Ashburton Salt Project

Nutrient Pathway Assessment and Modelling

K+S Salt Australia Pty Ltd

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Project Details

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Background

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

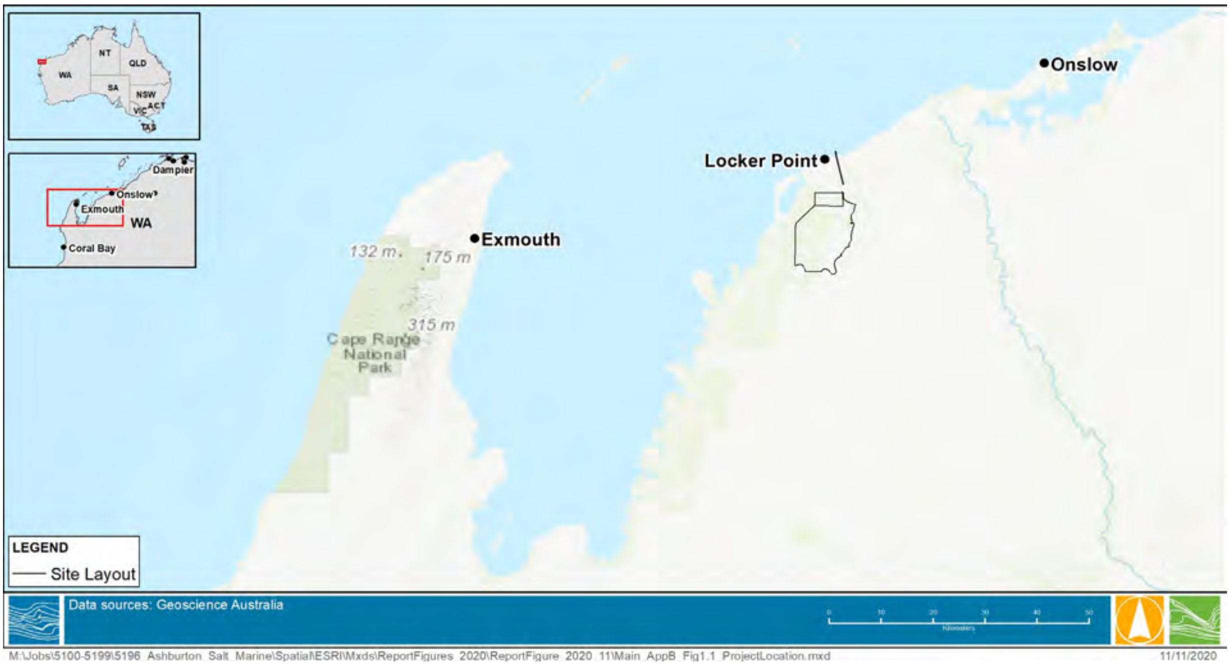

FIGURE 1-1 PROJECT LOCATION

K+S engaged Water Technology to undertake a Nutrient Pathways Assessment and Modelling investigation (this study) to support the preparation of an Environmental Review Document (ERD) for the project. This study seeks to understand the magnitude of impacts to nutrient flows and quantities due to altered hydrological processes, as defined in the 2017 Environmental Scoping Document (ESD) (EnviroWorks Consulting 2017).

In order to assess potential changes in local nutrient pathways, including contributions to Exmouth Gulf, a nutrient pathway assessment was undertaken which involved the following key steps:

- Characterisation of the existing environment - Section 3.
- Development of conceptual nutrient pathway model (descriptive diagram) and nutrient budget - Section 3.
- Development of a numerical model simulating nutrient pathways related to tidal inundation and overland flows – Section 4.3.
- Project related impact assessment including - Section 4.4:
  - Modelled impacts to tidal inundation and overland flow nutrient pathways; and
  - Calculated nutrient loss, due to habitat loss.

1.2 Project Description

The Ashburton Salt Project seeks to harvest seawater salt through solar evaporation. The infrastructure necessary for the Project includes a seawater intake, solar evaporation ponds, crystalliser ponds, an outfall for the discharge of hypersaline wastewater (bitterns), and a salt export jetty.

Figure 1-2 shows the general arrangement of the facility studied in this report. This is the 8th layout for the Project and many revisions underpin the iterative nature of the design process and the work carried out since the ESD to manage environmental impacts.

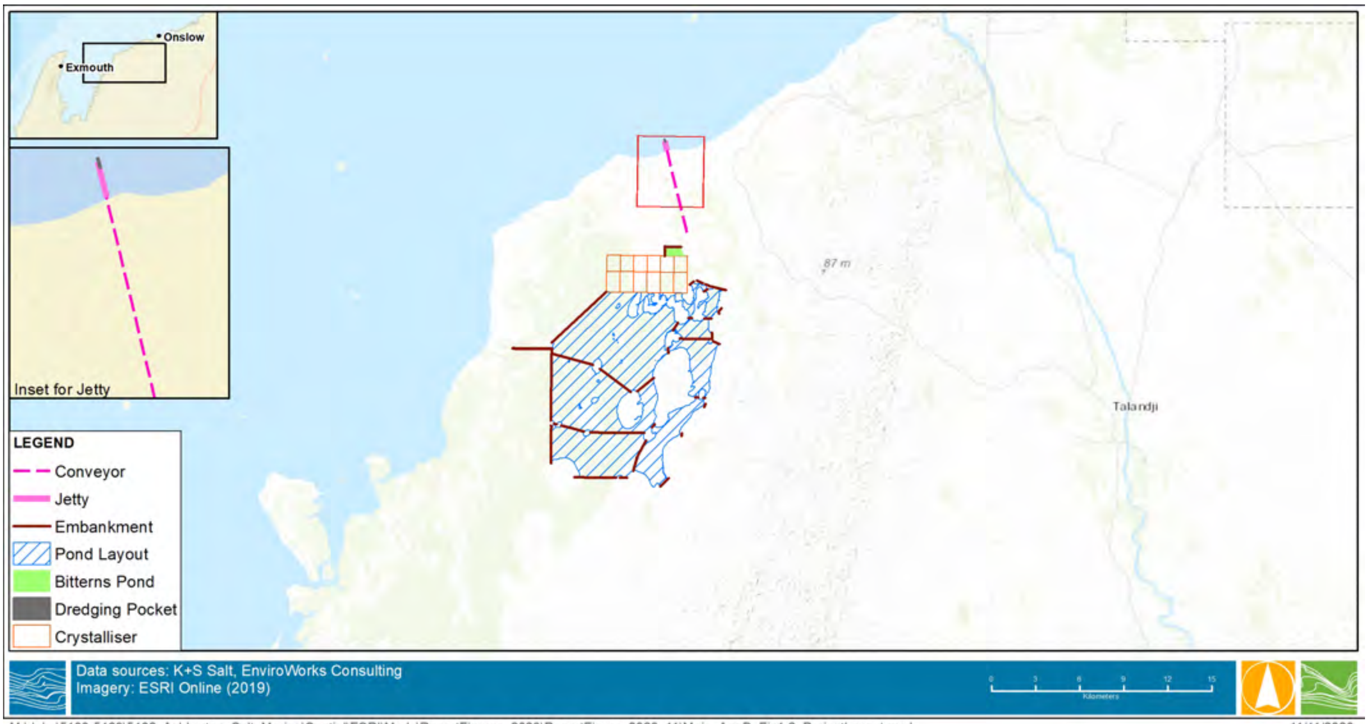

FIGURE 1-2 PROPOSED PROJECT LAYOUT

A technical overview of the coastal infrastructure required for the Project follows:

- **Seawater Intake** - The seawater intake is located in Urala Creek South, and has an annual intake estimated to be 250 gigalitres (GL).

  A peak monthly intake of 29 GL per month is anticipated to occur in October to December, when solar evaporation rates are highest. This intake volume includes all seawater required for the entire project including evaporation ponds, wash plant and bitterns dilution water.

- **Solar Evaporation Ponds** - Seawater will be pumped from Urala Creek South into a series of eight evaporation (salt concentration) ponds. As seawater passes through the pond system, water evaporates, thereby producing a progressively denser brine with an increasing concentration of dissolved salts. Calcium salts precipitate out of the brine at an early stage, initially as calcium carbonate, then as calcium sulphate (i.e., gypsum). As the calcium salts settle to the pond floors, the pond becomes less and less permeable.

- **Crystalliser Ponds** - Twelve crystalliser ponds are located immediately north of the solar evaporation ponds. They are laid out in two rows of six ponds. Their purpose is to perform the final crystallisation process to create the salt product.

The saturated brine enters the crystalliser ponds where water is evaporated by solar energy until salt crystals (predominantly sodium chloride) are precipitated. Once the brine reaches a particular specific gravity, most of the remaining calcium will have been precipitated.

- **Export Jetty** – Salt will be carried by the conveyor to the jetty where it will be conveyed along the 700m long jetty to a shiploader to an self-unloading transhipment vessel (transhipper). Dredging of a berthing pocket at the end of the jetty (on the northern side) is required to allow the laden transhipper adequate water depth to remain within the berthing pocket without tidal restriction. The dimensions of the berthing pocket are 200m x 35m x 2.5m seabed depth (6 m water depth at low tide). The volume of material to be dredged for the berthing pocket is estimated to be 17,000m^3. Dredging would be carried-out by a cutter suction dredge. Dredge spoil disposal will occur on land with appropriate management in place.
- **Sea Outfall -** The remaining hypersaline wastewater left from the crystallisation process is called bitterns. This concentrated salt solution flows from the crystalliser ponds into a bitterns dilution pond. The bitterns dilution pond will be located directly to the north of the northern set of crystalliser ponds. Seawater will be pumped into the bitterns dilution pond to dilute the bitterns prior to being discharged in the sea.

  The diluted bitterns will be pumped via a pipeline to the jetty for disposal offshore via an outfall equipped with a diffuser. The pipeline overland route will follow the salt conveyor route and will extend offshore along the export jetty. A bitterns pump station will provide the pumping requirements to transport the bitterns to the coast. A multi-port diffuser will be installed at the end of the pipeline to mix discharged bitterns with seawater.

1.3 Supporting Studies

The preparation of this nutrient pathway report included physical data collection, a detailed review of scientific documentation related to the site coastal and marine environment as well as numerical modelling investigations. Supporting studies include:

- **Marine, Coastal and Surface Water Data Collection, Ashburton Salt Project, Water Technology 2021** - A physical data collection program was undertaken for this study which included the deployment of water level, wave and water quality data loggers. It also included the collection of water quality monitoring data, bathymetric data and current transects to assist in characterising the physical coastal environment. The data collected has been used to support the development and calibration of numerical models.
- **Marine, Coastal and Surface Water Existing Environment, Ashburton Salt Project, Water Technology 2021** - An extensive literature review and interpretation of field data was undertaken to document existing catchment, coastal and marine conditions within the local and regional environment. This report describes the existing environment based on desktop analyses and field data collection.

1.4 Nutrient Pathway Modelling

A suite of numerical models including hydrodynamic and water quality models were developed to enable the simulation of tides, freshwater inflows and extreme events on physical processes within the study area. The Danish Hydraulic Institute's (DHI) MIKE Modelling suite was used to assess the conditions and impacts of the proposed Project related to nutrient pathways. The extent and resolution of the primary MIKE model is presented in Figure 1-3. The local nutrient model displayed in Figure 1-3 was coupled with a regional marine and regional catchment model.   Further details on the modelling methodology are described in Section 4.3.

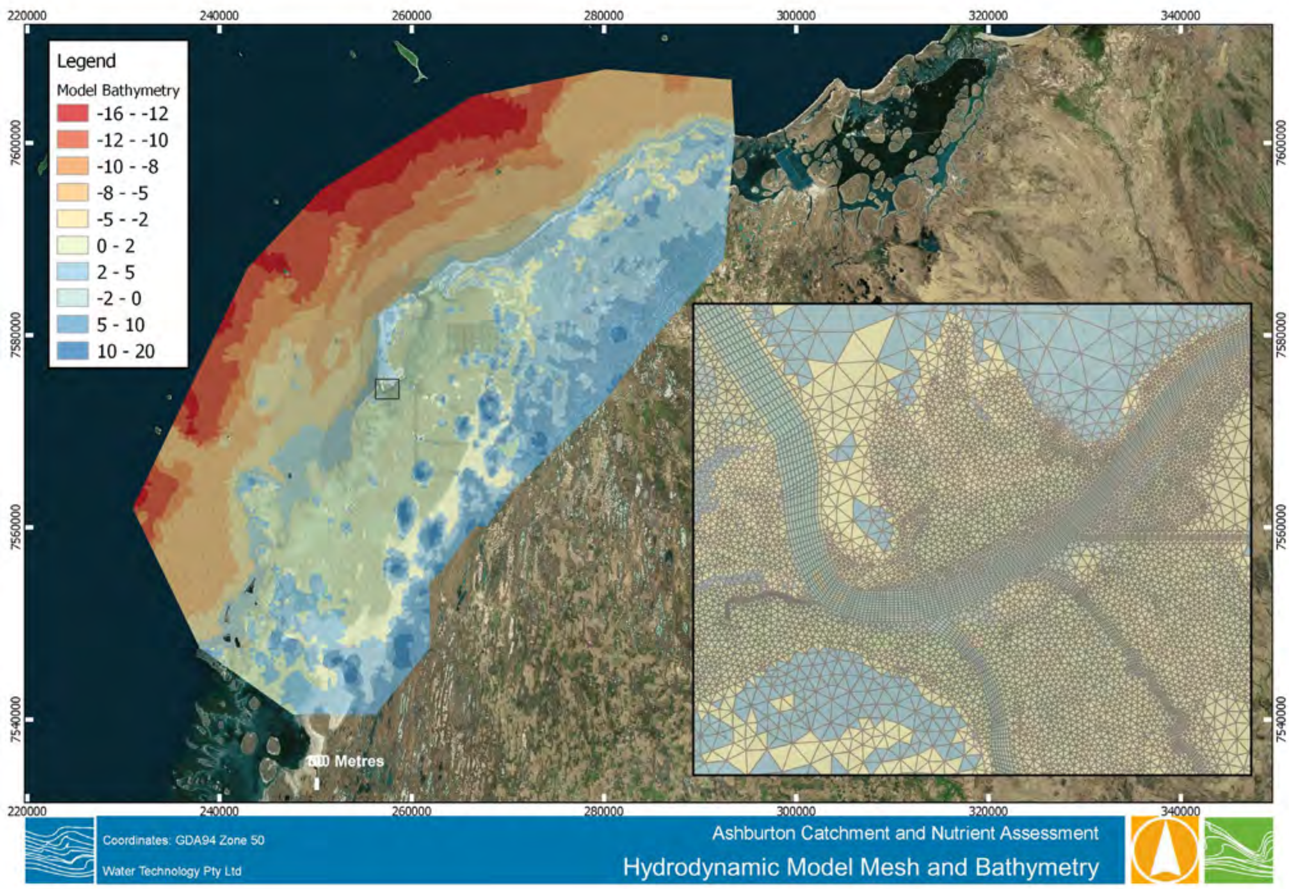

FIGURE 1-3 MIKE MODEL DOMAIN

2 ENVIRONMENTAL OBJECTIVES AND TARGETS

2.1 Environmental Objectives

The numerical modelling undertaken by Water Technology is to address the following EPA environmental objectives:

- To maintain the hydrological regimes of groundwater and surface water so that environmental values are protected.
- To maintain the quality of groundwater and surface water so that environmental values are protected.

This assessment focuses on the surface water component, with particular focus on surface water related nutrient pathways. Groundwater is addressed in a separate study.

2.2 Regulatory Framework

The Western Australian Environmental Protection Authority (EPA) has determined that the Project is to be assessed under Part IV of the Environmental Protection Act 1986 (EP Act). The Australian Department of the Agriculture Water and Environment (DAWE) has determined that the proposal will be assessed under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) as a controlled action, via an accredited process. The requirements of both the EP Act and the EPBC Act are thus to be addressed.

In line with the ESD submitted to the EPA, this report covers modelling work associated with the following environmental factors for inclusion in the environmental review:

- Hydrological Processes; and
- Inland Waters Quality.

The study has been undertaken in accordance with the following regulatory frameworks:

- Environmental Factor Guideline: Hydrological Processes (Environmental Protection Authority 2016); and
- A Directory of Important Wetlands in Australia (Australian Nature Conservation Agency 1993).

3 EXISTING ENVIRONMENT DESCRIPTION

3.1 Background

The existing environment at both a local and regional scale is described comprehensively in *Marine, Coastal and Surface Water Existing Environment* (Water Technology 2021). A brief summary of key features and processes considered relevant to this study is provided below.

3.2 Meteorology

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

Key climatic drivers are illustrated in Figure 3-1, presented by the Bureau of Meteorology (BOM 2010). Along the Pilbara coast, the Indian Ocean Dipole, West Coast Troughs and Northwest Cloudbands dominate climatic conditions. In addition to this, the position of the subtropical ridge influences the seasonal change as the ridge shifts to the south in summer and to the north in winter, resulting in contrasting wet and dry seasons, respectively.

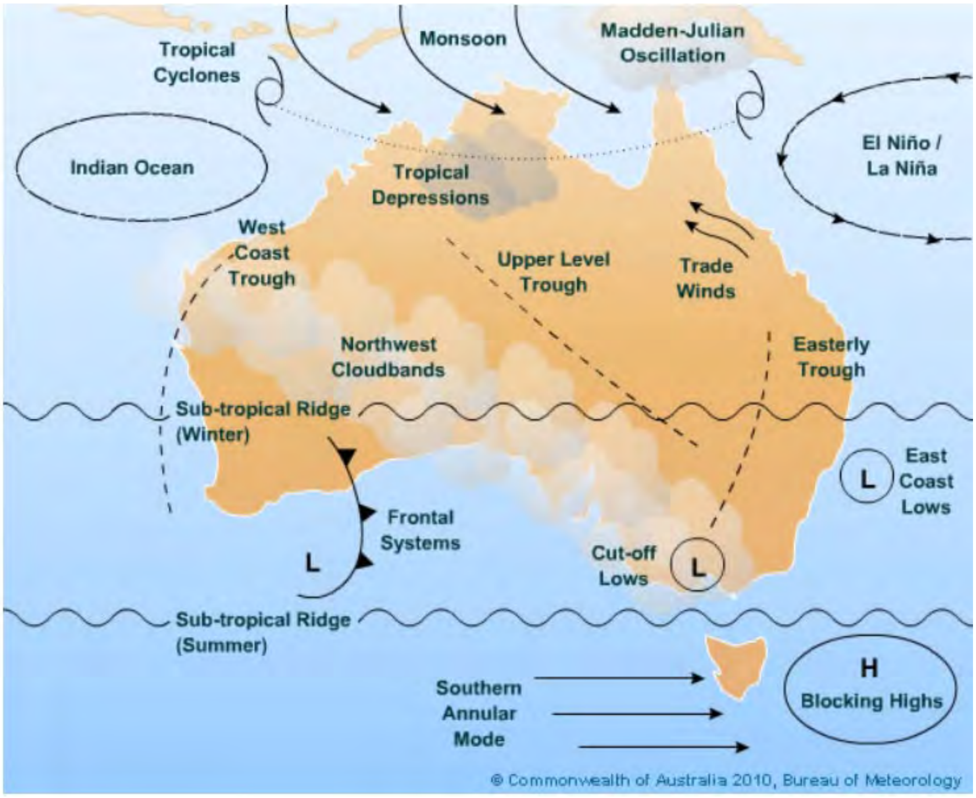

FIGURE 3-1 AUSTRALIAN CLIMATE DRIVERS (BOM 2010)

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

3.3 Coastal Oceanography

3.3.1 Regional Currents

Oceanographic conditions at the proposed facility and within Exmouth Gulf are driven by the variations in climate described previously and astronomical tides and ocean currents such as the Leeuwin Current.

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

Figure 3-2 illustrates the main surface currents of the region (DEWHA 2007). All of these current systems experience strong seasonal to inter-annual variations, which indicate that they are likely to be influenced by climate change over the coming decades. Although there are strong seasonal trends, there are also periods when strong winds can cause intermittent reversals of these currents, with occasional weak upwellings of colder deep water. The Ningaloo Current is one such current that can strengthen in summer and cause upwelling on the shelf.

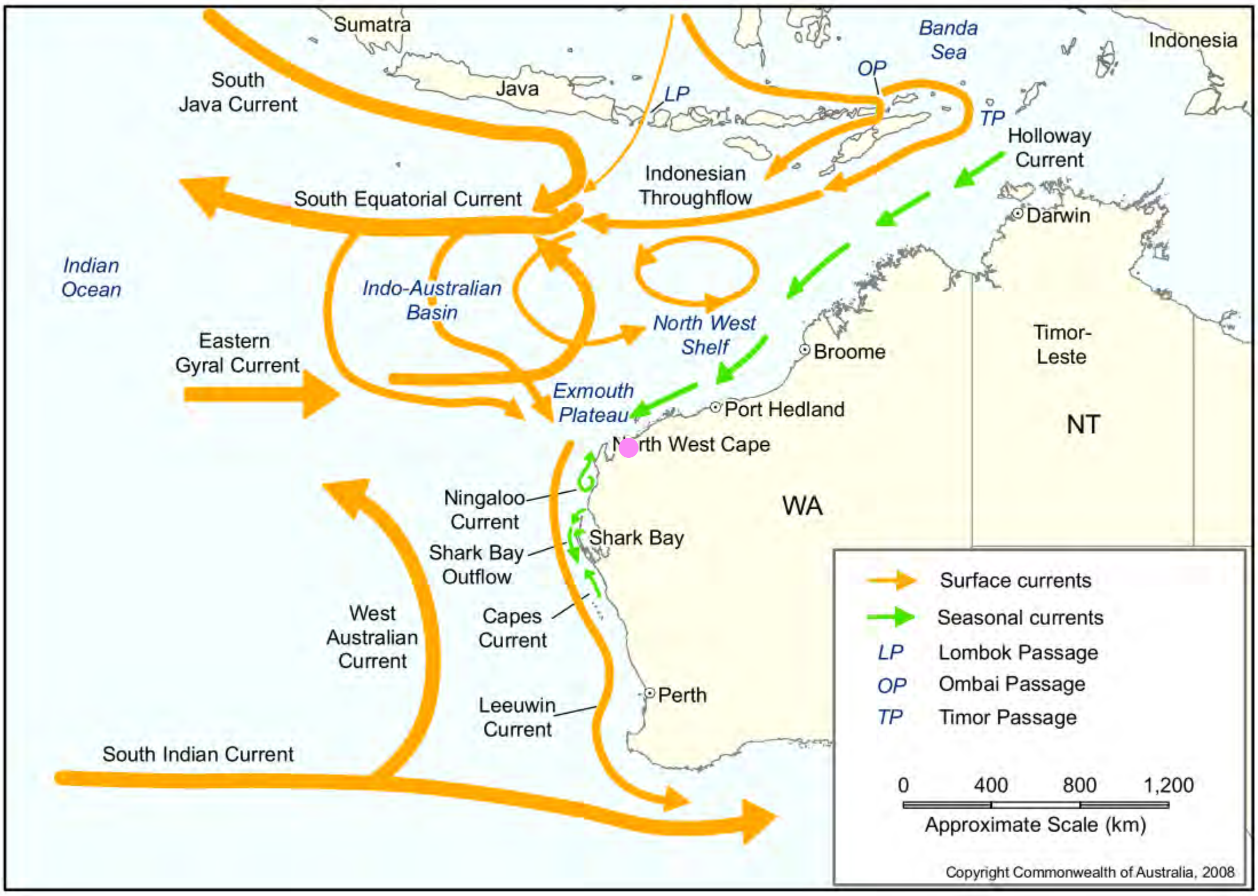

FIGURE 3-2 REGIONAL OCEANOGRAPHY AND CURRENTS (DEWHA 2007). APPROXIMATE FACILITY LOCATION INDICATED BY THE PINK DOT

3.3.2 Water Levels

The astronomical tide along the coast and within Exmouth Gulf is semi-diurnal (i.e., two high and two low tides daily) with a slight diurnal inequality resulting in one higher tide and one lower tide per day.

Tidal plane data is presented below from the following sources:

- Royal Australian Navy 'Australian National Tide Table' (ANTT) – This data is considered the most reliable and uses a tidal datum epoch of 20 years which covers 1992 – 2011;
- RPS – Performed an analysis on existing tidal constituent datasets in the area to produce a site-specific set of constituents which were used to derived tidal planes (RPS 2017); and
- Water Technology (WT) – Tidal planes were derived from measured water levels collected by University of Western Australia (UWA) or Water Technology. Data had varying degrees of accuracy and should be considered indicative only. The datum is MSL.

The tidal planes are presented in Table 3-1 and the water level monitoring locations are displayed in Figure 3-3. The mean spring tide range (0.89 m AHD) at Exmouth is the same as Onslow, whilst the range between the Highest Astronomical Tide (HAT) and the Lowest Astronomical Tide (LAT) is slightly smaller at Exmouth. This demonstrates the general consistency of tidal height magnitude along the coast and within Exmouth Gulf.

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

TABLE 3-1 ASTRONOMICAL TIDAL PLANES (M AHD); WATER TECHNOLOGY (WT) VALUES ARE TO M MSL

Location	Data Source	Data Length	HAT	MHWS	MHWN	MSL	MLWN	MLWS	LAT
Ashburton Jetty	RPS	~	1.20	0.99	0.16	0.07	-0.05	-0.96	-1.18
Exmouth	ANTT	20 years	1.39	0.89	0.29	-0.01	-0.31	-0.91	-1.51
Onslow/Beadon Creek	ANTT	20 years	1.49	0.89	0.29	-0.01	-0.31	-0.91	-1.61
Locker Point/Outfall	WT/UWA	9 months	1.3	0.9	0.2	0.0	-0.2	-0.9	-1.1
Urala Creek North	WT	2 months	1.2	0.8	0.2	0.0	-0.2	-0.8	-1.1
Urala Creek South	WT/UWA	12 months	1.1	0.75	0.2	0.0	-0.2	-0.75	-1.1

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

FIGURE 3-3 WATER LEVEL MONITORING LOCATIONS

In addition to tidal water level variations, longer term changes in water levels at the site occur in response to local weather conditions including tropical cyclones, seasonal climatology and global climate forces. A summary of the period and magnitude of these changes is provided in Table 3-2.

TABLE 3-2 MAJOR PROCESSES IMPACTING SEA LEVEL VARIABILITY

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

3.4 Coastal Features and Habitats

3.4.1 Coastal Areas

The coastal area adjacent to the proposed Ashburton Salt Project is in the northeast section of the Urala Creek coastline which lies within the broader Exmouth Gulf. The Exmouth Gulf is an inverse mesotidal estuarine embayment (tidal range of 1.6 m) with limited riverine inputs (Brunskill et al. 2001). The Gulf is open to the north and covers an area of approximately 2,200 km^2, with a width of about 40 km and length of about 80 km. The water depth outside the shallow intertidal waters ranges from about 5 m in the south-east to about 20 m in the north and west.

Nearshore waters in the vicinity of the Project appear to have elevated turbidity near tidal creek outlets. During periods of increased creek discharge, the release of nutrients from these creeks can play an important role in stimulating primary productivity. Nearshore waters also experience coastal trapping, which is evidenced by the turbid coastal boundary layer adjacent to nearshore areas (Brewer et al. 2007).

3.4.2 Ashburton River

The Ashburton River is one of the largest rivers in the Pilbara region, fed by numerous ephemeral tributaries that generally only flow during large rainfall events. Flows are highly seasonal and variable, with most flow following rainfall during January to March and peak flows in February because of major storms or cyclones.

Long term average nutrient loads from the Ashburton River catchment are estimated to be of the order of 405 tonnes Nitrogen (N) per year and 134 tonnes Phosphorus (P) per year (URS 2010).

3.4.3 Tidal Creeks

The Urala Creek coastline is characterised by major and minor tidal creeks. The tidal creeks generally have unvegetated bottom sediments, likely a result of the strong currents and turbid, saline waters present in these waterways. Historical monitoring indicated that nitrogen in the tidal creeks is predominantly organic, with low levels of dissolved inorganic nitrogen. Water that leaves the tidal creeks on the ebb tide contains elevated nutrients and organic materials and tends to spend at least 24 hours in the shallow bank areas, causing coastal trapping of nutrients and organic matter offshore (Biota Environmental Sciences 2005).

The tidal creeks facilitate complex tidal inundation in intertidal areas and salt flats due to the low gradient. The relatively flat expansive areas of the upper intertidal zone and supratidal salt flats become inundated by shallow (<10 cm) tidal sheet flow during high spring tides or storms surge events. This phenomenon is more apparent during March and April when the seasonal water level trend is elevated, as described in *Marine, Coastal and Surface Water Existing Environment* (Water Technology 2021).

A description of the monitoring undertaken is described further in *Marine, Coastal and Surface Water Data Collection* (Water Technology 2021).

3.4.4 Mangroves

Mangroves occur on the western coastal fringes of the mud flats in areas that are generally inundated twice daily by normal tides and submerged approximately 5 to 50% of the time. There are seven species of mangroves in the Pilbara bioregion, with six species (from four families) recorded in the vicinity of this project (Biota Environmental Sciences 2005, AECOM 2021). Mangrove habitat is typically located above mean sea level (MSL) while below mean high water springs (MHWS). The typical elevation range for mangroves in the project area is approximately 0 to 0.7 m above MSL for the lower to upper range of the mangrove zone.

3.4.5 Cyanobacterial Mats

Mapping indicates extensive areas of cyanobacterial mats throughout the Gulf. These mats occur on the intertidal area behind the mangroves before elevation increases into the salt flat areas (Lovelock et al. 2010). Cyanobacterial mats form in a narrow tidal range of slow-moving currents and stable sediments that are submerged approximately 1 to 3% of the time. Algal mat habitat is typically located above the range of mangrove habitat with the upper limit approximating highest astronomical tide (HAT). The typical elevation range is approximately 0.8 to 1.1 m above MSL for the lower to upper range of the algal mat zone. These areas are usually nitrogen limited (Adame et al. 2012).

Nitrogen and carbon from cyanobacterial mats would act as an ongoing nutrient source to the ecosystem, as nutrients are exported when they are inundated 1-3% of the time. They will also contribute to nutrient exports during intermittent rainfall events.

3.4.6 Salt Flats

Salt flats extend approximately 80 km along the coast from Sandalwood Peninsula in the south to Locker Point in the north and range in width from approximately 6 to 12 km. Salt flats occur landward of the algal mats in the area where tidal inundation ceases and salinity levels become too great for cyanobacteria to tolerate (Biota Environmental Sciences 2005, AECOM 2021). Water discharges onto the salt flats occur from the catchment via a number of overland flow paths and poorly defined drainage paths (*Surface Water Assessment and Modelling,* Water Technology 2021). During cyclonic events, rainfall and catchment sourced water accumulates on the salt flats and the area is inundated by seasonal spring tides in March/April, and also occasionally inundated by marine waters during storm surge events.

3.5 Nutrient Pathways, Sources and Sinks

A description of nutrient pathways, sources and sinks is provided below.

3.5.1 Tidal Creeks and Flats

Tidal creeks are a key nutrient pathway and different habitats within surrounding tidal flats act as sources and/or sinks for nutrients. The two key habitats within the tidal flats responsible for nutrient pathways are mangroves and algal mats, with salt flats providing more sporadic nutrient pathways following storm surge or flooding events. Tidal flows and tidal inundation are the main factors that maintain mangroves and algal mats, and tidal creeks act as conduits of tidal flows to and from tidal flats. Nutrients are largely recycled within the creeks, with limited exports to the wider Exmouth gulf (Brewer et al 2007).

Monitoring indicated a nutrient gradient which showed the upstream-downstream nutrient cycling process produces a distinct longitudinal pattern in the creek ecosystem (*Marine, Coastal and Surface Water Data Collection*, Water Technology 2021). This indicates that nutrients in tidal creeks can remain trapped upstream due to limited tidal flushing, and when the system is flushed the nutrient rich water is likely to remain nearshore due to coastal trapping.

The key habitats responsible for nutrient pathways surrounding the project area are discussed in further detail below.

3.5.1.1 Mangroves

Primary producers, including mangroves and cyanobacterial mats, can sequester carbon from the atmosphere through photosynthesis. Much of the carbon fixed by mangroves is retained as standing biomass, particularly in oligotrophic, arid environments (Alongi et al. 2002). Organic matter and carbon rich sediment from the catchment is also stored in soils and sediments of mangrove ecosystems. Plants and detritus from mangrove ecosystems support herbivores and detritivores, which are in turn consumed by carnivores, thus supporting a complex food web. Most of the organic matter from floral and faunal remains and excretory products from animals is broken down by bacteria and enters the microbial cycle. Microbial production and cycling is likely to be the primary carbon sink in mangrove systems, however Adame et al. (2010) found that mangroves can act as a net carbon source in dry environments such as the Ashburton region.

Nitrogen is largely recycled in mangrove systems, with little tidal export or import (Adame et al. 2010, Boto and Bunt 1981). Adame and Lovelock (2011) found values of nitrogen exchange with the tide are highly variable, with dissolved nitrogen exchange rates ranging from an export of -5.0 g N m^{-2} $year^{-1}$ to an import of 1.6 g N m^{-2} $year^{-1}$, with an overall mean dissolved nitrogen exchange of -0.58 ± 1.64 g N m^{-2} $year^{-1}$ (a net import of dissolved nitrogen) (Adame and Lovelock 2011). There is a tendency for nitrogen export to occur with high tidal amplitudes (> 2.4 m) and with high nitrogen concentrations in floodwaters (Adame and Lovelock 2011).

A study by Boto and Wellington (1988) found that the mangrove forests were in a finely balanced state with respect to primary macronutrients and found that they were efficiently recycled within the system. Overall, it was found there was a net import (sink) of nitrogen into the system of 1.45 g N m^{-2} y^{-1} (or 0.16 mg N m^{-2} h^{-1}).

The monitoring undertaken in the Project site indicated that there were low levels of particulate nutrients in the tidal creeks which could indicate that mangroves in the area do not export a large amount of particulate litter.

It is hypothesised, based on water levels, water quality monitoring and literature that nutrients in mangroves are largely recycled in the project area and act as minor sink of nitrogen.

3.5.1.2 Cyanobacterial Mats

Cyanobacterial (or algal) mats fix nitrogen from the atmosphere and are an important component of the coastal nitrogen cycle (Paling and McComb 1994, Paling et al. 1989). Cyanobacterial mats in Exmouth Gulf have been shown to fix nitrogen both during the day and at night, with higher rates during the day (Adame et al. 2012). Further, cyanobacterial mats from the low intertidal zone have been shown to have higher nitrogen-fixation rates than those at higher intertidal elevations, which reflects the higher chlorophyll and phaeophytin observed in closer to intertidal areas and with higher moisture content (Adame et al. 2012).

Nitrogen is exported from cyanobacterial mats primarily as organic nitrogen to coastal waters during tidal inundation, with an estimated export of 68 kg of nitrogen per hectare per year for the Pilbara coast (Paling and McComb 1994). The export rate of 68 kg/ha/yr includes the predicted rate of inundation, whilst the leaching rates of 3 to 7 mg N $m^{-2}h^{-1}$ do not. Relatively similar rates of nitrogen export have been estimated for cyanobacterial mats elsewhere (e.g., Stal et al. 1984 estimated up to 24 kg/ha/yr for the German coast and Joye and Paerl 1994 estimated between 20 to 280 kg/ha/yr in California).

In contrast to normal conditions (Paling and McComb 1994), in wet conditions cyanobacterial mats become completely functional and assimilate nutrients from floodwater after being submerged for some time (Adame et al. 2012). This results in a net removal of nutrients from floodwaters (Adame et al. 2012) at such times.

Tidal inundation is the key nutrient pathway whereby dissolved and particulate organic matter is liberated from algal mats and exported with the tide. This creates a diurnal trend in carbon, phosphorus and nitrogen concentrations in tidal creeks. Concentrations in creeks decrease on the flood tide as less saline oceanic water flows into the system, dilutes in-water nutrient concentrations, interacts with the mangroves and algal mats releasing nutrients into the water. The tide then recedes allowing concentrations to increase in the creeks until the next flush from the flood tide occurs. Nitrogen exported to adjacent coastal systems support the growth of primary producers (seagrass and macroalgae) and the complex coastal food web (CALM 1994, Oceanica 2006).

3.5.1.3 Bare Intertidal Mudflats

Bare intertidal mudflats which exist between the mangroves and algal mats may also play a minor role in the nutrient pathway process, however exchange rates have not been studied extensively. Adame et. al. postulated that wet bare sediments can actually uptake nitrogen (become a sink) at a rate of -0.24 mg N m2 h-1, whilst Brunskill (2001) hypothesised that bare sediment could leach nutrients (source). The differing conclusions is likely due to different spatial context and ‘sediment’ classification between the studies. Regardless both studies estimated low contributions whether it be as a source or sink, it can therefore be surmised that bare intertidal mudflats contribute minimally to the nutrient budget for the project area. Therefore, it is not explicitly included in the nutrient budget, however nitrogen losses from this habitat have been accounted for conservatively in the modelling to ensure that any post-development nutrient loss from this habitat is accounted for in the impact assessment.

3.5.2 Overland Flows

Overland flows, although infrequent (due to sporadic heavy rainfall), are considered to be a nutrient pathway. Post rainfall monitoring data showed significant levels of phosphorus, nitrogen and carbon in surface water samples, with a mean nitrogen concentration of 1.1 mg/L (one sample was omitted due to it resembling a slurry). This is significantly greater than background concentrations in tidal creeks, and highlights that during rainfall events overland flows can provide a significant pulse of nitrogen, carbon and phosphorus.

Overland flow paths connect to extensive salt flats and in large storm events produce overland flows into tidal creeks and the coastal marine environment, providing an intermittent surge of nutrients that result in increased productivity. In general, it is agreed that catchment derived sources of nitrogen are less important in tidal creeks as input only occurs during extreme events (versus daily tidal inundation), however in low nutrient environments they have greater value (Harris 2001). During smaller rainfall events with an ARI of 5 years or less, these overland flows are unlikely to reach tidal creeks, however under large events such as cyclones they will be delivered to creeks, with some coastal trapping followed by transportation further into Exmouth Gulf.

3.5.2.1 Salt Flats

Salt flats occur between the algal mats and hinterland and experience infrequent inundation and wetting due to seasonal spring tides, storm surge or flooding. The salt flats have a salt crust which causes the water when flooded to be hypersaline. They do not directly produce significant nutrients but may receive and store nutrients from water and entrained sediments during infrequent inundation events.

The portion of salt flats closest to the coastline are inundated by seasonally high spring tides during March and April, however this shallow tidal inundation does not reach salt flats areas closest to the hinterland. The coastal portion of the salt flats are likely store nutrients from the overlying tidal waters, as small areas of ponded water remain after the receding tide and eventually evaporate, leaving nutrients in the salt crust.

The hinterland side of the salt flats may receive nutrients from overland flows during minor to moderate rainfall events which occur every 1-3 years, however during this time surface runoff and associated overland flows are not sufficient to connect to tidal creeks. During these smaller rainfall events, small levels of nutrients from further up in the catchment may be stored in the salt crust. During more significant rainfall events (once every 5-10 years), nutrients stored in salt flats are liberated and mixed with nutrient rich overland flows from the hinterland. During these events, overland flows connect with tidal creeks - providing a pulse of nutrients into nearshore waters with some coastal trapping, followed by further transportation into Exmouth Gulf..

Salt flat sediments were sampled in the project area in 2019 and analysed for chlorophyll-a and pheophytin and microscopically assessed for the presence of cyanobacterial cells (AECOM 2021). The results are summarised in Table 3-3 which show very low chlorophyll-a and phaeophytin levels in the salt flats compared to the algal mats. The average chlorophyll-a level for the combined algal mat and peripheral algal mat areas is 275 mg/m^2 (AECOM 2021). These results support the assumption that the salt flats do not support significant cyanobacterial growth and therefore do not generate significant amounts of nutrients themselves. Whilst some minor amounts of chlorophyll-a and phaeophytin were detected in the salt flat samples these were very low compared to the algal mat samples (salt flat levels were approximately 7 – 15% of levels detected in the core algal mat areas). The minor amounts of chlorophyll-a and phaeophytin detected in the salt flat samples could be due to small amounts of microalgae present in the salt flat. These low levels of chlorophyll-a and phaeophytin in the salt flat samples indicate that the salt flat is highly unlikely to be significant generator of nutrients compared with the algal mat areas.

TABLE 3-3 SUMMARY OF AECOM SAMPLING RESULTS FOR ALGAL MATS AND SALT FLATS

Sample	Chlorophyll-a (mg/m^2)	Phaeophytin	Microscopic analysis
Algal mat - core	414 ± 77	166 ± 29	Distinct dark green mat structure present. Main algae species were *Microcoleus* sp. and *Lyngbya* sp. and Oscillatoria sp. as noted from other Pilbara algal mat areas. Also present were some additional blue green algal species including *Schizothrix* sp. *Calothrix* and *Cyanothece* sp, and the diatom, *Navicula* sp.

Sample	Chlorophyll-a (mg/m^2)	Phaeophytin	Microscopic analysis
Algal mat - peripheral	137 ± 22	133 ± 27	The presence of a distinct mat became less apparent in peripheral areas and the diversity of algae species was reduced with *Oscillatoria* sp. and *Lyngbya* sp. being dominant.
Salt flat	29 ± 5	25 ± 5	No algae/cyanobacteria observed. The minor amounts of chlorophyll-a and phaeophytin detected in the salt flat samples could be due to small amounts of microalgae present in the salt flat. These low levels of chlorophyll-a and phaeophytin in the salt flat samples indicate that the salt flat is highly unlikely to be significant generator of nutrients compared with the algal mat areas.

Post rainfall sampling was also conducted in 2019 and 2021 whereby surface water samples were collected from ponded water in the bare salt flats, near the algal mats, within overland flows paths, claypans and hinterland sites (*Marine, Coastal and Surface Water Data Collection,* Water Technology 2021). Samples collected within bare salt flat sites generally had lower levels of nitrogen, compared to the inland and algal mat sites which had higher dissolved nitrogen concentrations. This supports the conceptual model assumption that salt flats do not generate significant nutrients, and act primarily as a nutrient pathway that conveys nutrients from overland flows and tidal inundation.

3.5.2.2 Terrestrial Nutrient Runoff (Overland Flow)

Brunskill (2001) investigated interactions between Exmouth Gulf waters and coastal runoff and estimated that terrestrial nutrient runoff is relatively low. Brunskill (2001) estimated that total nitrogen supply was approximately 0.8 mmol N (0.012 g N) per square metre of the Gulf per year. As discussed previously there is large inter-annual variability in runoff volumes which would impact annualised nitrogen estimates. Considering this, 0.8 $mmol/m^2/year$ as estimated by Brunskill (2001), converted to 0.12 kg/ha/year, is considered suitable for characterising overland flow nitrogen contributions from areas higher up in catchment beyond the intertidal zone and salt flats areas.

3.5.3 Offshore Waters - Upwelling and Tidal Exchange

Two key processes deliver nutrients into Exmouth Gulf from offshore waters:

- Upwelling - an intermittent or “pulse-like” process whereby deep, cold water rises to the surface, bringing with it nutrient rich waters. Essentially, winds blowing across the ocean surface push water away. Water then rises up from beneath the surface to replace the water that was pushed away. This phenomenon is known as Ekman transport and the process is known as “upwelling.” Conditions are optimal for upwelling when winds blow along the coast; and
- Tidal exchange - the regular (daily) ebb and flood of tides providing water from offshore sources and removing water from nearshore sources, which has a “mixing effect” combining nutrients from offshore sources into nearshore water.

The two nutrient sources work in tandem with small daily loads delivered from offshore waters due to tidal exchange, in addition to large scale intermittent nutrient pulses related to upwelling.

3.5.3.1 Upwelling - Regional Information

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

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

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

3.5.3.2 Upwelling - Local Data

The monthly water quality monitoring as outlined in *Marine, Coastal and Surface Water Data Collection* (Water Technology 2021) identified a significant nutrient pulse on the 9th of January 2019 where total nitrogen concentrations exceeded 1 mg/L at Fly Island. This pulse was not accompanied by rainfall however it did occur during a spring tide (Figure 3-7).

Water level measurement commenced in January 2019 as outlined in Figure 3-4 below.

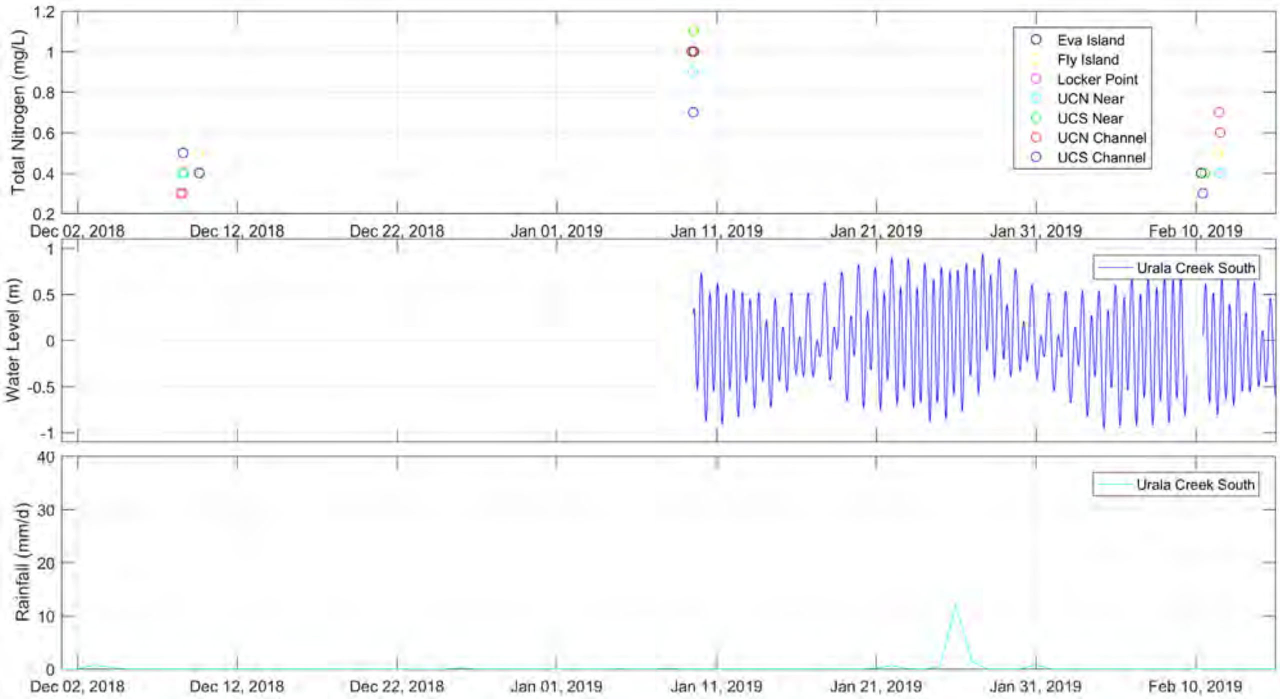

FIGURE 3-4 JANUARY 2019 NUTRIENT PULSE

The analysis below assesses sea surface temperatures and winds over the days prior to the measured nutrient pulse and concludes that the persistent south-westerly winds would have strengthened the Ningaloo counter current and induced Ekman transport resulting in the upwelling of nutrient rich waters. During this time cold surface waters were also observed travelling into Exmouth Gulf from the south, also indicative of an upwelling event.

Wind roses over the 14 days prior to the January nutrient pulse are shown for Learmonth (which is the closest station to the Ningaloo Current), and Barrow Island (an offshore location north of the project site) in Figure 3-5. The location of the Learmonth and Barrow Island weather station are also shown in Figure 3-6. The wind roses show strong wind speeds (> 10 m/s) at both sites. The sustained wind speed and south-westerly directions at Learmonth are likely to have strengthened the Ningaloo counter current and induced Ekman transport along the Cape Range Peninsula resulting in the upwelling of nutrient rich waters, whilst the westerly winds further north at Barrow Island combined with tidal forcing would enable these upwelled nutrient rich waters be transported nearshore in Exmouth Gulf.

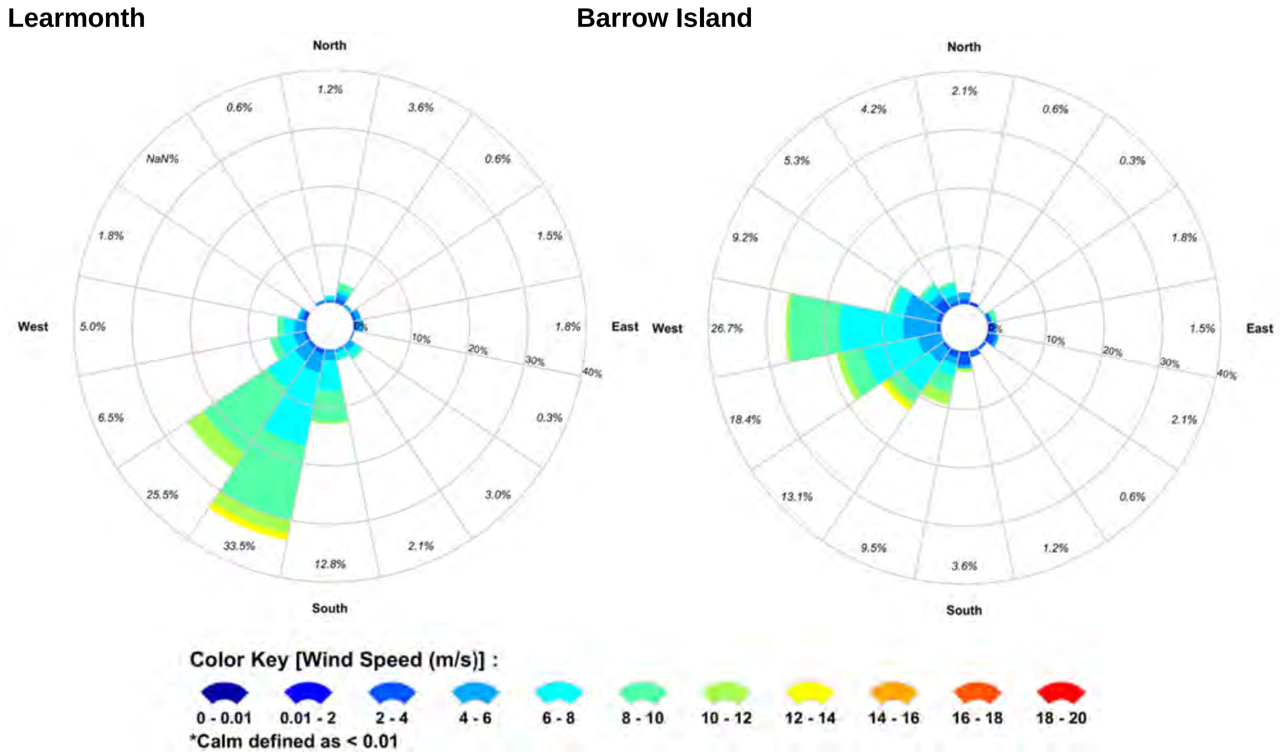

FIGURE 3-5 MEASURED WINDS AT BARROW ISLAND AND ONSLOW FOR THE FOURTEEN DAYS PRECEDING THE NUTRIENT PULSE (26TH DECEMBER 2018 TO 9TH JANUARY 2019)

In addition to a review of winds, ocean currents and sea surface temperatures were also investigated. Analysis of the IMOS Ocean Current database (IMOS 2020) showed that in the days prior to the measured nutrient pulse on the 9th January 2019, cold surface waters were observed flowing into Exmouth Gulf as shown in Figure 3-6. This observation is indicative of upwelling and the timing aligns with historical observations along the Western Australia coastline which have shown that during summer, cold water, suggestive of upwelling, has been periodically observed on the continental shelf (Simpson and Masini 1986; Taylor and Pearce 1999; Wilson et al. 2002).

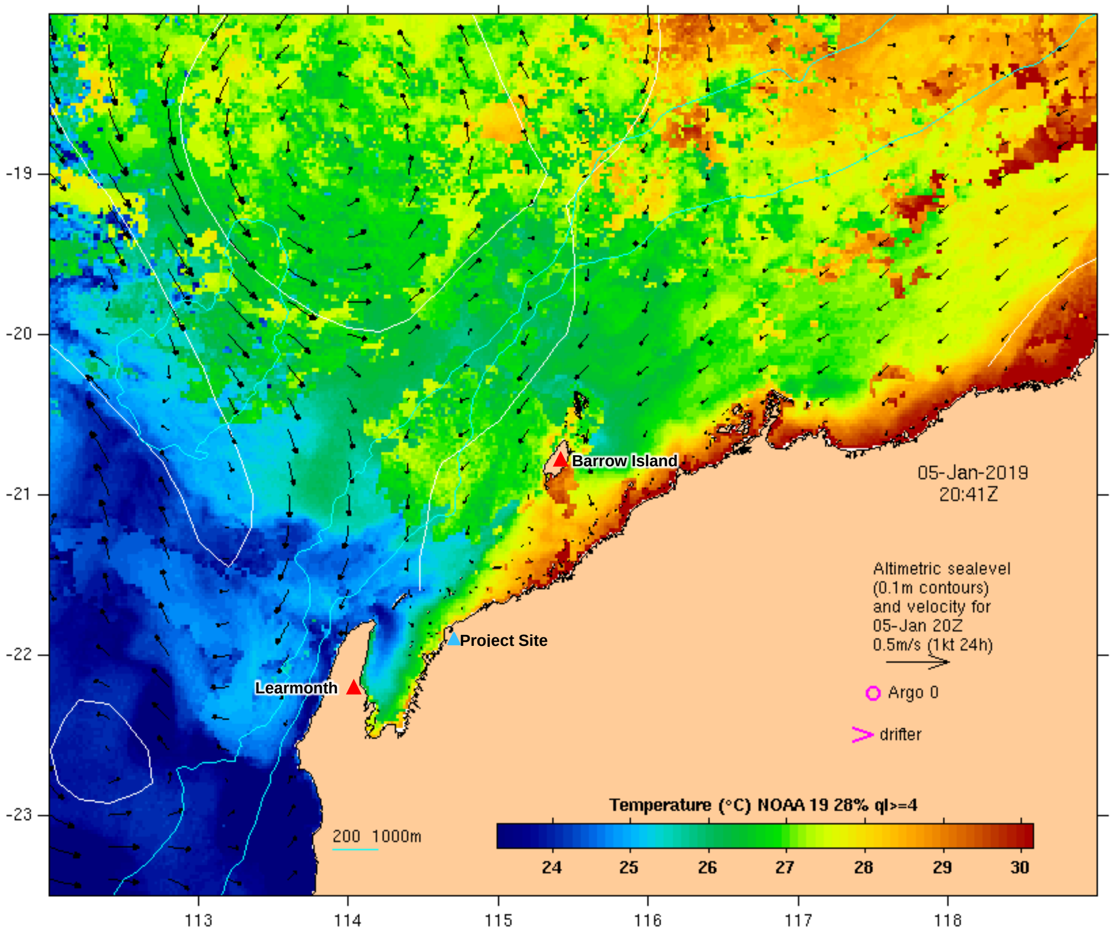

FIGURE 3-6 SEA SURFACE TEMPERATURES ON 5TH JANUARY 2019 (SOURCE: (HTTP://OCEANCURRENT.IMOS.ORG.AU/INDEX.PHP)

There was also a secondary pulse of nitrogen observed in August 2019, which was not accompanied by rainfall. The wind conditions during the August pulse were not conducive to upwelling from the Ningaloo Current, as winds were from the northeast however it could be due to the interaction of the southward flowing Leeuwin current and transient local effects of offshore eddy advection, combined with a spring tide. Consequently, the August event is likely due to a combination of metocean conditions that are independent of rainfall.

3.5.3.3 Quantification of Nitrogen from Upwelling

In order to quantify the contribution of the upwelling event to the project area an estimation was performed in this study, using the measured nitrogen data and the volume of water during three different tidal levels and two different calculation areas. The tidal levels were lowest astronomical tide (LAT), Australian Height Datum (AHD) and highest astronomical tide (HAT) which represent the lower, middle and upper limits of the water volume within the calculation areas. The average nitrogen concentration from four sampling sites (which had the most consistent data) was applied to the three volumes of water representing LAT, AHD and HAT. The monitoring sites and areas (local and regional area) used in the estimation are displayed in Figure 3-7.

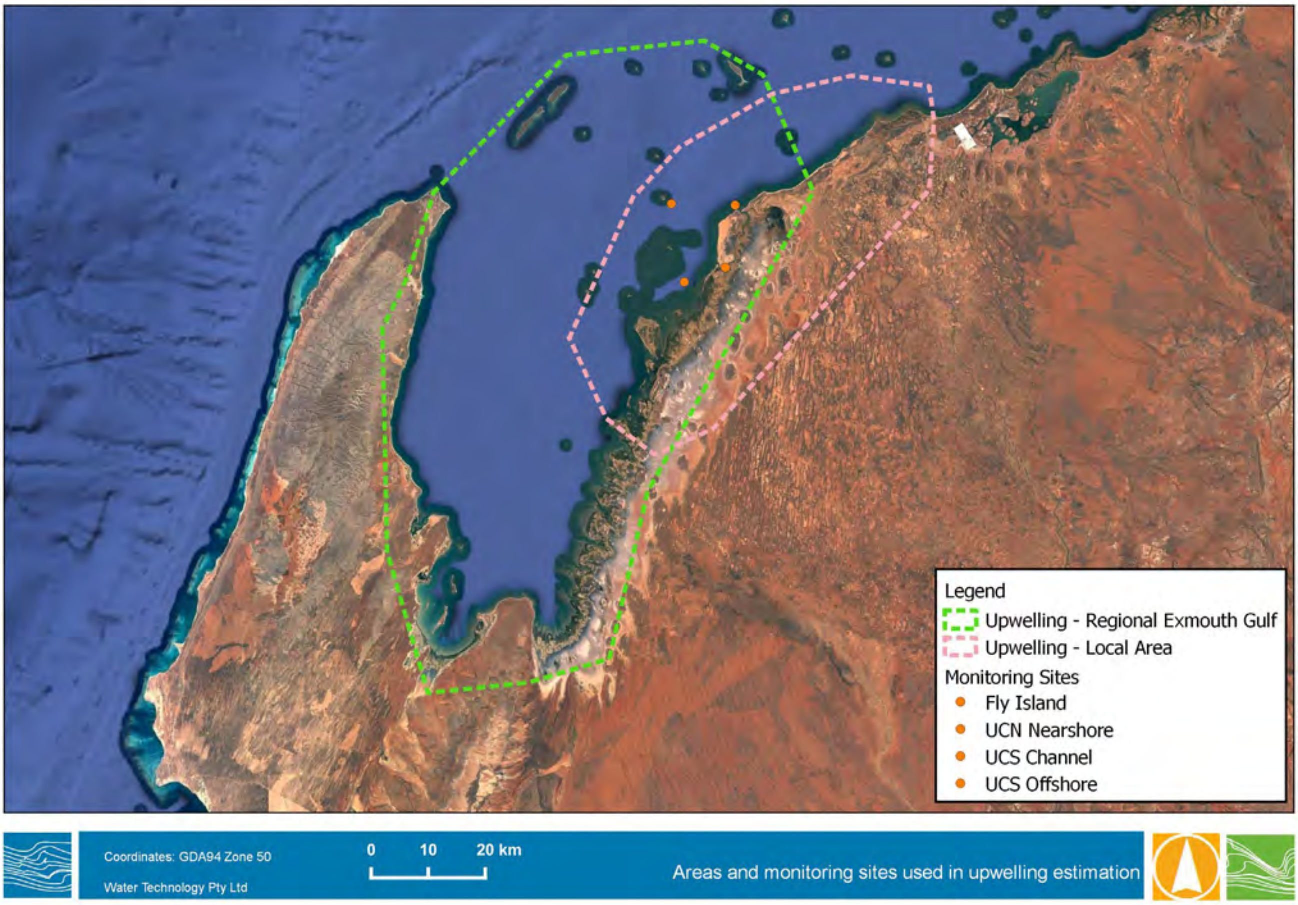

FIGURE 3-7 AREAS AND MONITORING SITES USED IN THE UPWELLING ESTIMATION

The results of the nitrogen estimation for the local area (which approximately represents the local model extent) is shown in Figure 3-8. This timeseries show the calculated mass of nitrogen in the local area, based on measured nitrogen data and the volume of water at three tidal stages. The upwelling event in January is clearly observable, as well as a secondary pulse in August which was not accompanied by rainfall.

Based on the estimation, the January upwelling event could have contributed an additional 1,500 to 2,200 tonnes of nitrogen to the project area, whilst the August event potentially contributed between 1,100 to 1,800 tonnes. These values were derived by subtracting the mass of nitrogen in the pulse month from the mass in the preceding month. Additionally, Figure 3-8 also shows that at any one time there is more than 1,000 tonnes of nitrogen available in waters within the local area. These numbers support the conclusions by the literature (Meekan et al. 2006, Xu. Et al 2016, Hanson et al.2005) that Exmouth Gulf is reliant on nutrients from upwelling and eddies.

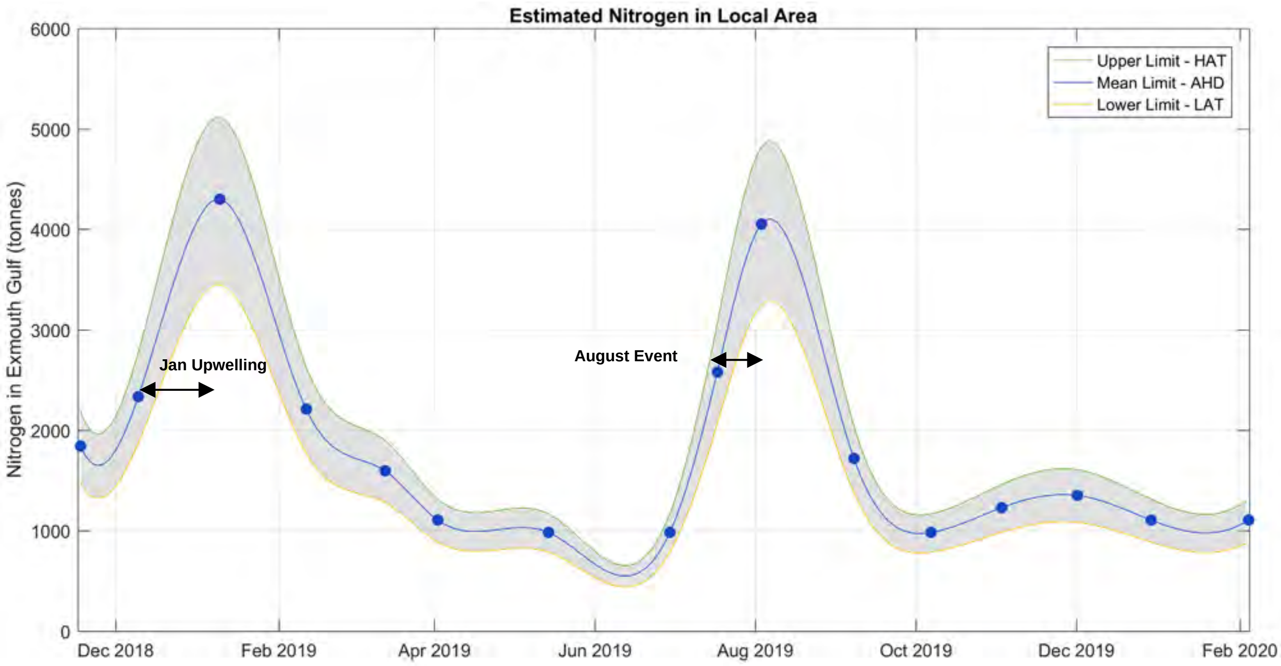

FIGURE 3-8 ESTIMATED NITROGEN IN PROJECT AREA

The same methodology was applied to the broader Exmouth Gulf (shown in Figure 3-7 as 'Upwelling – Regional Exmouth Gulf), with the resultant nitrogen mass throughout the year shown in Figure 3-9. Nitrogen increases are in the order of 9,100 to 11,800 tonnes of nitrogen for the January event and 6,800 to 8,900 for the August event. This is equivalent to a combined contribution of 15,900 to 20,700 tonnes from upwelling and offshore sources.

For the regional estimation it is assumed upwelling influences are observed equally throughout the entire Gulf and we have extrapolated a small set of data over a large area, however in reality the northern portion of the Gulf maybe be more affected by nutrient rich waters related to upwelling, compared to the southern areas. In order to be conservative, we have reduced the nitrogen event totals by 50% to better represent nitrogen concentrations which could be spatially variable within the wider Exmouth Gulf. This is equivalent to 7,950 to 10,350 tonnes per annum (tpa).

For estimation of local contribution to nearshore waters the lower estimates from the recorded 2019 upwelling events were used 1,500 tonnes for January and 1,100 tonnes for August, providing a total of 2,600 tpa.

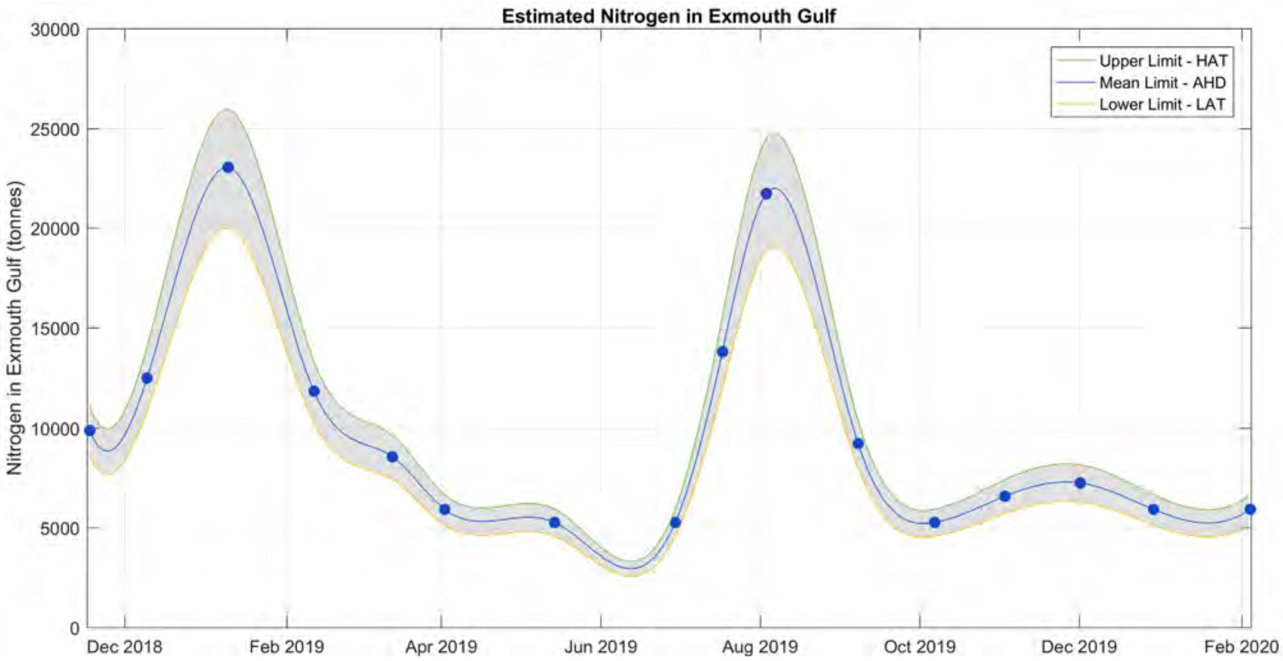

FIGURE 3-9 ESTIMATED NITROGEN IN EXMOUTH GULF

The literature, monitoring, and analysis shows there is a key connection between Exmouth Gulf biological productivity and offshore nutrient delivery as the productivity on the shelf is, to a large extent, dependent on the offshore currents, upwelling and eddy formation (Zhang 2016, Xu et al. 2016).

The Ashburton Solar Salt development will not have any impact on the seasonal and oceanographic processes that cause upwelling given these processes are regionally derived.

3.5.3.4 Quantification of Nitrogen from Tidal Exchange

A previous estimate in Oceanica (2006) quantified nitrogen contribution from offshore sources by looking at the twice daily tidal exchange in Exmouth Gulf and estimated that the annual exchange of water in the shallows is ~7.71×10^{11} m^3. This annual volume of tidal exchange was then combined with a nearshore measurement of dissolved inorganic nitrogen (DIN) (~9.4 µg/L) to derive an annual load of 7,400 tpa of nitrogen from offshore waters. This estimate focuses on the daily nitrogen contribution from offshore waters as opposed to the event-based estimation performed above.

3.5.3.5 Selection of Conservative Value for Offshore Nitrogen Contribution

Tidal exchange and upwelling work in tandem with small daily loads delivered from offshore waters due to tidal exchange, in addition to large scale intermittent nutrient pulses related to upwelling and eddies. A flow diagram of these two inputs is shown in Figure 3-10. It should be noted that although there is daily tidal exchange between offshore waters and Exmouth Gulf (as shown by the double ended arrow) Oceanica (2006) estimated that there is a net import of 7,400 tpa of nitrogen from offshore.

To ensure conservatism in the nutrient budget, the Oceanica (2006) estimate of 7,400 tpa of nitrogen input from tidal exchange has been ignored. We have selected the lower value from the upwelling estimation (7,950 tpa for the entire Exmouth Gulf and 2,600 tpa for the project nearshore waters see Section 3.5.3.3) as conservative values for the annual offshore nitrogen contribution (essentially reducing the offshore contribution of nitrogen by around half given tidal exchange has been ignored). This approach will underestimate nitrogen loads from offshore sources and therefore overestimate the proportion of nutrients provided to Exmouth Gulf from terrestrial and intertidal sources.

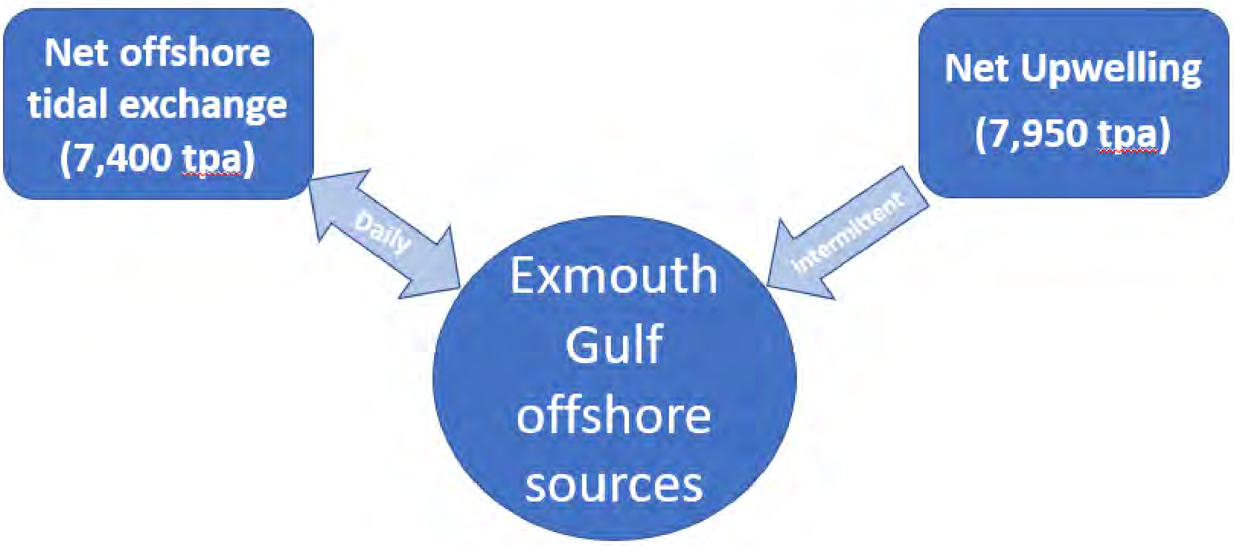

FIGURE 3-10 OFFSHORE NITROGEN IMPORT SOURCES TO EXMOUTH GULF

3.5.4 Conceptual Nutrient Pathway Model

The nutrient pathways described above have been incorporated into a conceptual nutrient pathway model (diagrammatic representation), that details sources and sinks (see Figure 3-11). The conceptual model has been used to inform numerical modelling and assess potential impacts from the proposed development on nutrient pathways and the nutrient budget.

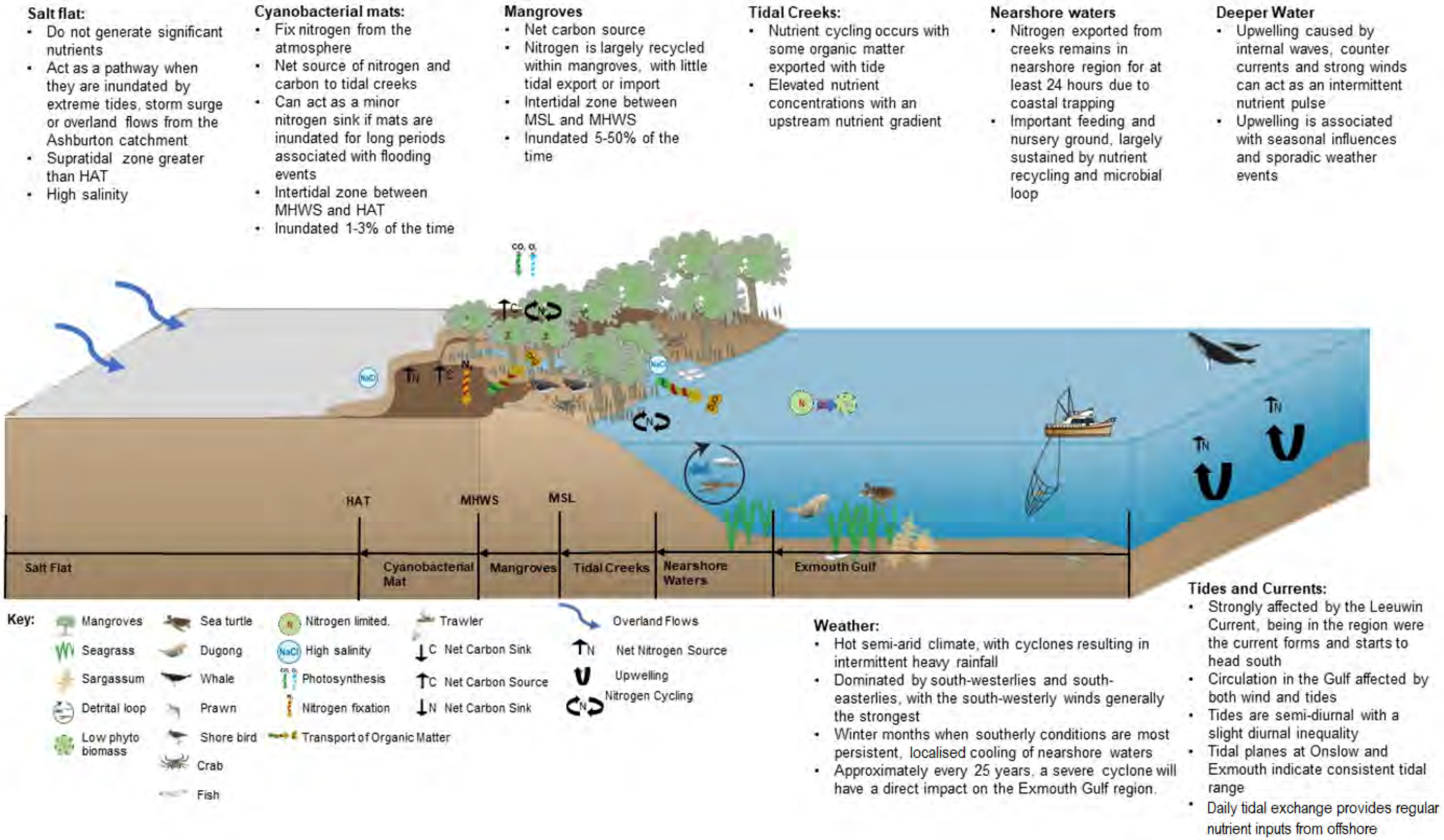

FIGURE 3-11 CONCEPTUAL NUTRIENT PATHWAY MODEL

3.5.5 Nutrient Budget

3.5.5.1 Overview

To add context to the conceptual nutrient pathway model, a nitrogen budget was developed based on literature values, laboratory analysis and mapping of key habitats (refer to Figure 3-12). The mapping is an amalgamation of regional mapping undertaken in 2005 by Biota, and more recent mapping by AECOM (2021).

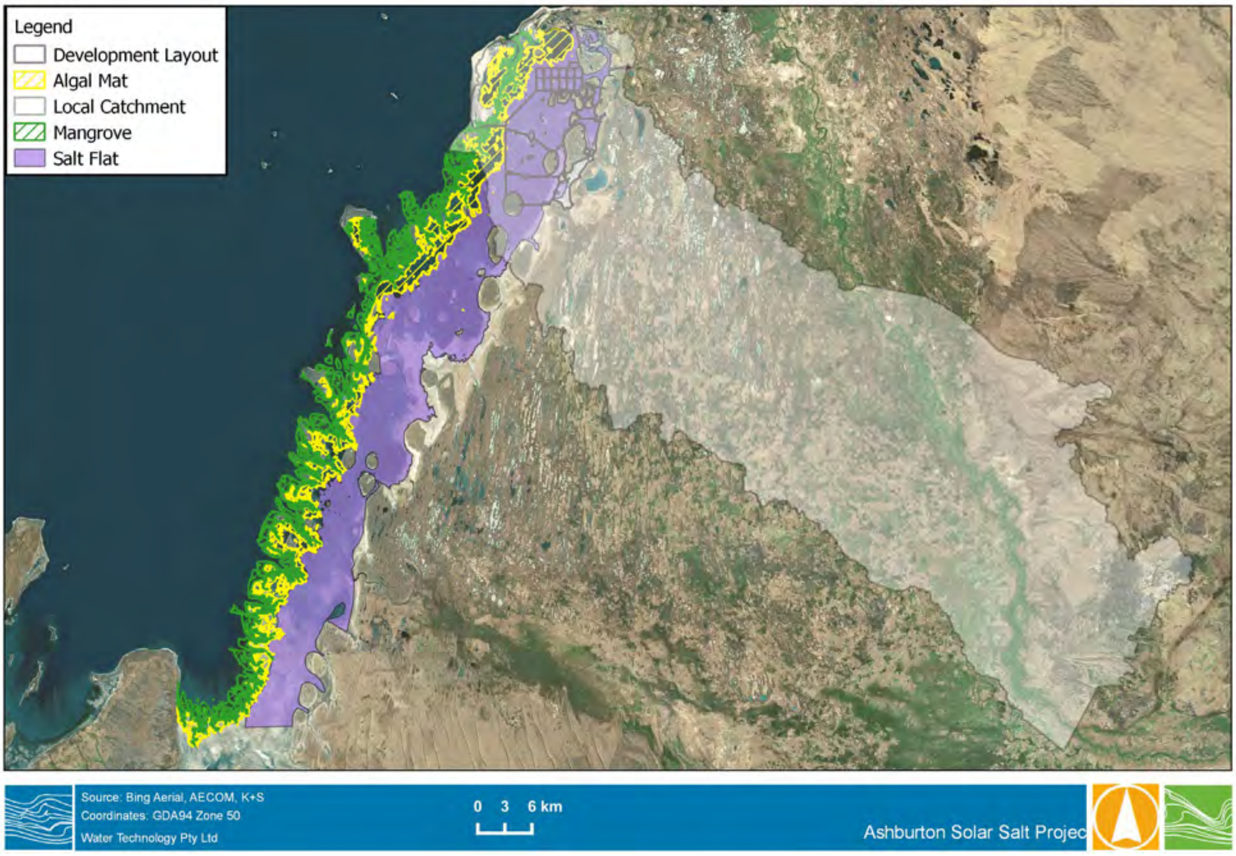

FIGURE 3-12 MAPPING USED FOR NUTRIENT BUDGET

Historically, marine and terrestrial systems have primarily been considered as nitrogen limited, whereas lakes are often phosphorus limited (Ptacknik, Andersen and Tamminen 2010). Comparing nitrogen to phosphorus ratios is a common way to assess nutrient limitation on planktonic production in waterbodies and an analysis of the water quality data collected as part of this study found creeks and offshore waters to be nitrogen limited (*Marine, Coastal and Surface Water Data Collection,* Water Technology 2021). Consequently, the nutrient budget has focussed on quantification of nitrogen, as this is considered the key nutrient for the functioning of marine ecosystems within the Exmouth Gulf and will provide a reasonable indication of the likely nutrient impact of the Ashburton Salt Project, with respect to other nutrient types.

The regional annual total nitrogen budget is quantified in Table 3-4, whilst the budget specific to the project site is described in Table 3-5. The project specific budget used the habitat areas that lie within the local catchment area for calculations. A summary of assumptions used in the nutrient budget is provided below.

3.5.5.2 Key Assumptions

Mangroves

For mangroves, literature suggests they are likely to recycle nitrogen, with little tidal export or import, however based on the conditions at the site (i.e., tidal amplitude, nutrient rich floodwaters) they are likely to represent a net nitrogen sink within the system. Boto and Wellington (1998) found mangroves have a net import (sink) of 0.16 mg N m^{-2} h^{-1}. In converting this to an annual rate, inundation frequency needs to be considered, which is estimated to be 5 to 50%, with a mean inundation frequency of ~20%. The calculated annual import (nitrogen removal rate) rate is 2.8 kg/ha/y.

Cyanobacterial (Algal) Mats

With regard to cyanobacterial mats, Paling and McComb (1994) estimated an annual export rate of 68 kg/ha/y and a leaching rate of 3 to 7 mg N m^{-2} h^{-1}. This export rate has already taken into account inundation frequency and is based on a study in Dampier that has similar climatic conditions to the Project site.

Salt Flats

At present no studies have been conducted in the area with regard to leaching rates for salt flats. A previous study by Burford et al. (2016) estimated areal nitrogen contributions for supratidal salt flats in North Queensland to be 48 to 468 mg N m^{-2} for NH_4 and 41 to 180 mg N m^{-2} for NO_x. These values are not considered appropriate for the Project site, as climatic and catchment conditions are vastly different. The North Queensland location has a tropical climate with a regular wet season and high nutrient inputs as opposed to the arid and low nutrient environment at the Project site. Additionally, the North Queensland study uses the term salt flat to broadly cover intertidal mudflats which support algal growth, which is different to the salt flats at the Project site, which occur in a dry, hypersaline environment that does not contain any active algal mat growth (see Section 3.5.2.1).

With regard to the leaching rate of algal mats, it is directly related to the presence of cyanobacteria, therefore based on our understanding of the salt flats the nitrogen leaching rate in these areas would be far less due to the absence of cyanobacteria. Analysis of sediment samples in the area found the average chlorophyll-a concentration for algal mats was 275 mg/m^2 compared to just 29 mg/m^2 for salt flats (i.e., 10.5% of the algal mat level) (AECOM 2021). Using the Redfield ratio, this can be scaled and applied to nitrogen leaching rates. The Redfield ratio is a stoichiometric ratio used to describe the composition of phytoplankton biomass and nutrient concentrations in marine waters (Ptacknik, Andersen and Tamminen 2010). On average, each atom of phosphorus in phytoplankton biomass is attended by 16 atoms of nitrogen and 106 atoms of carbon, which equates to a C:N:P ratio of 106:16:1, whereby a reduction in nitrogen results in a proportional reduction in carbon and phosphorus and therefore plankton biomass. Chlorophyll-a is an indicator of plankton biomass and using the Redfield ratio, a reduction in chlorophyll-a (plankton biomass) within the salt flats, would correspond to a complimentary reduction in nitrogen. Thus, it could be assumed that the nitrogen leaching rate of the salt flats would be 10.5% of the algal mat rate.

Paling and McComb (1994) found that leaching rates for algal mats were 3-7 mg N m^{-2} h^{-1}, with 6.5 mg N m^{-2} h^{-1} adopted within the nutrient model. This value was also validated with sensitivity testing and yielded a good result in the model calibration process, which is detailed in Section 4.3. Applying the proportional change methodology between algal mats and salt flats (with the salt flats containing 10.5% of the amount of chlorophyll-a found within the algal mats), this would result in a nitrogen leaching rate of 0.6 mg N m^{-2} h^{-1} for salt flats. Considering the above assumptions made in the estimated salt flat leaching rate, a more conservative value of 2 mg N m^{-2} h^{-1} has been applied within the study to avoid under-estimating potential nutrient leaching from the salt flats.

When converting the leaching rate to an annual rate, the inundation frequency needs to be considered, which can vary spatially and temporally within the salt flats. Inundation modelling showed more frequent inundation in the salt flats closer to the coastline during March/April, however salt flats closer to the hinterland undergo little to no inundation. On average, the percentage of time inundated within the salt flats ranges from 0 to 1%. For the purpose of this calculation, it was assumed that the salt flats are inundated 0.5% of the time (or ~2 full days per year), which is a conservative assumption given much of the salt flat is inundated for less than this and this will likely overestimate the contribution from salt flats. The 2 mg N m^{-2} h^{-1} leaching rate and 0.5% inundation estimations results in an annual nitrogen exchange rate of 0.9 kg/ha/y for salt flats.

Overland Flow

With regards to overland flow from the hinterland, Brunskill (2001) investigated interactions between Exmouth Gulf waters and coastal runoff and estimated that terrestrial nutrient runoff is relatively low. Brunskill (2001) estimated that total nitrogen supply was approximately 0.8 mmol N (0.012 g N) per square metre of the Gulf per year (converted to 0.1 kg/ha/year) and this estimate is considered suitable for characterising nitrogen contributions from areas higher up in catchment beyond the intertidal zone and salt flats areas.

Offshore Marine Water Nitrogen Contribution

Marine offshore nitrogen contribution was estimated for 2019 based on measured nitrogen data near the project site and water levels (and associated volumes). As described in Section 3.5.3.5, the annual estimate of 7,950 tpa is considered a conservative approximation of the scale of nitrogen inputs from offshore waters to Exmouth Gulf, whilst 2,600 tpa is considered a conservative approximation of the nitrogen inputs from offshore waters to the local catchment.

3.5.5.3 Summary

The regional nutrient budget for the Exmouth Gulf (Table 3-4) shows that by far, offshore sources (approximated conservatively by calculating ocean upwelling contribution) is the most important source of nutrients within the Exmouth Gulf, representing approximately 92.5% of total nutrient sources, whilst land based (terrestrial and intertidal) sources represent around 7.5% of total nutrient sources.

The project site nutrient budget (Table 3-5) shows that again offshore sources are the most significant contributor, whilst algal mats also contribute a significant amount of nitrogen to the tidal creeks and nearshore areas representing 8.4% of the total nitrogen budget for the project area catchment. However, it should be noted that these nutrients are largely recycled within the creeks and nearshore areas.

The salt flats in the project area are estimated to generate less than 0.4% of the total nutrient budget for the project area catchment (Table 3-4), and similarly when compared to the nutrient budget for entire Gulf (Table 3-5) they represent an insignificant amount (0.5% of the total Exmouth Gulf nutrient budget).

TABLE 3-4 REGIONAL LAND AND OCEAN NITROGEN CONTRIBUTIONS TO EXMOUTH GULF WATERS

Habitat	N Source or Sink	Primary Nutrient Pathway	Secondary Nutrient Pathway	Area (ha)	Exchange rate (kg/ha/y)	Net TN (tpa)	% of Total to Exmouth Gulf	Source
Mangroves	Sink	Tidal creeks/inundation	Overland Flows	11,780	-3	-34.7	N/A – no net N export to Exmouth Gulf	Adame et al. 2010
Algal Mats	Source and sink	Tidal creeks/ inundation/	Overland Flows	8,080	68	541	6.3	Paling and McComb 1994
Salts Flats	Source	Overland flows	Tidal creeks/ inundation	50,500	0.9	44.7	0.5	Paling and McComb 1994, Project data collection
Hinterland	Source	Overland flows	Wind	560,000	0.12	55.1	0.6	Brunskill et al. 2001
Offshore	Source	Upwelling/Eddies	Tidal forcing	-	-	7,950	92.5	See Section 3.5.3
					Intertidal and terrestrial total	**641**	**7.5**	
					Total	**8,591**	-	

TABLE 3-5 PROJECT SITE CATCHMENT AND OCEANIC NITROGEN CONTRIBUTIONS TO NEARSHORE WATERS

Habitat	N Source or Sink	Primary Nutrient Pathway	Secondary Nutrient Pathway	Area (ha)	Exchange rate (kg/ha/y)	Net TN (tpa)	% of Total to Exmouth Gulf Nearshore	Source
Mangroves	Sink	Tidal creeks/inundation	Overland flows	650	-3	-1.9	N/A – no net N export to Exmouth Gulf	Adame et al. 2010
Algal Mats	Source and sink	Tidal creeks/ inundation/	Overland Flows	3,600	68	241	8.4	Paling and McComb 1994
Salts Flats	Source	Overland flows	Tidal creeks/ inundation	14,000	0.9	12.4	0.4	Paling and McComb 1994, Project data collection
Hinterland	Source	Overland flows	Wind	197,000	0.12	19.4	0.7	Brunskill et al. 2001
Offshore	Source	Upwelling/Eddies	Tidal forcing	-	-	2,600	90.5	See Section 3.5.3
					Intertidal and terrestrial total	**273**	9.5	
					Total	**2,872**	-	

4 IMPACT ASSESSMENT

4.1 Objective

The study area is comprised of tidal creeks dominated by mangrove habitats in the intertidal zone with algal mats and salt flats beyond the tidal limit of the mangrove zone. The algal mat habitats provide a significant nitrogen source for tidal creeks and nearshore waters during regular tidal inundation and nutrient rich overland flows reach the coastal environment after major rainfall events.

The relevant EPA environmental objectives are:

- To maintain the hydrological regimes of groundwater and surface water so that environmental values are protected.
- To maintain the quality of groundwater and surface water so that environmental values are protected.

This assessment focuses on the surface water component with particular reference to surface water nutrient pathways, with groundwater addressed in a separate study.

4.2 Methodology

The project layout could cause changes in surface water flows and potential changes in nutrient pathways. Although the development layout does not directly remove significant amounts of algal mats which contribute nitrogen to surface waters, it will cover areas of salt flats and alter overland flows path (see Figure 4-1), The salt flats only contribute a small amount of nitrogen to the overall nutrient budget.

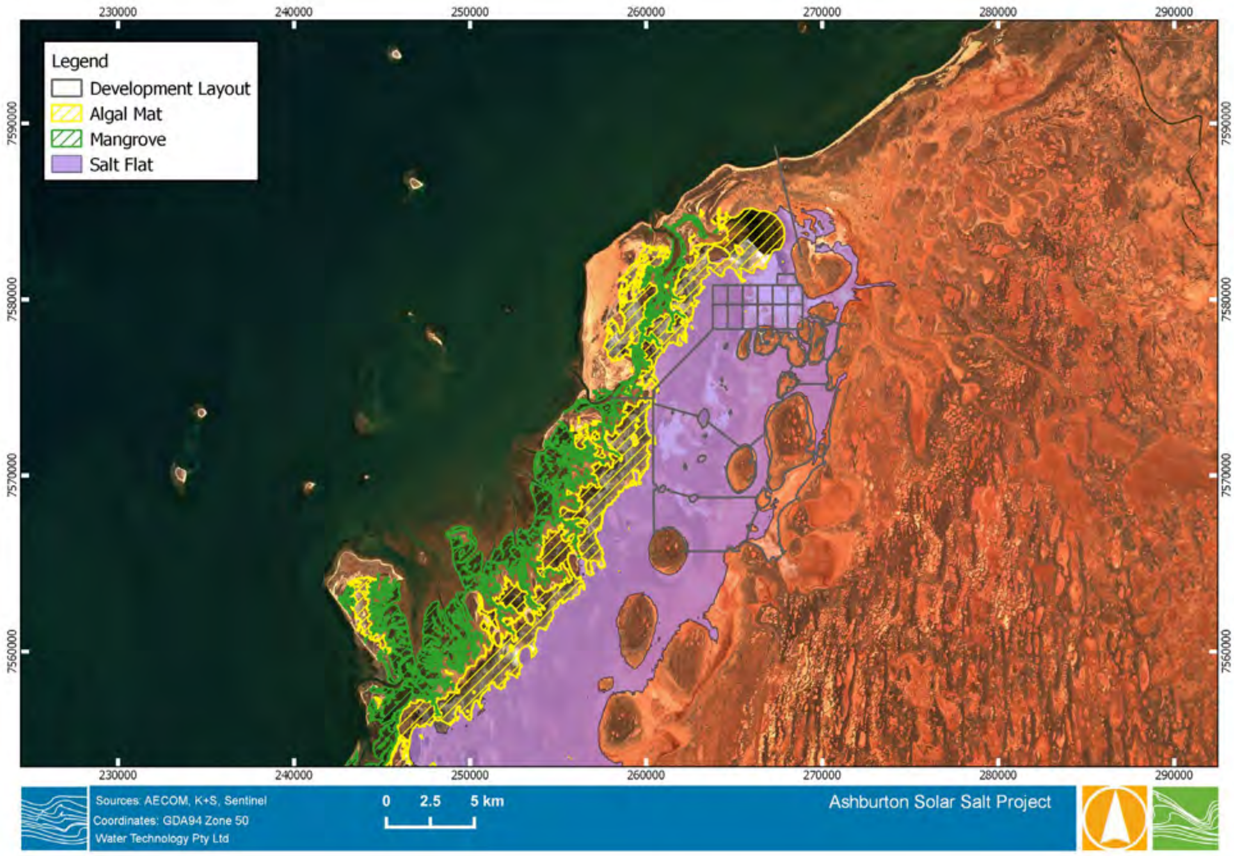

FIGURE 4-1 MANGROVE, ALGAL MAT AND SALT FLAT HABITAT

In order to assess potential changes in nutrient contributions to Exmouth Gulf, a nutrient pathway assessment was undertaken which involved the following key steps:

- Characterisation of the existing environment - Section 3.
- Development of conceptual nutrient pathway model (descriptive diagram) and nutrient budget - Section 3.
- Development of a numerical model simulating nutrient pathways related to tidal inundation and overland flows – Section 4.3.
- Project related impact assessment including - Section 4.4:
  - Modelled impacts to tidal inundation and overland flow nutrient pathways; and
  - Calculated nutrient loss, due to habitat loss.

4.3 Modelling Approach, Design and Parameterisation

The approach adopted for this study to evaluate potential changes to inland and subsequent estuarine water quality associated with the proposed development, involved the interpretation of a calibrated two-dimensional hydrodynamic (HD) water quality model in the Danish Hydraulics Institute (DHI) MIKE software package. Nitrogen, which previous studies and water quality monitoring showed is the limiting nutrient within the Exmouth Gulf, is the primary focus of the modelling exercise. This modelling was supported, guided and informed by a range of data and other relevant information. A detailed description of the model design and parametrisation is presented below.

DHI MIKE FM Hydrodynamic model (HD) has been used for this study. It is a general modelling system for the simulation of flows in estuaries, bays and coastal areas as well as in oceans. The model simulates unsteady three-dimensional flows driven by density variations, bathymetry as well as external forcing from meteorologic forces, tide, ocean currents and river inflows.

The MIKE ECO Lab module was used to simulate nutrient exchanges from four different habitat types:

- Mangroves;
- Algal mats;
- Salt flats; and
- Bare mudflats.

Each habitat type had a nitrogen flux rate applied, with a conditional approach applied for algal mats. Flux rates were derived from literature in combination with sensitivity testing during the calibration period.

A description of key model parameters is provided below.

4.3.1 Model Bathymetry

The model was developed with the spatial extent shown in Figure 4-2. The model was built on an unstructured flexible mesh and uses a finite volume solution technique. Horizontally, the mesh is comprised of triangular and quadrilateral elements. This approach enables a variation of the horizontal resolution of the model mesh within the model area, and hence a finer resolution in selected areas. Smaller quadrilateral cells were used throughout Urala Creek North and South to better resolve the complex flows and bathymetry of the area.

A description of bathymetry sources and the post-processing undertaken on the LiDAR is detailed further in *Marine and Coastal Assessment and Modelling* (Water Technology, 2021).

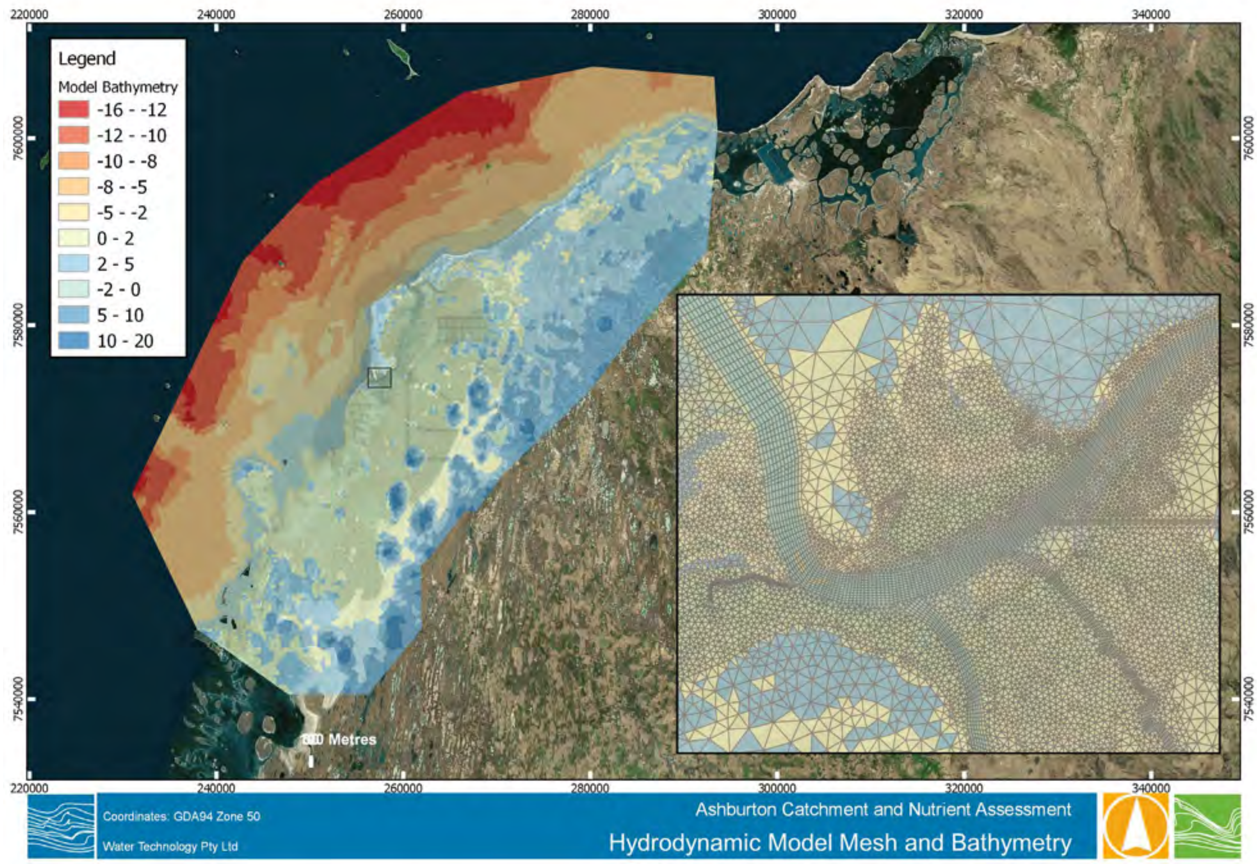

FIGURE 4-2 HYDRODYNAMIC MODEL MESH AND BATHYMETRY

4.3.2 Boundary Conditions

4.3.2.1 Water Levels

The local model boundary was forced by a coarser regional marine model. The transfer boundaries to the local model are illustrated in Figure 4-3. The regional model utilised tidal boundaries that were extracted from the Global Tide Model developed by DTU Space (a part of the Technical University of Denmark). The model is available on a 0.125° x 0.125° resolution grid for the major 10 constituents in the tidal spectra. The model utilises the latest 17 years' multi-mission measurements from TOPEX/Poseidon, Jason-1 and Jason-2 satellite altimetry for sea level residual analysis. The constituents consider semidiurnal (M2, S2, K2, N2), diurnal (S1, K1, O1, P1, Q1) and shallow water constituents (M4).

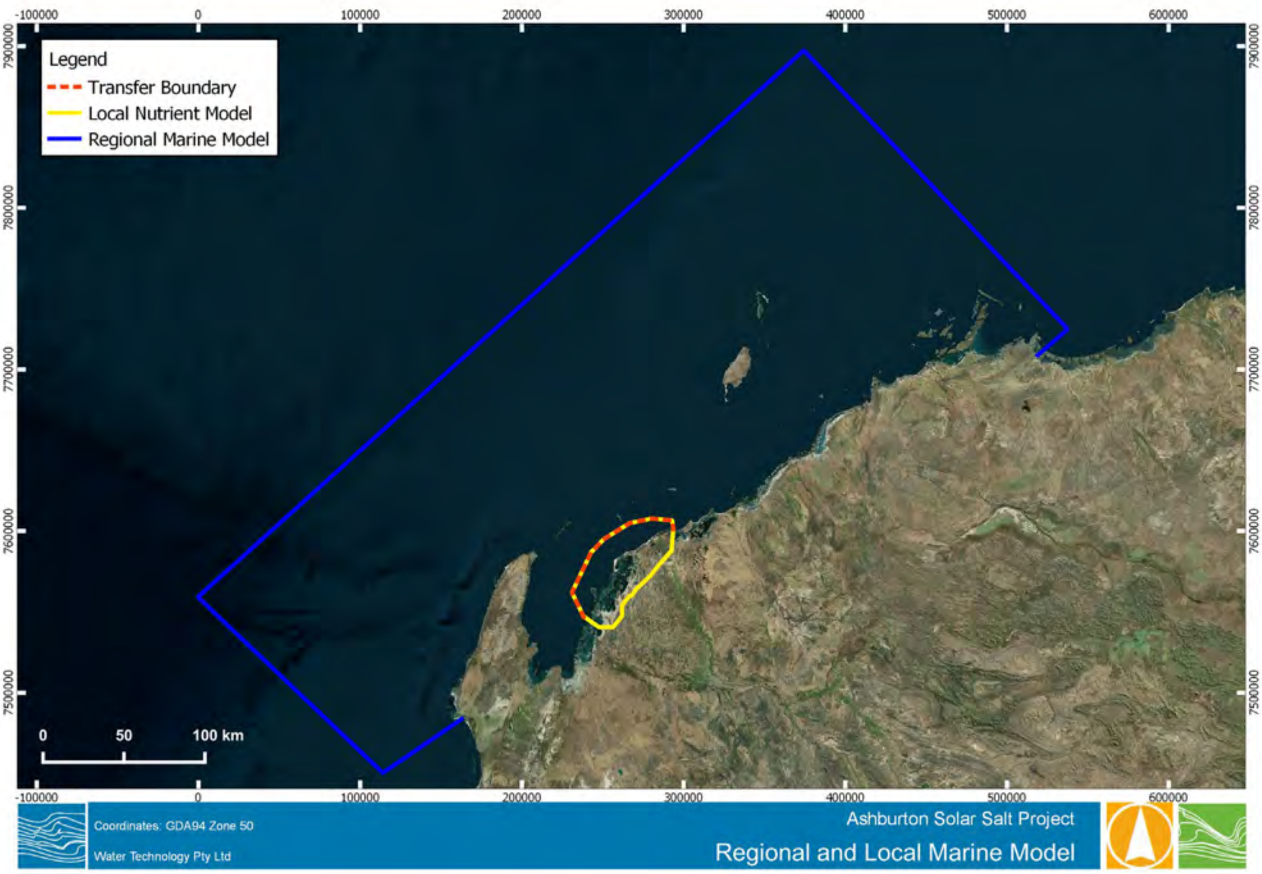

FIGURE 4-3 REGIONAL MARINE AND LOCAL NUTRIENT MODEL EXTENT

4.3.2.2 Wind Forcing

Wind data was sourced from the National Centre for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) model. The CFSR wind model includes data from many sources including surface, upper-atmosphere air balloon, aircraft and satellite observations. The model has a resolution of 0.25° at the equator and 0.5º globally and is capable of accurately representing the interaction between the earth's oceans, land and atmosphere (Saha et al. 2010).

CFSR derived spatially varying wind and pressure data were applied throughout the model domain.

4.3.2.3 Catchment Inflows

Catchment inflows were applied as boundary conditions to the local nutrient model based on outputs from the regional catchment model. The extents of the regional catchment model, local nutrient model and inflow locations are illustrated in Figure 4-4.

Surface water samples across the site were collected after a rainfall event. The mean total nitrogen concentration was 1.1 mg/L, and this was applied to catchment inflows within the model. A description of the monitoring and data collection is provided in *Marine, Coastal and Surface Water Data Collection* (Water Technology 2021).

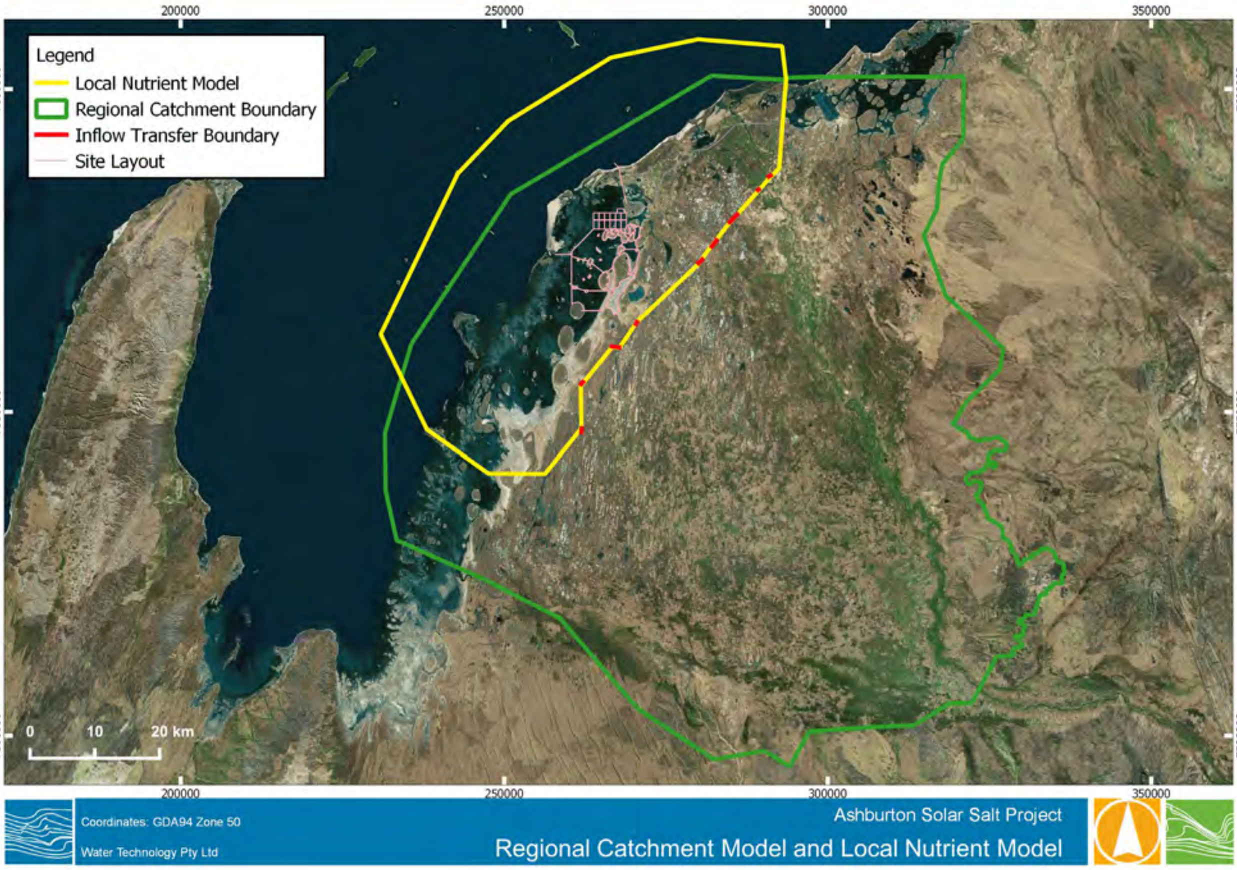

FIGURE 4-4 INFLOW LOCATIONS AND REGIONAL CATCHMENT AND NUTRIENT MODEL EXTENT

4.3.3 Model Parameters

4.3.3.1 Eddy Viscosity/diffusivity

Sub-grid scale horizontal eddy viscosity was parameterised as a function of the local grid resolution using a Smagorinsky formulation. This expresses the effects of sub-grid scale turbulence by an effective eddy viscosity related to a characteristic length scale and local spatial current variations.

4.3.3.2 Bed Resistance

A refined bed resistance map was prepared where land use and vegetation cover were represented. Hydraulic roughness values adopted for the catchment and nutrient model are summarised in Table 4-1, which show the different values adopted for each land use or land cover category.

TABLE 4-1 ROUGHNESS VALUES

Land Use/Topographic Description	Manning's "n"
Offshore	0.03
Sandy/Beach Areas	0.05
Salt Flats	0.05
Algal Mats	0.06
Light Vegetation	0.06
Heavy Vegetation	0.09
Mangrove	0.12

4.3.3.3 Precipitation and Evaporation

Spatially variable precipitation data was obtained from Climate Forecast System Reanalysis (CFSR) (see Section 4.3.2.2) and applied for the calibration simulation. Design rainfalls were used for the nutrient scenario assessments, with a Rain on Grid approach applied to the regional catchment and local models.

The annual mean evaporation from Learmonth Airport weather station was applied to nutrient simulations (see Table 4-2).

TABLE 4-2 MONTHLY AVERAGE LEARMONTH EVAPORATION (1975 – 2017)

	Average Evaporation (mm/day)
January	14.0
February	12.4
March	11.3
April	9.0
May	6.1
June	4.5
July	4.6
August	6.2
September	8.7
October	11.2
November	12.5
December	13.9

4.3.3.4 Nitrogen Fluxes

Conservative nitrogen fluxes (import/leaching rates) were applied to areas of mangroves, algal mats, salt flats and bare intertidal mudflats based on literature values and sensitivity testing. The nutrient pathways and habitats were incorporated into the model based on the conceptual nutrient pathway model presented in Figure 3-11.

All habitats have been assigned conservative values to ensure that the model will likely overestimate the impact of the development. Specifically, leaching rates applied were greater than or close to the upper limit of literature values (in order to over-estimate nitrogen flowing from these habitats), whilst import rates were less than literature values (in order to under-estimate nitrogen being taken up by intertidal habitats). Further detail on model conservatism is provided in Section 4.3.7.

A conditional approach was applied to algal mats within the model, whereby if the average 6-hourly average water depth was greater than 30 cm, the algal mats were assumed to become fully functional and would then take up nutrients from the surrounding waters. This assumption was based on Adame et al. (2012) which found that during the wet season and flooding events algal mats import nutrients from overlying surface waters. A lower import rate was used in the model compared to the literature, building in another conservative assumption.

The salt flats were assigned a conservative leaching rate as described in Section 3.5.5 and 4.3.7.

A summary of relevant nitrogen fluxes is provided in Table 4-3. Positive values represent nitrogen export from the habitat to surrounding waters, whilst negative values represent nitrogen import (uptake/removal) rates. Nitrogen removal occurs in the mangroves, and when algal mats are submerged for longer periods of time.

TABLE 4-3 NITROGEN FLUXES BASED ON AUSTRALIAN LITERATURE

Habitat	Conditions	Literature leaching rate (mg $m^{-2}h^{-1}$)	Model adopted value (mg m^2 h^{-1})	Literature Source
Mangroves	Dry Annual	DIN -0.16	TN -0.1	Adame et al, 2010, Boto and Wellington 1988
Algal Mats	Dry Wet	TN +3 to 7 DIN -1.59	TN +6.5 TN -1.0	Paling and McComb 1994 Adame et al 2012
Bare Intertidal Sediments	Annual Wet	TN 0.0017 DIN -0.24	TN +0.1	Brunskill et al, 2001 Adame et al 2012
Salt Flats	Annual	See Section 3.5.4	TN +2	See Section 3.5.4

4.3.4 Model Calibration

Model calibration consisted of an iterative process of adjusting modelling parameters to arrive at a reasonable comparison between modelled data and recorded measurements. These parameters include but are not limited to bathymetry, boundary and initial conditions, bed resistance and other model constants.

Water levels were calibrated to evaluate model performance in simulating water level variations driven by tides, air pressure, winds and other metrological and oceanographic forces in the model domain and specifically in the vicinity of the project site. Modelled water levels over 4 weeks were compared against measured data at the intake location in Urala Creek South and the discharge location at Locker Point.

4.3.4.1 Calibration and Validation Standards

The evaluation of model performance measures was undertaken to demonstrate the model's ability to accurately replicate natural processes characteristic of the region of interest. Model performance criteria applied to the hydrodynamic models were derived from Williams and Esteves (2017).

Hydrodynamic model performance guidelines are defined as follows:

- Water levels:
  - Modelled water levels should be within 10% and 15% of the tidal range over a spring and neap tidal cycle, respectively or within ± 0.1 m; and
  - Timing of high water and low water should be within 15 minutes.

4.3.4.2 Water Level Calibration

Measured data was compared to predicted water levels at two locations, Urala Creek South Channel and near the jetty at Locker Point, as illustrated in Figure 4-5. The statistical analysis of measured vs model predicted water levels is presented in Table 4-4. The model performed extremely well and met the model performance criteria for water levels at both monitoring locations (Figure 4-6).

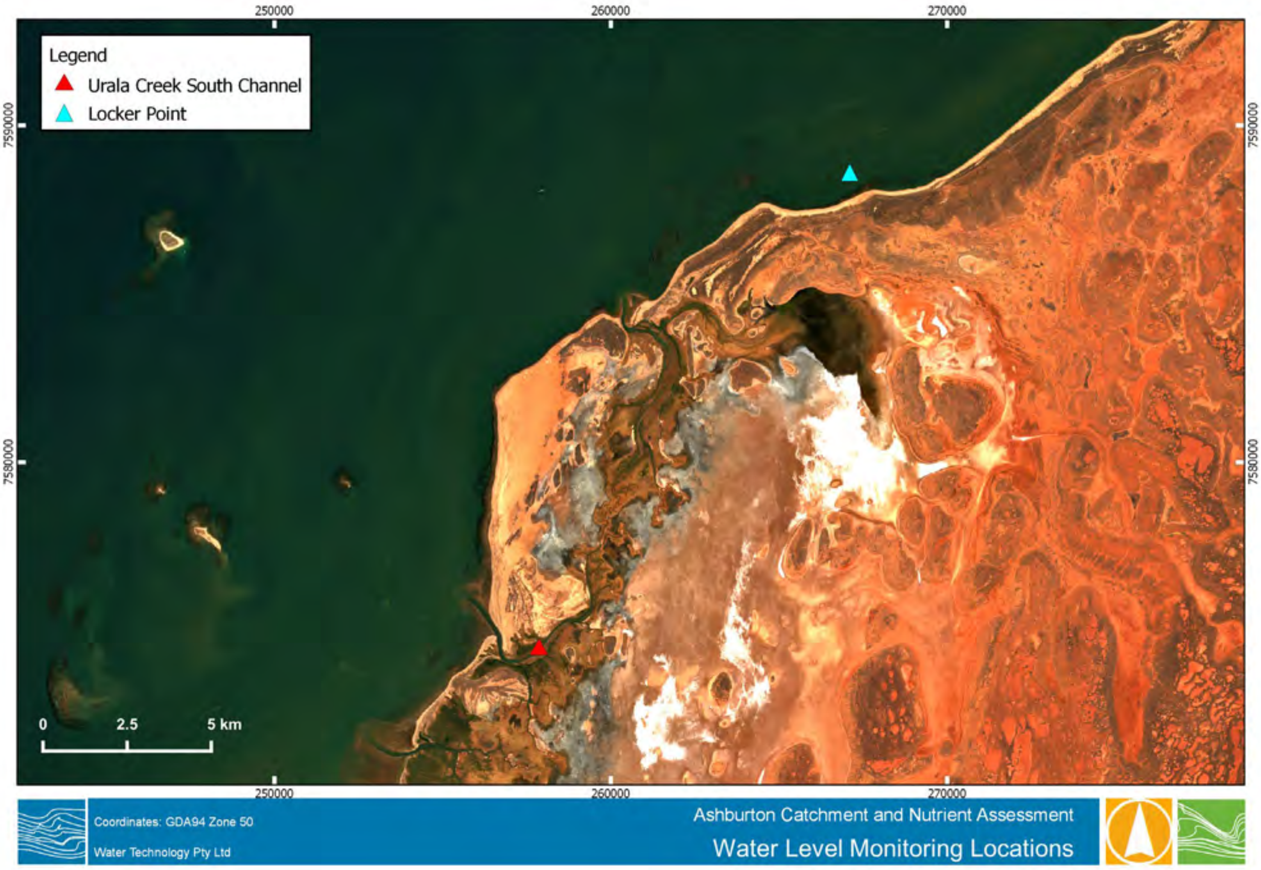

FIGURE 4-5 WATER LEVEL MONITORING LOCATIONS

TABLE 4-4 MODEL PERFORMANCE MEASURES FOR WATER LEVEL

Performance Measures	UCS Intake	Locker Point
Mean HW Difference (m)	-0.01	-0.08
Mean LW Difference (m)	-0.05	-0.04
Mean HW phase difference (min)	-0.86	-0.82
Mean LW phase difference (min)	2.44	3.54
HW percentage difference relative to tidal range (%)	-1.05	-7.15
LW percentage difference relative to tidal range (%)	-4.74	-3.45
R Squared	0.92	0.95

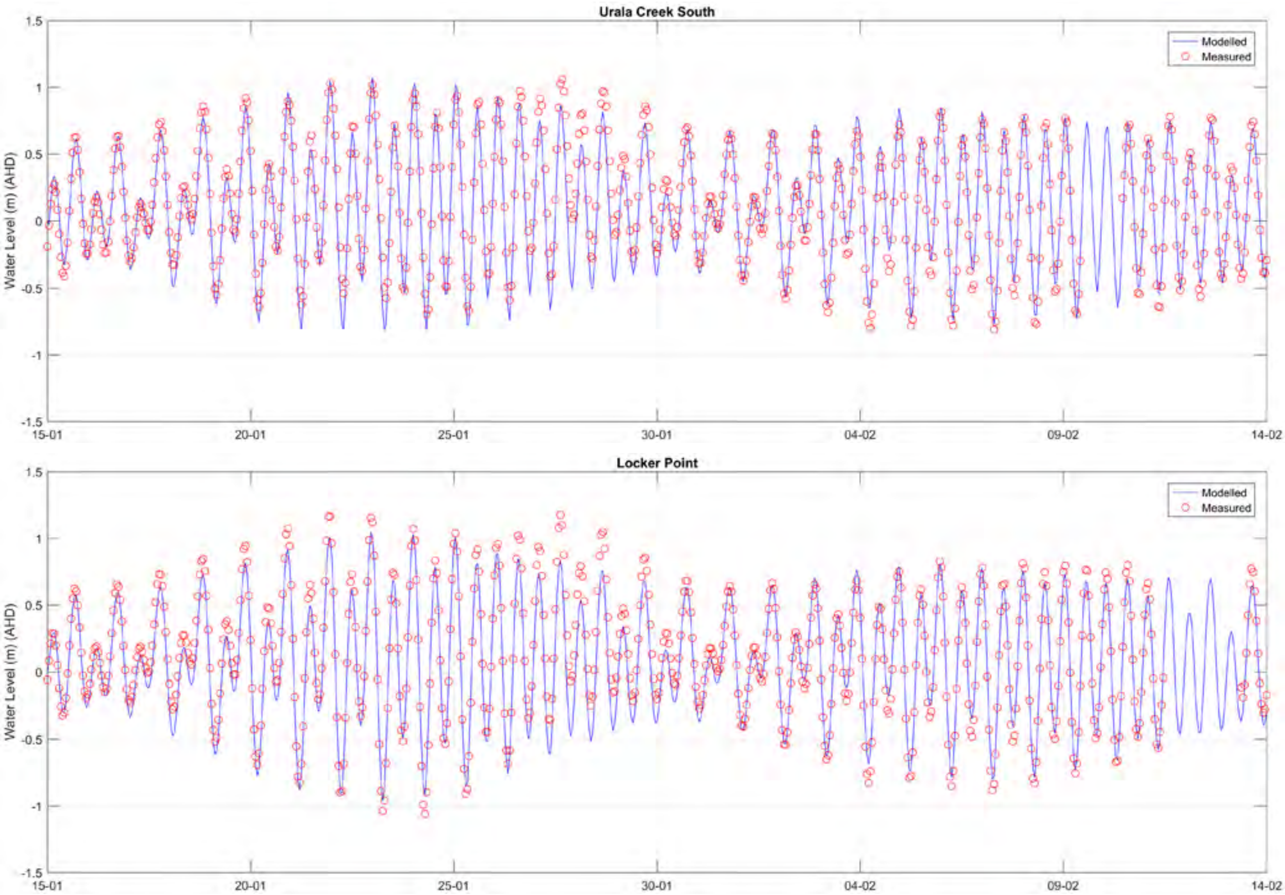

FIGURE 4-6 MODELLED VS MEASURED WATER LEVELS AT URALA CREEK SOUTH AND LOCKER POINT

4.3.4.3 Nitrogen Calibration

A range of data was collected for the Ashburton Solar Salt study, which is detailed in *Marine, Coastal and Surface Water Data Collection* (Water Technology 2021). The water quality data collected was used to guide the development of the conceptual nutrient pathway model, and the February 2019 and October 2019 datasets were found suitable for model calibration for the following reasons:

- Laboratory analysis had an appropriate limit of reporting;
- Monitoring locations were within creeks that were suitably resolved within the model; and
- Data established a nutrient gradient due to intertidal inputs.

February Calibration

The model was initialised with a uniform hot start (elevated level) nitrogen concentration of 0.15 mg/l, this allowed the model to warm up and reach equilibrium within a week. The nitrogen calibration for Urala Creek South is presented in Figure 4-7. The model accurately predicts the diurnal nutrient variation associated with tidal inundation and leaching from intertidal sediments and algal mats. The model also predicts the upstream nutrient gradient, due to the mixing of oceanic water with water from the upper estuary which is more nutrient rich.

The model reliably predicts nitrogen concentrations throughout Urala Creek South.

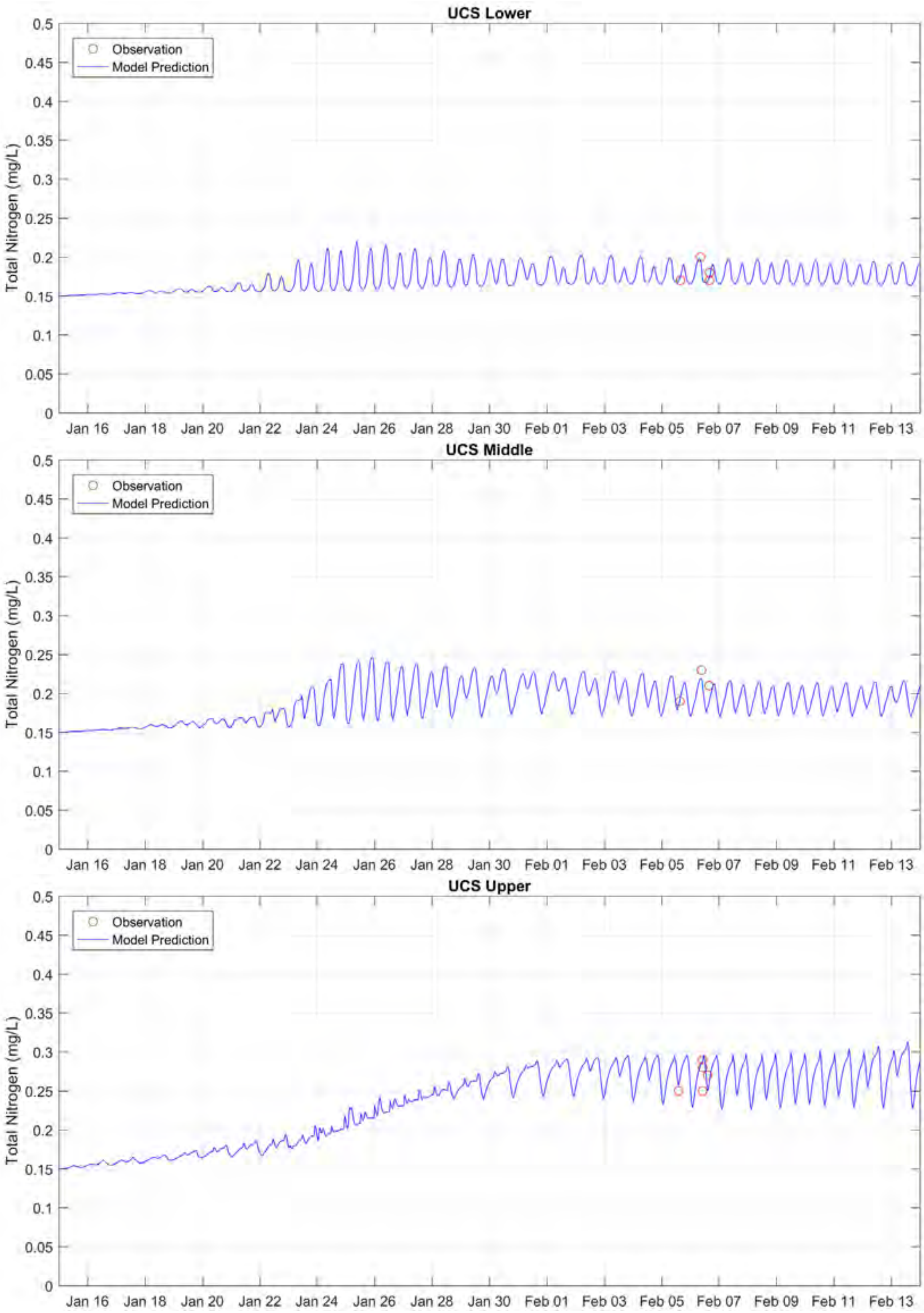

FIGURE 4-7 URALA CREEK SOUTH FEBRUARY NITROGEN CALIBRATION

The February model calibration for Urala Creek North is shown in Figure 4-8. The model predicts that the diurnal variation is much lower at the mouth of Urala Creek North, which aligns with measured data. The model slightly underpredicts the diurnal range of nitrogen concentrations in the mid-estuary, however considering the good results at the upper and lower estuary, the model is still performing well and appropriately captures the tidal nitrogen flux in Urala Creek North due to tidal inundation.

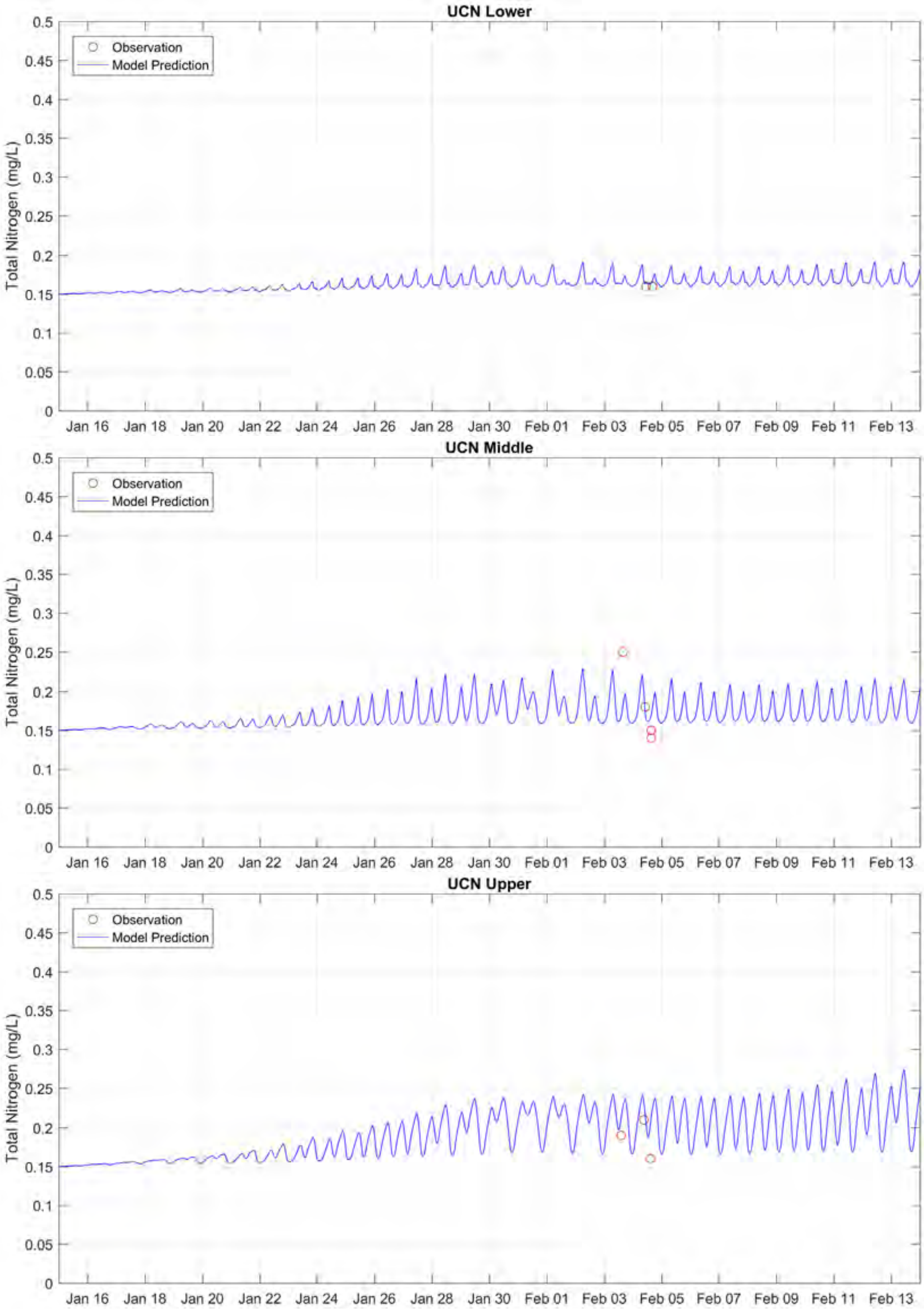

FIGURE 4-8 URALA CREEK NORTH FEBRUARY NITROGEN CALIBRATION

October Calibration

The October validation period had higher nitrogen concentrations and therefore required a higher initial condition concentration compared to February. The results of the calibration for Urala Creek South are shown in Figure 4-9. The model performed well, slightly under predicting the diurnal nitrogen exchange in the mid and upper estuary, however it did accurately capture the upstream nitrogen gradient.

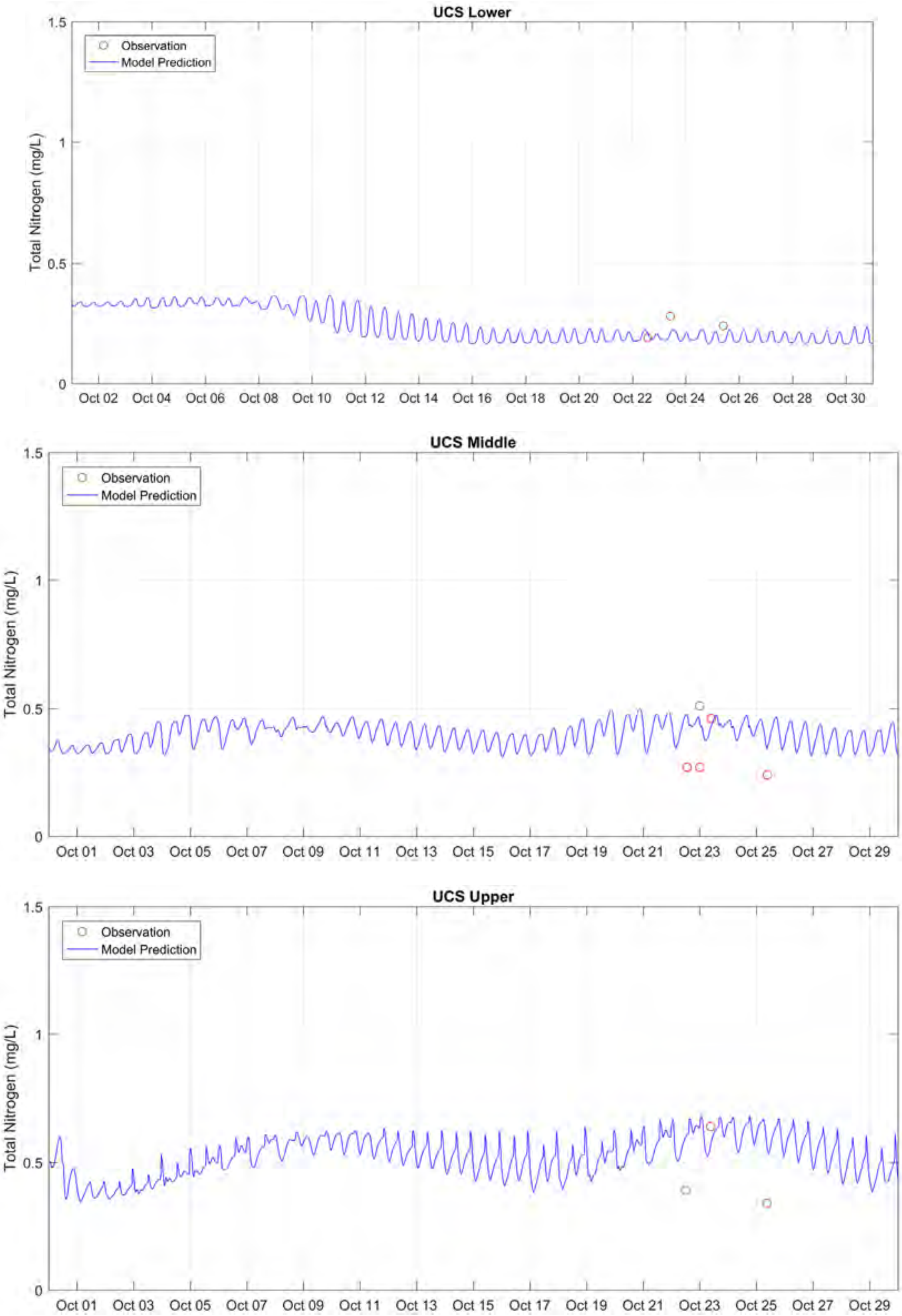

FIGURE 4-9 URALA CREEK SOUTH OCTOBER NITROGEN CALIBRATION

The results of the calibration for Urala Creek North are shown in Figure 4-10. The model performed accurately in Urala Creek North.

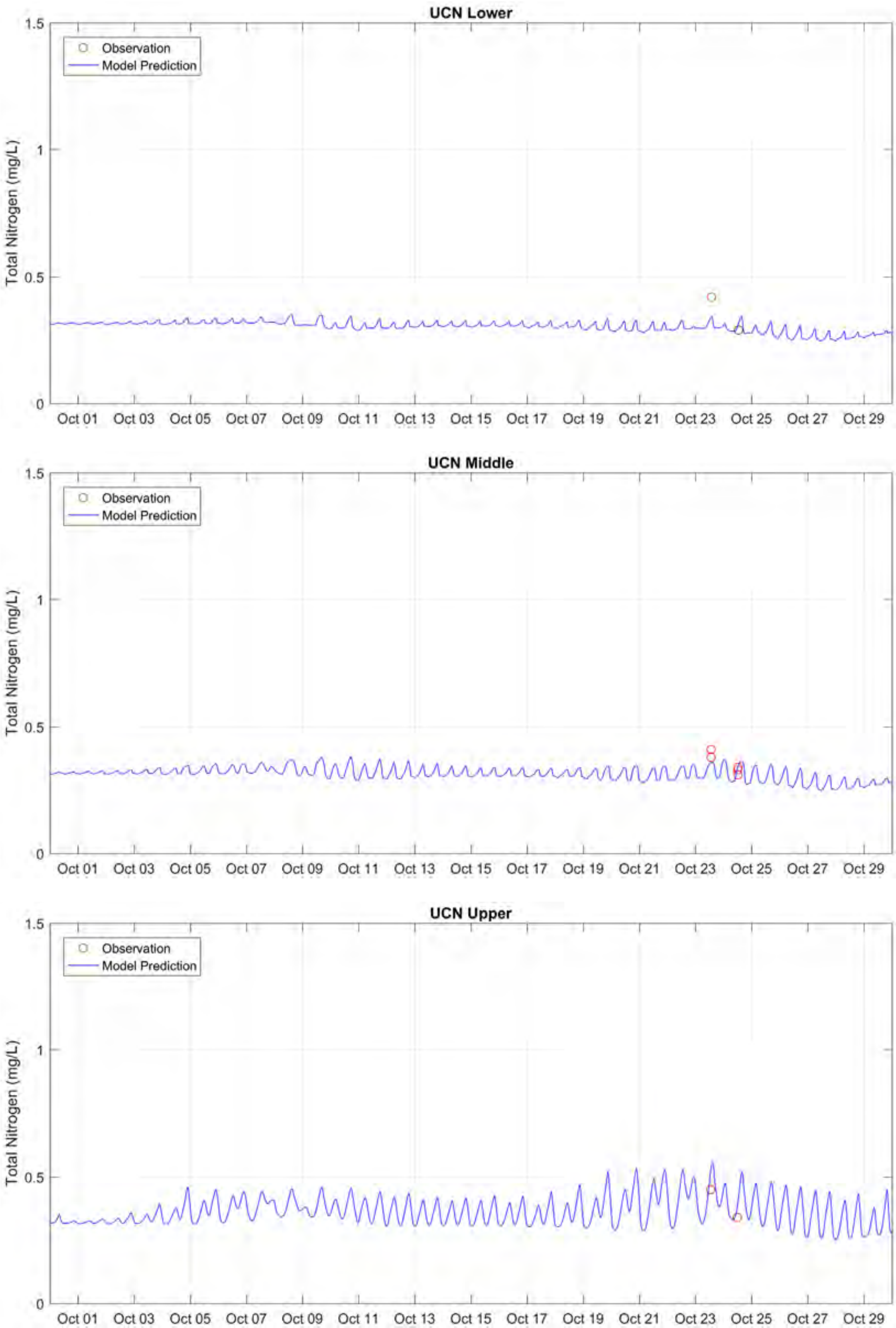

FIGURE 4-10 URALA CREEK NORTH OCTOBER NITROGEN CALIBRATION

4.3.5 Modelled Scenarios

The modelling has focussed on changes to tidal inundation and overland flows from rainfall events. The nutrient pathway model used inflows at the model boundary from the regional hydraulic model and rainfall from the hydrology model. These models are described in *Surface Water Assessment and Modelling* (Water Technology 2021).

4.3.5.1 Tidal Inundation Scenarios

Algal mats can only tolerate a narrow band of inundation at the upper end of the tidal regime, which the development layout is not predicted to impact as the upper limit of the tidal range was not reduced in any meaningful way, despite this, two inundation scenarios were modelled without rainfall:

- Ambient tidal conditions during January and February: and
- Seasonally high-water levels during March and April.

The modelling scenarios were initialised with a hot start (elevated level) of nitrogen concentrations from the February calibration period.

4.3.5.2 Rainfall Scenarios

The following rainfall design scenarios were simulated in the nutrient pathway model:

- 50% AEP (~2-year ARI) with 24-hour critical duration;
- 20% AEP (~5-year ARI) with 24-hour critical duration;
- 10% AEP (~10-year ARI) with 24-hour critical duration;
- 5% AEP (~20-year ARI) with 24-hour critical duration; and
- Cyclone Vance, a category 5 cyclone and 5% AEP (~20 year ARI) rainfall event.

The modelling scenarios were initialised with the hot start (elevated level) of nitrogen concentrations from the February calibration.

4.3.6 Sensitivity Testing

Sensitivity testing was undertaken to assess the appropriate length of time to run design simulations. The sensitivity testing found that 4 weeks was appropriate and captured the nutrient export from Urala Creek South and North. Running the simulation for an additional 2 weeks found the nutrient mass balance was altered by less than 1%, as after the rainfall event, the system stabilises and reaches a nitrogen flux equilibrium whereby exports equal imports.

Extensive sensitivity testing of boundary conditions and tidal inundation was also undertaken in *Marine and Coastal Assessment and Modelling* (Water Technology, 2021).

4.3.7 Modelling Conservatism

Overall, the modelling approach applied has been designed to be extremely conservative, so as to ensure that impacts are overestimated, rather than underestimated. The conservative design parameters can be summarised as:

- Conservative nitrogen import and leaching rates have been applied within the model as follows:
  - Mangroves: Boto and Wellington (1988) found that there was net import (sink) of nitrogen into mangroves of 0.16 mg N m^{-2} h^{-1}). A conservative import rate less than this of 0.1 mg N m^{2} h^{-1} has been adopted in the model in order to under-estimate the amount of nitrogen taken up by mangroves and therefore over-estimate the amount of nitrogen flowing from mangroves into the coastal system.

- Algal Mats: Paling and McComb (1994) estimated an annual nitrogen leaching rate of 3 to 7 mg N m^2 h^{-1}. A conservative leaching rate has been applied in the modelling at the upper end of this range of 6.5 mg N m^2 h^{-1} in order to estimate upper amounts of nitrogen flowing from the algal mats into the coastal system.
- Bare Intertidal Mudflats: Brunskill et. al. (2001) estimated that bare intertidal mudflat (sediment) leaching rates can approximate 0.0017 mg N m^2 h^{-1} on an annual basis, whilst Adame et. al. postulated that wet bare intertidal mudflats can actually uptake nitrogen at a rate of -0.24 mg N m^2 h^{-1}. A conservative leaching rate of 0.1 mg N m^2 h^{-1} has been applied in the model 100 times larger than the estimated annual rate of 0.001 mg N m^2 h^{-1} in order to over-estimate the amount of nitrogen flowing from the bare sediment into the coastal system.
- Salt Flats: Paling and McComb (1994) found that leaching rates for algal mats were 3-7 mg N m^{-2} h^{-1}, with a conservative rate of 6.5 mg N m^{-2} h^{-1} adopted within the nutrient model. The Redfield ratio is a stoichiometric ratio used to describe the composition of phytoplankton biomass and nutrient concentrations in marine waters (Ptacknik, Andersen and Tamminen, 2010). Chlorophyll-a is an indicator of plankton biomass and using the Redfield ratio, a reduction in chlorophyll-a (plankton biomass) within the salt flats, would correspond to a complimentary reduction in nitrogen. Thus, based on chlorophyll-a proportions within the algal mat and salt flat (with the salt flat containing 10.5% of that within the algal mat) it could be assumed that the nitrogen leaching rate of the salt flats would be 10.5% of the algal mat rate. Applying the proportional change methodology between algal mats and salt flats, this would result in a nitrogen leaching rate of 0.6 mg N m^{-2} h^{-1} for salt flats. Considering the assumptions made this estimate, a more conservative value of 2 mg N m^{-2} h^{-1} (more than 3 times the estimated proportional rate of 0.6 mg N m^{-2} h^{-1}) has been applied within the modelling to avoid under-estimating potential nutrient leaching from the salt flats. This value also yielded a good result in the model calibration process, which is detailed in Section 4.3.4.

- The annual nitrogen exports from the creeks were calculated by extrapolating out the ambient and seasonal high-water levels. As a conservative estimate 10 months of ambient simulation were combined with 2 months of the seasonal high-water results. This is a conservative estimate because the low water months (where inundation to the algal mats is less) were not considered, therefore increasing the potential nitrogen contribution from algal mats.
- The modelling results represent changes to nitrogen exports from the mouth of Urala Creek North and South only, and do not account for altered overland flow paths which may result in some nutrients being exported via different land/water interfaces, thus are likely an overestimation of nutrient flow reductions into nearshore waters.
- The design rainfall events used are considered extremely conservative as they apply a spatially constant rainfall rate over the entire model domain, which in reality would be very unlikely to occur due to the vast extent of the catchment.

4.4 Impacts to Nutrient Pathways

Due to the oligotrophic and potentially sensitive environment, the nutrient pathways study focuses on quantifying the potential nutrient load reduction to surface waters near the project site. This is contrary to impacts from most developments, which are concerned with the addition of nutrient loads.

4.4.1 Modelled Tidal Inundation Scenarios

Nitrogen fluxes at the entrance of Urala Creek North and South were extracted from the model and used to estimate the nitrogen mass entering (oceanic import) or exiting (export) Urala Creek North and South for existing and developed conditions. The results of this analysis are presented in Table 4-5 and are for two scenarios, one with ambient (or normal) water levels, and the other with seasonal high water levels during March and April.

The results for the ambient water level simulation indicate that under normal tidal conditions Urala Creek North and South actually receive nitrogen from oceanic and coastal waters, as opposed to exporting it. This shows that under normal ambient tidal conditions there is a net import of nitrogen to creeks which highlights that on a day-to-day basis the wider Exmouth Gulf does not rely on nutrients generated from algal mats for productivity. This is in agreement with findings by Adame et al. 2010, Boto and Bunt 1981, Boto and Wellington (1988) who found that nitrogen is largely recycled in mangrove systems and Paling and McComb (1994) which concluded that algal mats acted primarily as a nutrient source for the creeks and near coastal waters, rather than offshore waters.

The modelling shows that the development is predicted to have no impact to this nutrient import process or on coastal trapping (Table 4-5). The net import under ambient conditions is related to the discharge asymmetry whereby the volume of water entering the creeks on the flood tide is larger than then volume exiting the creeks on ebb tide. This flow inequality means that under most conditions there will be a slight import of nitrogen from sources outside the creeks. This highlights that nutrients generated from algal mats and salt flats generally remain trapped within the creek and undergo localised nutrient cycling and coastal trapping, and that the creeks act as nutrient sink as opposed to major export to Exmouth Gulf in accordance with findings by Adame et al. 2010, Boto and Bunt 1981, Boto and Wellington (1988) and Paling and McComb (1994). During periods with higher water levels, the same trend is observed whereby nutrient imports from offshore are larger than those being exported from the creek.

The annual nitrogen exports from the creek were calculated by extrapolating out the ambient and seasonal high water levels. As a conservative estimate 10 months of ambient simulation were combined with 2 months of the seasonal high-water results. This shows that annually Urala Creek North and South sink and cycle up to 4.8 t of nitrogen from coastal and offshore sources. The development layout has not impact on this nutrient cycling process.

TABLE 4-5 NITROGEN LOADS TO URALA CREEK NORTH AND SOUTH OVER 1 MONTH SIMULATION

Scenario	Location	Existing N flux (t)	Developed N flux (t)	N Difference (t)	% Change
1 month ambient water levels	Urala Creek North	-0.1	-0.1	0	0
	Urala Creek South	-0.2	-0.2	0	0
	Urala Creek North and South	-0.3	-0.3	0	0
1 month seasonal high water levels	Urala Creek North	-0.4	-0.4	0	0
	Urala Creek South	-0.5	-0.5	0	0
	Urala Creek North and South	-0.9	-0.9	0	0
Annual	Urala Creek North	-1.8	-1.8	0	0
	Urala Creek South	-3	-3	0	0
	Urala Creek North and South	-4.8	-4.8	0	0

Table Note: Red shading relates to Table 5-1.

4.4.2 Modelled Rainfall Scenarios

Predicted discharges (i.e. tidal flux/flow) and nitrogen fluxes at the entrance of Urala Creek North and South were extracted from the model and used to estimate the mass of nitrogen leaving the creeks under existing and developed conditions for different rainfall scenarios over a one month simulation. The net nitrogen export results are presented in Table 4-6 as well as the percentage change in nitrogen mass between post-development and existing conditions.

TABLE 4-6 NITROGEN LOADS TO URALA CREEK NORTH AND SOUTH OVER 1 MONTH SIMULATION FOR DIFFERENT RAINFALL EVENT SCENARIOS

Scenario	~ Average Recurrence Interval (ARI)	Existing N export (t)	Developed N Export (t)	N Difference (t)	% of Nutrient Sources for Exmouth Gulf
50% AEP	2 year	0	0	0	0
20% AEP	5 year	40	25	-15	0.2
10% AEP	10 year	188	140	-48	0.6
5% AEP	20 year	304	268	-36	0.4
Cyclone Vance	20 year	66	54	-12	0.1

The nitrogen reductions predicted for all scenarios are relatively small in comparison to the annualised nitrogen budgets for the project site and Exmouth Gulf (see Table 3-4 and Table 3-5). The maximum reduction of 48 t for the 10% AEP scenario (which is only likely to occur every ten years) represents only 0.4-0.6% of the annual nitrogen budget for the Exmouth Gulf 8,591 – 10,991 t) coming from all sources including intertidal, terrestrial and ocean upwelling. These nutrients are important for both offshore and inshore areas of Exmouth Gulf.

Additionally, the results presented herein represent changes to nitrogen exports from the mouth of Urala Creek North and South only, and do not account for altered overland flow paths which will result in some nutrients being exported via different land/water interfaces, thus the are likely an overestimation or conservative representation of post-development overland flow nutrient reductions.

This is illustrated by Figure 4-11 below (*Surface Water Assessment and Modelling,* Water Technology, 2021) which shows the post-development 5% AEP (20 year AR) modelling results with proposed flood mitigation methods (drainage diversions and culverts) in place. Although a proportion of nutrients may not flow into Urala Creek North and South, a proportion will still flow into the surrounding intertidal environment which is important for functioning of the creek and nearshore environments via nutrient cycling.

Overall, although hydrological processes have been altered in some areas, the overland flows still have the ability to interact with the algal mats and salt flats, which results in only minor changes to overall nutrient loads during moderate rainfall conditions (e.g. 10% AEP Table 4-6).

Under ambient and frequent rainfall events, the development is not predicted to affect nutrient pathways as these rainfall events to not cause overland flows which cause significant flows into nearshore waters – that is they do not connect with the tidal creeks (e.g. 50% AEP, 2 year ARI – Table 4-6).

Under more extreme events, the volume of water over the floodplain dampens the impact related to the development, resulting in only minor nitrogen reductions. The greatest impacts were observed for the more moderate events, such as the 10% AEP, however as mentioned previously when considering the scale of the nutrient budget, a reduction of the predicted scale is not expected to have any impact on the tidal creeks, nearshore waters or wider Exmouth Gulf. The key nutrient pathway is tidal inundation, which has not been impacted as described above in Section 4.4.1.

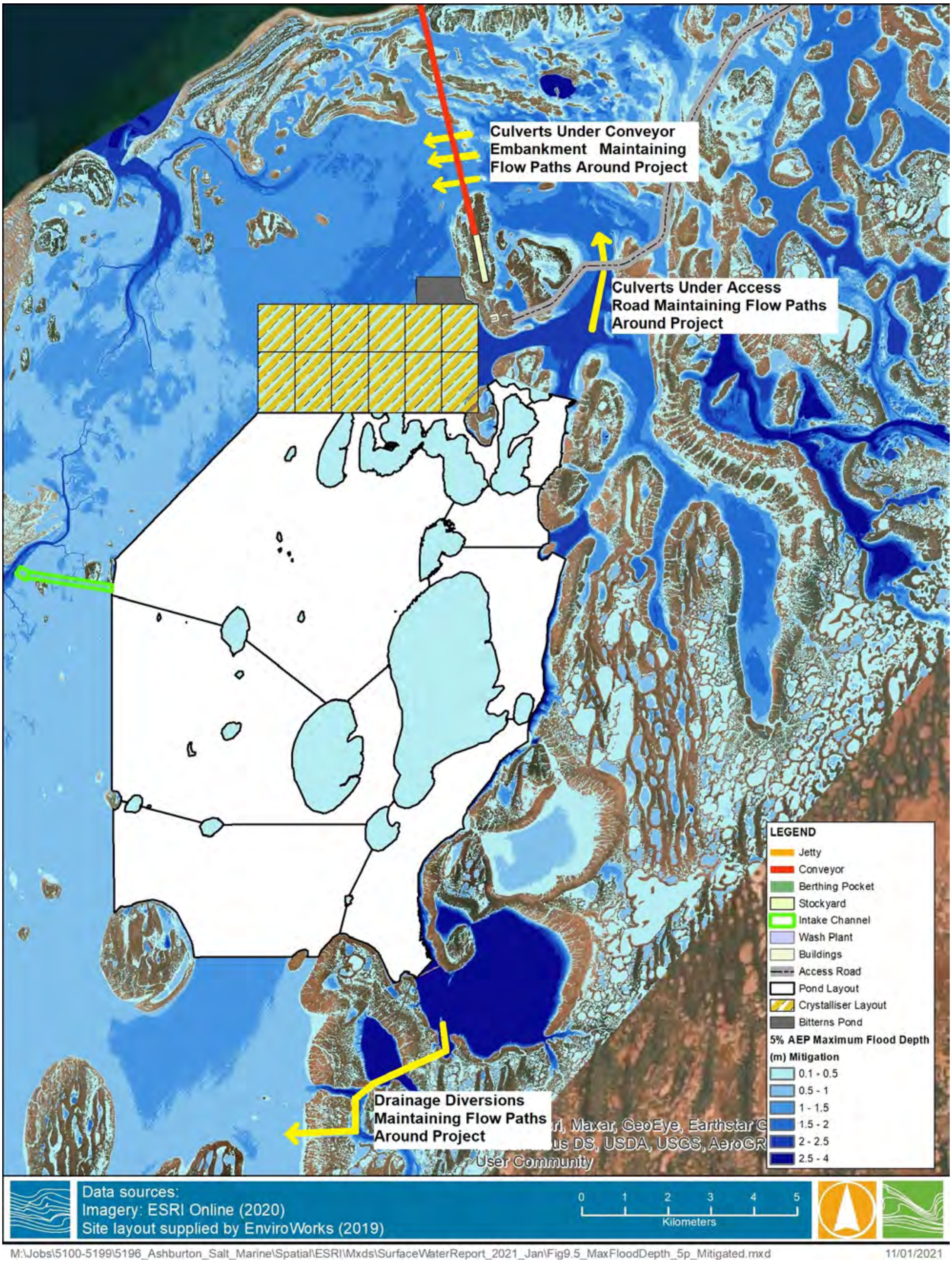

FIGURE 4-11 MODELLED POST-DEVELOPMENT 5% AEP FLOOD DEPTH WITH MITIGATION IN PLACE

To place this in context the conservatively predicted overland flow reductions in nutrient delivery to Urala Creek North and South under various rainfall scenarios have been upscaled by calculating the loss of nutrients over the life of the project (50 years). Each rainfall scenario has been upscaled to occur a number of times over the life of the project (according to its probability of occurrence) and the amount of nitrogen loss over the 50 year project life has been estimated as illustrated in Table 4-7.

Such upscaling over the life of the project (Table 4-7) estimates that:

- Over 50 years there will be an approximate reduction of overland flow delivery of nitrogen to Urala Creek North and South of approximately 492 tonnes, which represents:
  - ~3.8% of all intertidal and terrestrial nitrogen sources from the project site over 50 years (~273 t x 50 or 13,650 t).
  - Less than ~0.4% of the total nitrogen budget (oceanic, intertidal and terrestrial) for the project site over 50 years (~2,872 t x 50 or 143,600 t).
  - ~1.6% of all intertidal and terrestrial nitrogen sources from land to the east of Exmouth Gulf over 50 years (~641 t x 50 or 32,050 t).
  - ~0.12% of all Exmouth Gulf nitrogen sources - terrestrial, intertidal and ocean upwelling (~8,591 t x 50 or 429,500 t).

TABLE 4-7 ESTIMATED NITROGEN LOADS TO URALA CREEK NORTH OVER PROJECT LIFE (50 YEARS)

Scenario	~ Average Recurrence Interval (ARI)	No. Times in 50 years	Existing N export over 50 years (t)	Developed N Export over 50 years (t)	N Difference over 50 years (t)	% of Nutrient Budget over 50 years			
						Project Site - Intertidal & Terrestrial (13,650 t)	Project Site (143,600 t)	Exmouth Gulf Intertidal & Terrestrial (32,050 t)	Exmouth Gulf Land and Ocean Sources (429,500 t)
50% AEP	2 year	25	0	0	0	0	0.0	0	0
20% AEP	5 year	10	400	250	150	1.1	0.10	0.5	0.03
10% AEP	10 year	5	940	700	240	1.8	0.17	0.7	0.06
5% AEP	20 year	2.5	760	670	90	0.7	0.06	0.3	0.02
Cyclone Vance	20 year	2.5	165	135	35	0.2	0.02	0.1	0.01
Total					510	3.8	0.4	1.6	0.12

Table Note: Coloured shading relates to Table 5-1.

4.4.3 Loss of Nutrient Pathways due to Habitat Modification

The Ashburton Salt Project will result in habitat modification due to clearing and construction of project ponds and other infrastructure. The habitat modification (both direct clearing and indirect impacts) have been estimated and the resulting change in nutrient generation from the remaining intact habitat has been calculated as shown in Table 4-8 and 4-9. As outlined in the tables below approximately 11,466 ha of nutrient pathway related habitat is conservatively estimated be modified directly and indirectly by the project, resulting in a reduction in nutrient export to Exmouth Gulf of 10.2 tonnes of nitrogen per annum. Table 4-8 and 4-9 estimate:

- A regional post-development proportional reduction in nitrogen flows into Exmouth Gulf of:
  - 1.6% of land sources.
  - 0.12% of land and ocean sources.
- A local post-development proportional reduction in nitrogen flows into the project catchment of:
  - 3.9% of land sources.
  - 0.36% of land and ocean sources.

The calculations in Table 4-8 and 4-9 have been prepared on a conservative basis, with nitrogen exchange rates in kg/ha/y being the equivalent of the highly conservative import/leaching rates in mg N m^{-2} h^{-1} outlined in Section 4.3.3.4 and Section 4.3.7. In addition, the estimated habitat modification areas are conservative with larger disturbance areas than expected being included.

TABLE 4-8 ESTIMATED HABITAT MODIFICATION RELATED NITROGEN REDUCTION FROM REGIONAL LAND AND OCEAN TO EXMOUTH GULF WATERS

Habitat	Area (ha)	Exchange rate (kg/ha/y)	Net TN (tpa)	% of Total to Exmouth Gulf	Estimated Habitat Modification (ha)	Estimated Remaining Intact Habitat (ha)	Revised Net TN (tpa)	Reduction in Net TN (tpa)	%Reduction from all sources to Exmouth Gulf
Mangroves	11,780	-3	-34.7	N/A – no N export to Exmouth Gulf	4.3	11,775.7	-35	N/A – no N export to Exmouth Gulf	N/A – no N export to Exmouth Gulf
Algal Mats	8,080	68	541	6.3	12.2	8,067.8	540	0.8	0.009
Salts Flats	50,500	0.9	44.7	0.52	10,500	40,000	35	9.3	0.1
Hinterland	560,000	0.1	55.1	0.64	950	559,050	55	0.09	0.001
Offshore	-	-	7,950	92.5	-	-	7,950	0.0	0.0
Intertidal and terrestrial total			**641**	7.5	11,466	-	**630**	10.2	1.6
Total			**8,591**	-	11,466	-	**8,580**	10.2	0.12

Table Note: Coloured shading relates to Table 5-1.

TABLE 4-9 ESTIMATED HABITAT MODIFICATION RELATED NITROGEN REDUCTION FROM LOCAL LAND AND OCEAN TO PROJECT CATCHMENT

Habitat	Area (ha)	Exchange rate (kg/ha/y)	Net TN (tpa)	% of Total to Exmouth Gulf	Habitat Modification (ha)	Remaining Intact Habitat (ha)	Revised Net TN (tpa)	Reduction in Net TN (tpa)	% Reduction from land sources in N to Exmouth Gulf
Mangroves	650	-3	-1.91	N/A – no N export to Exmouth Gulf	4.3	645.7	-1.9	N/A – no N export to Exmouth Gulf	N/A – no N export to Exmouth Gulf
Algal Mats	3,600	68	241	8.4	12.2	3,587.8	240.1	0.8	0.03
Salts Flats	14,000	0.9	12.4	0.4	10,500	3,500	3.1	9.3	0.3
Hinterland	197,000	0.1	19.4	0.7	950	196,050	19.3	0.09	0.003
Offshore	-	-	2600	90.5	0	-	2600	0	0
Intertidal and terrestrial total			**273**		11,466		**262.5**	10.2	**3.9**
Total			**2,873**				**2,862.5**	10.2	**0.36**

Table Note: Coloured shading relates to Table 5-1.

5 DISCUSSION

5.1 Assessment Conservatism

This nutrient pathway assessment is extremely conservative because:

- Conservative nitrogen import and leaching rates have been applied within the model and habitat modification calculations (Section 3.5 and 4.3.7).
- The annual nitrogen exports from the creeks were calculated by extrapolating out the ambient and seasonal high-water levels. As a conservative estimate of 10 months of ambient simulation was combined with 2 months of the seasonal high-water results. This is a conservative estimate because months which have limited inundation due to seasonally lower water levels are not considered, therefore increasing the potential nitrogen exports from algal mats.
- The annual estimate for nitrogen contribution from offshore waters is also conservative. It underestimates the annual offshore nitrogen contribution by using only intermittent upwelling events and ignoring tidal exchange, thereby reducing the potential offshore contribution by approximately half. By using a low and conservative estimate for offshore (ocean) nitrogen sources, proportional changes to the nitrogen budget related to intertidal and terrestrial (land) sources will be larger, therefore potential impacts from the project will be overestimated.
- The modelling results represent changes to nitrogen exports from the mouth of Urala Creek North and South only, and do not account for altered overland flow paths which may result in some nutrients being exported via different land/water interfaces. Thus, the model likely overestimates post-development nutrient reductions.
- The design rainfall events used are considered extremely conservative as they apply a spatially constant rainfall rate over the entire model domain, which in reality would be very unlikely to occur due to the vast extent of the catchment.
- Estimated habitat modification areas are conservative with larger disturbance areas than expected being included in the salt flats and hinterland.
- Nitrogen losses associated with modelled overland flows and habitat modification overlap in the salt flats, and therefore have been accounted for twice.

5.2 Overall Analysis

The nutrient related impacts predicted by this study are small in proportion to the total estimated nutrient flows into the project catchment and Exmouth Gulf.

Table 5-1 is a summary of Table 4-5, Table 4-7, Table 4-8 and Table 4-9 and estimates:

- A local post-development proportional reduction in nitrogen flows into the project catchment of:
  - 7.7% of land sources.
  - 0.8% of land and ocean sources.
- A regional post-development proportional reduction in nitrogen flows into the Exmouth Gulf of:
  - 3.2% of land sources.
  - 0.24% of land and ocean sources.

TABLE 5-1 ESTIMATED REGIONAL AND LOCAL POST-DEVELOPMENT PROPORTIONAL NITROGEN REDUCTIONS

Nutrient Pathway	Nitrogen Reduction Project Catchment		Nitrogen Reduction Exmouth Gulf	
	% reduction of land sources	% reduction of land and ocean sources	% reduction of land sources	% reduction of land and ocean sources
Tidal Inundation	0 (see Table 4-5)	0 (see Table 4-5)	0 (see Table 4-5)	0 (see Table 4-5)
Rainfall Overland Flow	3.8 (see Table 4-7)	0.4 (see Table 4-7	1.6 (see Table 4-7	0.12 (see Table 4-7
Habitat Modification	3.9 (see *Table Note: Coloured shading relates to Table 5-1.* Table 4-9)	0.36 (see *Table Note: Coloured shading relates to Table 5-1.* Table 4-9)	1.6 (see Table 4-8)	0.12 (see Table 4-8)
Total	7.7	0.8	3.2	0.24

Table Note: Colour coding has been applied to help identify key information in origin tables.

5.3 Conclusion

Based on this highly conservative assessment, it can be concluded that the proposed development will not significantly alter nutrient exports or pathways due to the small scale of the predicted reductions and their infrequent nature, particularly when compared to the overall nitrogen budget of the Exmouth Gulf. Impacts related to nutrient pathways are not predicted to compromise existing environmental values.

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