dunn, J., 2003, National oceanographic description and information review for national bioregionalisation, report to the National Oceans Office by the Division of Marine Research, Commonwealth Scientific Industrial and Research Organisation.

ConocoPhillips, 2019. Barossa Gas Export Pipeline Installation Environment Plan, Document ID:BAA-100 0329.

CSIRO, 2018. Aboriginal calendars. <https://www.csiro.au/en/Research/Environment/Land-management/Indigenous/Indigenous-calendars/Gulumoerrgin> Accessed July 2021.

CSIRO, 2021. WaveWatch III hindcast data base. http://data-cbr.csiro.au/thredds/catalog/catch_all/CMAR_CAWCR-Wave_archive/CAWCR_Wave_Hindcast_aggregate/gridded/catalog.html Accessed March 2021.

Darwin Storm Surge, 2020. Storm surge inundation maps. Map prepared by the Department of Environment, Parks and Water Security, Geospatial Services Branch, Northern Territory Government <https://depws.nt.gov.au/water/water-resources/flooding-reports-maps/storm-surge-inundation-maps>

Dear, S-E, Ahern, C. R. O'Brien, L. E., Dobos, S. K., McElnea, A. E., Moore, N. G., Watling, K. M., 2014. Queensland Acid Sulfate Soil Technical Manual: Soil Management Guidelines. Brisbane: Department of Science, Information Technology, Innovation and the Arts, Queensland Government.

DEWHA, 2007. Department of the Environment, Water, Heritage and the Arts, Northern Territory Government. Characterisation of the marine environment of the North Marine Region. Outcomes of an Expert Workshop, Darwin, Northern Territory, 2-3 April 2007

DLRM, 2014. Department of Land Resource Management, Northern Territory Government. Darwin Harbour Water Quality Protection Plan. https://landresources.nt.gov.au/__data/assets/pdf_file/0011/254855/Water-Quality-Protection-Plan-Feb2014-web.pdf

Drewry, J., Fortune, J., Browne, D., 2010. Water Quality of the Elizabeth River Estuary, Darwin Harbour, before and during the 2006-2007 wet season. Aquatic Health Unit, Department of Natural Resources, Environment, The Arts and Sport.

Duggan, S., 2006. The water quality of Darwin Harbour: December 2002-December 2004. AIMS Technical Report: 37, Australian Institute of Marine Science.

Durrant, T., Greenslade, D., Hemer, M., Trenham, C., 2014. A Global Wave Hindcast focussed on the Central and South Pacific CAWCR Technical Report No. 070.

Falkowski, P. G. and Knoll, A.H., 2007. Evolution of primary producers in the sea. Amsterdam: Elsevier Academic Press.

Fortune, J., 2010. Water Quality Objectives for the Darwin Harbour Region - Background Document. Aquatic Health Unit, Department of Natural Resources, Environment, The Arts and Sport. Palmerston, NT.

Fortune, J., 2015. Supplement to the 2014 Darwin Harbour Region Report Card. Report No. 01/2015D. Aquatic Health Unit, Department of Land Resource Management. Palmerston, NT.

Fortune, J., 2019. Darwin Harbour Region 2019 Report Card. Aquatic Health Unit, Department of Environment and Natural Resources. Palmerston, NT

Fortune, J. and Patterson, R., 2016. Darwin Harbour Region 2015 Report Card Water Quality Supplement. Report No. 4/2016D. Aquatic Health Unit, Department of Land Resource Management. Palmerston, NT.

GA, 2021. Money Shoal Basin., Geoscience Australia, <http://www.ga.gov.au/scientific-topics/energy/province-sedimentary-basin-geology/petroleum/offshore-northwest-australia/money-shoal> Accessed June 2021

Hanley, J. R. and Caswell, G.M., 1995. East Arm Port – Stage 1. Water Quality monitoring program. Report on setup phase and baseline data collection. Marine Ecology Technical Report 95/1.

Harper, B. A., 2010. Modelling the Tracy storm surge – implications for storm structure and intensity estimation. Australian Meteorological and Oceanographic Journal, 60, 187-197.

Harvey, R., Lye, L., Khan, A., Paterson, R., 2013. The Influence of Air Temperature on Water Temperature and the Concentration of Dissolved Oxygen in Newfoundland Rivers. Canadian Water Resources Journal, 36:2, 171-192.

Hayes, D., Lyne, V., Condie, S., Griffith, B., Pigitt, S., Hallegraef, G., 2005. Collation and Analysis of Oceanographic Datasets for National Marine Bioregionalisation. A report to the Australian Government, National Oceans Office.

URS, 2011. Ichthys Gas Field Development Project, Summary of the long-term water quality program for Darwin Harbour. URS Australia, Prepared for INPEX Browse, Ltd.

Cardno, 2014, Bimonthly Water Quality and Subtidal Sedimentation Report 10, Ichthys Nearshore Environmental Monitoring Program, Prepared for INPEX June 2014

James, N. P., Bone, Y., Kyser, T. K., Dix, G. R., Collins, L. B., 2004. The importance of changing oceanography in controlling late Quaternary carbonate sedimentation on a high-energy, tropical, oceanic ramp: north-western Australia. *Sedimentology*, 51, 1179-1205.

Katsumata, K., Wijffels, S. E., Steinberg, C. R., Brinkman, R., 2010. Variability of the semidiurnal internal tides observed on the Timor Shelf, *Journal of Geophysical Research: Oceans*, Volume 115, Issue C10.

Landbridge, 2020. Darwin Port Environmental Management Plan, Version 2.2 May 2020, Landbridge Group, Darwin, Northern Territory.

Li, L., Wang, X.-H., Williams, D., Sidhu, H., Song, D., 2012. Numerical study of the effects of mangrove areas and tidal flats on tides: A case study of Darwin Harbour, Australia. *Journal of Geophysical Research: Oceans* 117 (C6).

Louanchi, F., and Najjar, R. G., 2000. A global monthly climatology of phosphate, nitrate and silicate in the upper ocean: Spring-summer export production and shallow remineralization, *Global Biogeochem. Cycles*, 14, 957–977.

Makarynska, D., 2019a. Developing an integrated long-term monitoring program for Darwin Harbour -Water quality Pilot Project WP1: Neap tide trial. Department of Environment and Natural Resources, Report No.10/2019.

<https://www.territorystories.nt.gov.au/jspui/handle/10070/307666>

Makarynska, D., 2019b. Developing an integrated long-term monitoring program for Darwin Harbour -Water quality Pilot Project WP2: Intra-annual water quality variability. Department of Environment and Natural Resources, Report No.22/2019. <https://pdfs.semanticscholar.org/5f66/a51447ab9d72f62d9377bcd3d211f36f2b3.pdf>

Makarynska, D. and Makarynsky, O., 2017. Hydrodynamic and sediment plume modelling in a macro-tidal estuary. Coasts & Ports 2017 Conference – Cairns, 21-23 June 2017.

Makarynsky, O. and Makarynska, D., 2019. Integrated marine monitoring for drilling discharges under mesotidal forcing. *Hydrometeorological Journal: Oceanography*, 23, 69-83.

McCue, K., 2013. Historical earthquakes in the Northern Territory, CQU Rockhampton, Queensland. Published at www.aees.org.au

McKinnon, A. D., Smit, N., Townsend, S., Duggan, S., 2006. Darwin Harbour: Water quality and ecosystem structure in a tropical harbour in the early stages of development, 433-459. In E.J. Wolanski (ed) *The environment in Asia Pacific Harbours*.

Michie, M. G., Grey, D. L., Griffin, R. K., 1991. Sea water salinity and temperature measurements in the Darwin Harbour area 1972-1978. Department of Primary Industries and Fisheries, Darwin NT May 1991.

NAA, 2021. Cyclones and the Northern Territory, Fact sheet 90, National Archives of Australia <https://www.naa.gov.au/sites/default/files/2020-05/fs-90-cyclones-and-the-northern-territory.pdf>

Némery, J. and Garnier, J., 2007. Typical features of particulate phosphorus in the Seine estuary (France), *Hydrobiologia*, 588(1):271-290.

NERP, 2021. National Environmental Research Program, Marine Biodiversity hub, Oceanic Shoals Commonwealth Marine Reserve – a guide.

Nichol, S. L., Howard, F. J. F., Kool, J., Stowar, M., Bouchet, P., Radke, L., Siwabessy, J., Przeslawski, R., Picard, K., Alvarez de Glasby, B., Colquhoun, J., Letessier, T., Heyward, A., 2013. Oceanic Shoals Commonwealth Marine Reserve (Timor Sea) Biodiversity Survey: GA0339/SOL5650 - Post Survey Report. Record 2013/38. Geoscience Australia: Canberra. (GEOCAT #76658).

Nicholas, W. A., Carroll, A., Picard, K., Radke, L., Siwabessy, J., Chen, J., Howard, F. J. F., Dulfer, H., Tran, M., Consoli, C., Przeslawski, R., Li, J., Jones, L. E. A., 2015. Seabed environments, shallow sub-surface geology and connectivity, Petrel Sub-basin, Bonaparte Basin, Timor Sea. Interpretative report from marine survey GA0335/SOL5463. Geoscience Australia, Record 2015/24

Nicholas, W. A., Smit, N., Siwabessy, P. J. W., Nanson, R., Radke, L., Li, J., Brinkman, R., Atkinson, R., Dando, N., Falster, G., Harries, S., Howard, F. J. F., Huang, Z., Picard, K., Tran, M., Williams D., 2019. Characterising Marine Abiotic Patterns in the Darwin-Bynoe Harbour region: Summary report, Physical Environments, Darwin Harbour Mapping Project. Department of Environment and Natural Resources. Darwin, Northern Territory, Australia. <http://pid.geoscience.gov.au/dataset/ga/127386>

NIRAS, 2015. Subsea Cable Interactions with the Marine Environment. Expert review and Recommendations Report, December 2015. NIRAS Consulting Ltd

- North West Atlas, 2021. <https://northwestatlas.org/nwa/oceanic-shoals-cmr> Accessed July 2021
- NT EPA, 2021. Draft Terms of Reference, Australia – ASEAN Power Link Project, Sun Cable Pty Ltd, October 2020.
- NTGOV, 2021. Shoal Bay Coastal Reserve, <https://nt.gov.au/environment/environment-data-maps/important-biodiversity-conservation-sites/conservation-significance-list> Accessed June 2021.
- Oke, P.; Sakov, P.; Cahill, M., Dunn, J.; Fiedler, R., Griffin, D., Mansbridge, J., Ridgway, K., Schiller, A., 2013. Towards a dynamically balanced eddy-resolving ocean reanalysis: BRAN3. Ocean Modelling. 2013; 67:52-70.
- OSPAR, 2009: OSPAR commission. Protecting and conserving the North-East Atlantic and its resources. Assessment of the environmental impacts of cables. – Publication Number: 437/2009.
- Padovan, A., 1997. The water quality of Darwin Harbour. October 1990- November 1991. Report No 34/1997D. Water Quality Branch, Department of Lands, Planning and Environment, NT.
- Padovan, A., 2003. Darwin Harbour water and sediment quality. Proceedings of the Darwin Harbour Public Presentations-February 2003. Darwin Harbour Regional Plan of Management, NT.
- Parkinson, G., 1996. Atlas of Australian resources. Third Series, Volume 4. Climate Division of National Mapping, Canberra.
- Parksaustralia, 2021. Oceanic Shoals Marine Park, Australian Marine Parks, Parks Australia <https://parksaustralia.gov.au/marine/parks/north/oceanic-shoals> Accessed June 2021
- Parry, D. L. and Munksgaard, N. C., 1995. Physiochemical Baseline Data for Darwin Harbour-East Arm Port Development. Northern Territory University, Darwin NT.
- Pietsch, BA 1983, Darwin 5073, Northern Territory Geological Survey, Department of Mines and Energy, Darwin.
- Przeslawski, R., Alvarez, B., Battershill, C., Smith, T., 2014. Sponge biodiversity and ecology of the Van Diemen Rise and eastern Joseph Bonaparte Gulf, northern Australia. Hydrobiologia 730, 1-16.
- Radke, L. C., Pappas, W., Webber, E., 2014. Seafloor environments of the eastern Timor Sea, Northern Australia: Inorganic chemistry of seabed sediments. Geoscience Australia, Canberra. <http://dx.doi.org/10.4225/25/54B8657D7C8B8>
- Radke, L. C., Li, J., Douglas, G., Przeslawski, R., Nichol, S., Siwabessy, J., Huang, Z., Trafford, J., Watson, T., Whiteway, T., 2015. Characterising sediments of a tropical sediment-starved shelf using cluster analysis of physical and geochemical variables. Environmental Chemistry, 2015, 12, 204–226
- Radke, L., Majid, M., Mummery, A., Lambrinidis, D., Logan, M., Wyatt, J., 2020. Sediment quality assessment of Outer Darwin Harbour: Survey record and data report. Technical Report No. 38/2020, Department of Environment and Natural Resources, Northern Territory Government, Darwin, Northern Territory.
- Rigby, P., Steinberg, C. R., Williams, D. K., Brinkman G, Tonin, H., 2014. Real-time marine observing systems: Challenges, benefits and opportunities in Australian coastal waters. Australian Journal of Civil Engineering, 12, 83-99.
- Rothlisberg, P., Condie, S., Hayes, D., Griffiths, B., Edgar, S., Dunn, J., 2005. Collation and Analysis of Oceanographic Datasets for National Marine Bioregionalisation: The Northern Large Marine Domain. A report to the Australian Government, National Oceans Office. May 2005 CSIRO Marine Research
- RPS, 2008. Meteorological Conditions Study for Ichthys Location in the Browse Basin. Prepared for INPEX Browse, Ltd. Perth
- RPS, 2016. Metocean Criteria Guidelines for MODU Mooring on Australia's North West Shelf. Prepared for APPEA Drilling Industry Steering Committee. Technical Note No. 100-CN-TNT-0819
- Saqab, M.M., 2016. Stratigraphic and tectonic evolution of the North-western Bonaparte Basin (North West Shelf of Australia) during Neogene, A thesis submitted for the degree of Doctor of Philosophy, Centre for Energy Geoscience, School of Earth and Environment, University of Western Australia
- SEA, 2006. Northern Territory Emergency Services, Darwin Storm Tide Mapping Study 2006. Systems Engineering Australia Pty Ltd
- SEA, 2010. High Resolution Storm Tide and Climate Change Impacts Study – 2010. Addendum to Darwin Storm Tide Study 2006. Systems Engineering Australia Pty Ltd
- Siwabessy, P. J. W., Tran, M., Huang, Z., Nichol, S., Atkinson, I., 2015. Mapping and Classification of Darwin Harbour Seabed. Record 2015/18. Geoscience Australia, Canberra. <http://dx.doi.org/10.11636/Record.2015.018>

- Siwabessy, P. J. W., Smit, N., Nicholas, W. A., Atkinson, I., Brinkman, R., Dando, N., Harries, S., Howard, F. J. F., Huang, Z. Li, J., Picard, K., Potter A., Radke, L., Tran, M., Williams, D., Whiteway, T., 2019. Seabed Mapping Darwin Harbour Region (including Bynoe Harbour). Final Report. Department of Environment and Natural Resources. Darwin, Northern Territory, Australia. <http://pid.geoscience.gov.au/dataset/ga/127384>
- Skinner, L., Townsend, S., Fortune, J., 2009. The Impact of Urban Land-use on Total Pollutant Loads Entering Darwin Harbour Report 06/2008D Department of Natural Resources, Environment, the Arts and Sport, Darwin.
- SKM, 2002. Sunrise Gas Project, Environmental Impact Statement, Existing Environment. Sinclair Knight Merz.
- Slomp, C. P., Malschaert, J. F. P., Van Raaphorst, W., 1998. The role of adsorption in sediment-water exchange of phosphate in North Sea continental margin sediments. *Limnology and Oceanography*, 43(5), 1998, 832-846.
- Smit, N., Billyard, R., Ferns, L., 2000. Beagle Gulf Benthic Survey: Characterisation of soft substrates. Technical Report No.66 (2000), Parks and Wildlife Commission of the Northern Territory
- Swan, J. M., Neff, J. M., Young, P. C., 1994. Environmental Implications of Offshore Oil and Gas Development in Australia – The Findings of an Independent Scientific Review. Australian Petroleum Exploration Association, Canberra, Australia.
- URS, 2004. Darwin City Waterfront Redevelopment Project, Draft EIS, prepared for DIPE. 36909-007.
- URS, 2011. Summary of the long-term water-quality program for Darwin Harbour. Ichthys gas Field development Project. Report prepared for INPEX
- Vernier, 2018. Earth Science with Vernier: <https://www.vernier.com/product/earth-science-with-vernier> Accessed May 2021.
- Water Monitoring Group, 2005. The Aquatic Health of Darwin Harbour Region. Report No. 5/2005D Department of Infrastructure, planning and Environment. Darwin, NT.
- Water Technology, 2017. Project Sea Dragon, Stage 1 Hatchery Coastal Environment and Impact Assessment, Seafarms Group Limited, October 2017
- Williams, D., Wolanski, E., Spagnol, S., 2006. Hydrodynamics of Darwin Harbour. The environment in Asia Pacific harbours, Springer, Dordrecht, 461-476.
- Wilson, D., Padovan, A., Townsend, S., 2004. The water quality of spring and neap tidal cycles in the Middle Arm of Darwin Harbour during the dry season. Water Monitoring Branch, Natural Resource Management Division, Department of Infrastructure, Planning and Environment, Darwin.
- Woodward, E., Jackson, S., Straton, A., 2008. Water resources of the Howard River region, Northern Territory: A report on the social and cultural values and a stakeholder assessment of water use scenarios. CSIRO Sustainable Ecosystems: Darwin.
- Wrigley, T. J., Cumberland, D. A., Townsend, S. A., 1990. Ambient Water Quality of Darwin Harbour, Report 71/90, Water Resources Division, Power and Water Authority.
- Wyrski, K., 1961. Physical Oceanography of the Southeast Asian Waters, The University of California Scripps Institution of Oceanography, La Jolla, California.
- Yang, G., Wang, X. H., Ritchie, E. A., Qiao, L., Li, G., Cheng, Z., 2018. Using 250-M Surface reflectance MODIS Aqua/Terra product to estimate turbidity in a macro-tidal harbour: Darwin Harbour, Australia. *Remote Sensing* 10(7), 997. <https://doi.org/10.3390/rs10070997>.
- YSI, 2005. Environmental Dissolved Oxygen Values Above 100% Air Saturation. In YSI Environmental Tech Note. <https://www.ysi.com/File%20Library/Documents/Technical%20Notes/T602-Environmental-Dissolved-Oxygen-Values-Above-100-percent-Air-Saturation.pdf> Accessed April 2021

7.0 Report Limitations

MetOcean Dynamic Solutions Pty Ltd (MetOcean) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of EcOz Environmental Services Pty Ltd to support preparation of an EIS for the Australia-ASEAN Power Link Project developed by Sun Cable Pty Ltd.

It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this Report.

Where this Report indicates that information has been provided to MetOcean by third parties, MetOcean has made no independent verification of this information except as expressly stated in the Report. MetOcean assumes no liability for any inaccuracies in or omissions to that information.

This Report was prepared between April 2021 and October 2021 and is based on the conditions encountered and information reviewed at the time of preparation. MetOcean disclaims responsibility for any changes that may have occurred after this time.

This Report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This Report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

Except as required by law, no third party may use or rely on this Report unless otherwise agreed by MetOcean in writing. Where such agreement is provided, MetOcean will provide a letter of reliance to the agreed third party in the form required by MetOcean.

To the extent permitted by law, MetOcean expressly disclaims and excludes liability for any loss, damage, cost or expenses suffered by any third party relating to or resulting from the use of, or reliance on, any information contained in this Report. MetOcean does not admit that any action, liability or claim may exist or be available to any third party.

Except as specifically stated in this section, MetOcean does not authorise the use of this Report by any third party.

It is the responsibility of third parties to independently make inquiries or seek advice in relation to their particular requirements.