

MARINE

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WA Marine Pty Ltd t/as O2 Marine ACN 168 014 819

Originating Office – Southwest Suite 5, 18 Griffin Drive, Dunsborough WA 6281 T 1300 739 447 | info@o2marine.com.au







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Transmission Register

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Name	Email Address
Neil Dixon	Neil.Dixon@bciminerals.com.au
Gavin Edwards	gedwards@prestonconsulting.com.au



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Acronyms and Abbreviations

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Acronyms/Abbreviation	Description
ВСН	Benthic Community Habitats
DoF	Department of Fisheries
DoTEE	Department of the Environment and Energy
DMP	Dredge Management Plan
DWER	Department of Water and Environment Regulation
EPA	Environmental Protection Authority
EPO	Environmental Protection Outcomes
ESD	Environmental Scoping Document
ha	Hectares
HAC	Harbour Approach Channel
ktpa	Thousand tons per annum
M^3	Cubic meters
mAHD	Meters Australian Height Datum
MEQ	Marine Environmental Quality
MTs	Management Targets
Mtpa	Million tons per annum
MWQMP	Marine Water Quality Monitoring Program
PASS	Potential Acid Sulfate Soils
PER	Public Environmental Review
The Proponent	Mardie Minerals Pty Ltd
The Proposal	The Mardie Project
SOP	Sulphate of Potash
SOPEP	Shipboard Oil Pollution Emergency Plan
SOW	Scope of Works
TMF	Tiered Management Framework
UAV	Unmanned Arial Vehicle
ZoHI	Zone of High Impact
Zol	Zone of Influence
ZoMI	Zone of Moderate Impact



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1. Introduction

1.1. **Short Summary of the Proposal**

Table 1. **Short Summary of the Proposal**

Proposal Title	Mardie Project
Proponent Name	Mardie Minerals Pty Ltd
Short Description	Mardie Minerals Pty Ltd is seeking to develop a greenfields high quality salt and sulphate of potash (SOP) project and associated export facility at Mardie, approximately 80 km south west of Karratha, in the Pilbara region of WA. The proposal will utilise seawater to produce a high purity salt product, SOP and other products derived from sea water.
	The proposal includes the development of a seawater intake, concentrator and crystalliser ponds, processing facilities and stockpile areas, bitterns disposal pipeline and diffuser, trestle jetty export facility, transhipment channel, drainage channels, access / haul roads, desalination (reverse osmosis) plant, borrow pits, pipelines, and associated infrastructure (power supply, communications equipment, offices, workshops, accommodation village, laydown areas, sewage treatment plant, landfill facility, etc.).

1.2. **Proponent**

The proponent for the proposal is Mardie Minerals Pty Ltd which is a wholly owned subsidiary of BCI Minerals Pty Ltd. Proponent details are provided in **Table 2**.

Table 2. **Proponent Details**

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Company Name:	Mardie Minerals Pty Ltd
Australian Business Number (ABN):	50 152 574 457
Address:	Level 1, 15 Rheola Street West Perth
Key Contact (Role):	Michael Klvac (General Manager Corporate Affairs))
Key Contact Details:	Email: Michael.Klvac@bciminerals.com.au
	Phone: +61 8 6311 3400



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1.3. **Project Description**

Mardie Minerals Pty Ltd (Mardie Minerals) seeks to develop the Mardie Project (the proposal), a greenfields high-quality salt project in the Pilbara region of Western Australia (Figure 1). Mardie Minerals is a wholly-owned subsidiary of BCI Minerals Limited.

The proposal is a solar salt project that utilises seawater and evaporation to produce raw salts as a feedstock for dedicated processing facilities that will produce a high purity salt, industrial grade fertiliser products, and other commercial by-products. Production rates of 4.0 Million tonnes per annum (Mtpa) of salt (NaCl), 100 kilo tonnes per annum (ktpa) of Sulphate of Potash (SoP), and up to 300 ktpa of other salt products are being targeted, sourced from a 150 Gigalitre per annum (GLpa) seawater intake. To meet this production, the following infrastructure will be developed:

- Seawater intake, pump station and pipeline;
- Concentrator ponds;
- Drainage channels;
- Crystalliser ponds;
- Trestle jetty and transhipment berth/channel;
- Bitterns disposal pipeline and diffuser;
- Processing facilities and stockpiles;
- Administration buildings;
- > Accommodation village,
- > Access / haul roads;

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- > Desalination plant for freshwater production, with brine discharged to the evaporation ponds; and
- > Associated infrastructure such as power supply, communications, workshop, laydown, landfill facility, sewage treatment plant, etc

Mardie Project: Dredge Management Plan



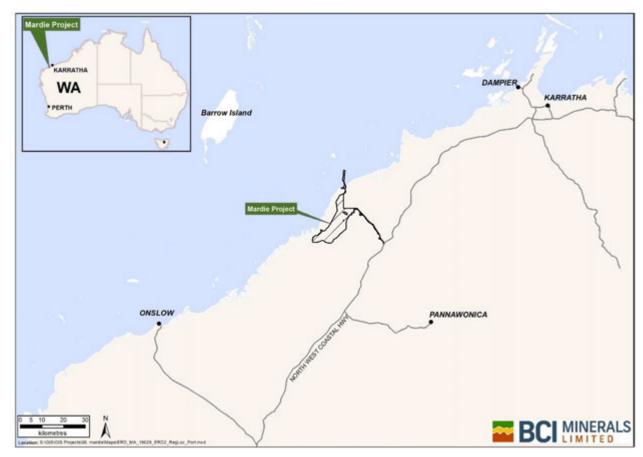


Figure 1. Project Location

Seawater for the process will be pumped from a large tidal creek into the concentrator ponds. All pumps will be screened and operated accordingly to minimise entrapment of marine fauna and any reductions in water levels in the tidal creek.

Concentrator and crystalliser ponds will be developed behind low permeability walls engineered from local clays and soils and rock armoured to protect against erosion. The height of the walls varies across the project and is matched to the flood risk for the area.

Potable water will be required for the production plants and the village. The water supply will be sourced from desalination plants which will provide the water required to support the Project. The high salinity output from the plants will be directed to a concentrator pond with the corresponding salinity, or managed through the project bitterns stream.

A 3.4 km long trestle jetty will be constructed to convey salt (NaCl) from the salt production stockpile to the transhipment berth pocket. The jetty will not impede coastal water or sediment movement, thus ensuring coastal processes are maintained.

Dredging of up to 800,000 m³ will be required to ensure sufficient depth for the transhipper berth pocket at the end of the trestle jetty, as well as along a 4 km long channel out to deeper water. The average depth of dredging is approximately 1 m below the current sea floor. The dredge spoil is inert and will be transported to shore for use within the development.



The production process will produce a high-salinity bittern that, prior to its discharge through a diffuser at the far end of the trestle jetty, will be diluted with seawater to bring its salinity closer to that of the receiving environment.

Access to the project from North West Coastal Highway will be based on an existing public road alignment that services the Mardie Station homestead and will require upgrading (i.e. widening and sealing).

The majority of the power required for the project (i.e. approximately 95%) is provided by the sun and the wind, which drives the evaporation and crystallisation processes. In addition, the Project will require diesel and gas to provide additional energy for infrastructure, support services and processing plant requirements.

The proposal will be developed within three separate development envelopes. The boundaries of these development envelopes are described in **Table 3** and shown in **Figure 2**.

Table 3. Location and proposed extent of physical and operational elements

Element	Ref.	Proposed Extent				
Physical Elements						
Ponds & Terrestrial Infrastructure Development Envelope – evaporation and crystalliser ponds, processing facilities, access / haul road, desalination plant, administration, accommodation village, quarry, laydown, other infrastructure.	Fig. 2	Disturbance of no more than 11,141 ha within the 15,667 ha Ponds & Terrestrial Infrastructure Development Envelope.				
Marine Development Envelope – trestle jetty, seawater intake and pipeline, bitterns pipeline.	Fig. 2	Disturbance of no more than 7 ha within the 53 ha Marine Development Envelope.				
Dredge Channel Development Envelope – berth pocket, channel to allow access for transhipment vessels, bitterns outfall diffuser, bitterns dilution seawater intake.		Disturbance of no more than 55 ha within the 304 ha Dredge Channel Development Envelope.				
Opera	tional E	Elements				
Desalination Plant discharge	Fig. 2	Discharge to concentrator ponds or to bitterns stream.				
Dredge volume	Fig. 2	Dredging is only to occur within the Dredge Channel Development Envelope.				
		Dredging of no more than 800,000 m3 of material from the berth pocket and high points within the transhipment channel, with the material to be deposited within the Ponds & Infrastructure Development Envelope.				
Bitterns discharge	Fig. 2	Discharge of up to 3.6 gigalitres per annum (GLpa) of bitterns within a dedicated offshore mixing zone.				



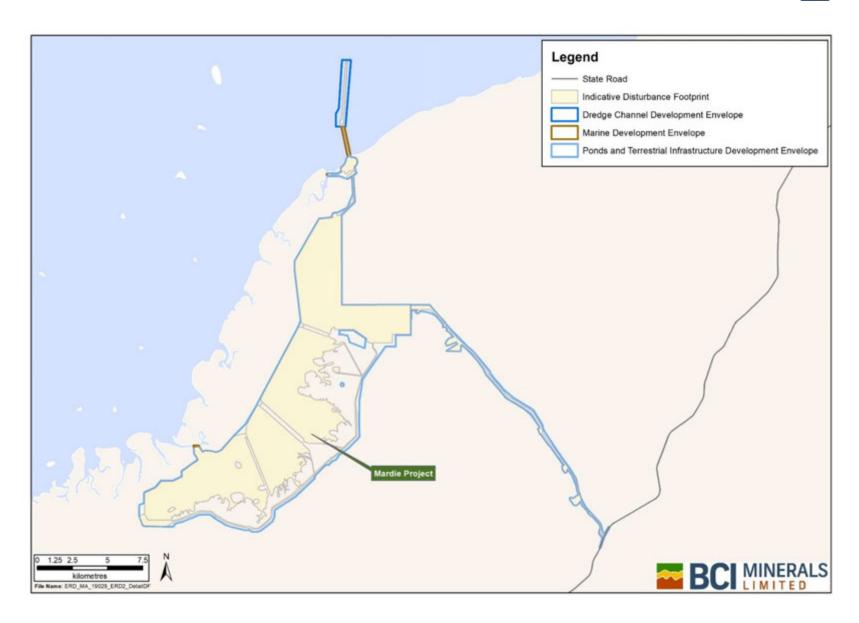


Figure 2 Mardie Project Development Envelopes: Marine, Ponds and Terrestrial Infrastructure and Transhipment Corridor



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1.4. Purpose

The purpose of this Dredge Management Plan (DMP) is to ensure compliance with Ministerial Statement (pending). Ministerial Statement (pending) includes project specific Environmental Protection Outcomes (EPO)s, and the Proponent has proposed Management Targets (MTs) and specific management and monitoring actions to ensure that these EPOs are achieved.

This document specifically details the management of potential marine impacts associated with dredge activities. Dredge spoil will be transported via previously constructed access/haul routes. Any potential terrestrial impacts will be managed via a separate management plan.

Mardie Minerals Pty Ltd Mardie Project: **Dredge Management Plan**



2. Existing Environment

2.1. Climate

The southern Pilbara region has a tropical monsoon climate with distinct wet and dry seasons. The Pilbara coast is the most cyclone prone area along the Australian coastline, with the cyclone season running from mid-December to April and peaking in February - March (Sudmeyer, 2016).

2.2. Wind

The dry season extends from May to October, and is characterised by warm to hot temperatures, easterly to south-easterly winds from the continental landmass, clear and stable conditions as the subtropical high-pressure ridge migrates over this area. In the afternoons, the winds generally shift to north-westerly, particularly later in the dry season, associated with the onset of the land sea breeze as the temperature difference between the continent and the ocean increases throughout the day. In the wet season the wind climate is dominated by westerly and north-westerly winds. Wind rose plots for the Dry Season months (May to October) and Wet Season months (November to April) are presented in Figure 3 based on analysis of the measured wind records from Mardie Airport over the period 2011 - 2018.

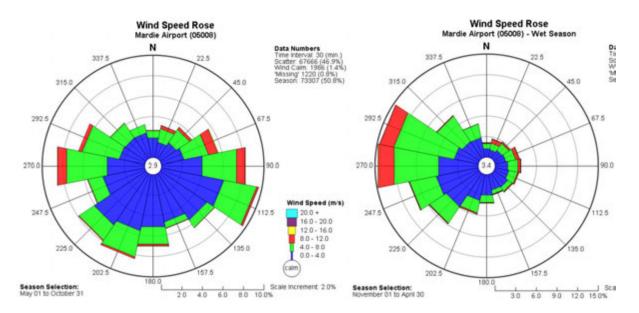


Figure 3. Wind Rose plots for Dry Season (left) and Wet Season Months (right) based data from Mardie airport.

Maximum daily temperatures at Mardie average 33.9 °C throughout the year, peaking at 38.0 °C in January and falling to 27.7 °C in July. The Pilbara is influenced by northern rainfall systems of tropical origin. These systems are responsible for heavy falls during the summer months, while the southern low-pressure systems sometimes bring limited winter rains. The annual average rainfall is only 128 mm, and the mean monthly rainfall has a bimodal distribution, peaking in January to March and also May to June, with very little rainfall from July to December. Daily rainfall can reach over 300 mm during extreme events that may occur one to two times per decade. Evaporation rates in the region are high, estimated to exceed by ten times the annual rainfall



2.3. Tides

The Mardie project location experiences a semi-diurnal tide (two highs and two lows a day) and the tidal planes have been defined by the National Tide Centre (NTC) based on field measurements completed for the project in late 2018 (O2 Marine 2020). The Mardi Gauge (MardiLAT18) datum definition completed by the NTC shows that the offset between LAT and MSL is 2.75 m and the total tidal range is 5.185 m. The mean tide range is 3.6m in springs and 1m in neaps.

2.4. Waves

The northwest shelf of Western Australia experiences waves generated from three primary sources: Indian Ocean swell, locally generated wind-waves and tropical cyclone waves. Along the shoreline the ambient (non-cyclonic) wave climate is generally mild. In dry season months low amplitude swell originating in the Indian Ocean propagates to the site and occurs in conjunction with locally generated sea waves of short period (<5s). In the wet season the wave climate is locally generated sea waves from the south to southwest. In general, the significant wave height is dominated by locally generated sea conditions within the range of 0.5m to 1m at short wave periods (Tp< 5 s). Measured data from an ADCP instrument deployed approximately 15km offshore for the project has been analysed to characterise the wave conditions in the wet and dry seasons as shown in **Figure 4**.

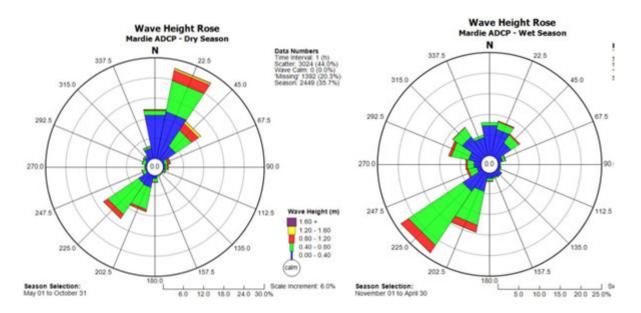


Figure 4. Mardie Wave conditions, Dry Season (left) and West Season (right) based on measured data April 2018 – January 2019.

Whilst the non-cyclonic ambient wave conditions are generally mild, in contrast the strong winds in a tropical cyclone can generate extreme wave conditions. It is noted that the offshore island features would provide some natural protection form extreme wave conditions depending on the direction of propagation. Extreme cyclonic waves contribute to the total water level through wave run-up which is the maximum vertical extent of wave uprush on a beach and is comprised both wave set-up and swash. The impact of cyclonic waves on the study site is dependent on the prevailing water level conditions and direction of cyclone approach. If coincident with a spring tide and storm surge, waves could



propagate beyond the typical position of the beach and induce erosion of the shoreline as well as sediment transport.

2.5. Substrate and BCH

The project area is located in shallow (<6 m) nearshore waters located approximately 5 km offshore, north from the Mardie Coastline and southwest from the Fortescue River-mouth. The seafloor in this area is generally comprised of unconsolidated silt, sand and gravel.

O2 Marine (2019b) identified the nearshore subtidal zone to support benthic primary producers such as sparse patches of macroalgae, seagrass and corals (**Figure 5**). The majority of the subtidal benthic substrata is abiotic characterised by bare sand and silt with limited limestone pavement and ridges. Many of the limestone ridges also occur around the offshore islands and support assemblages of macroalgae, corals and sponges. Whilst the extensive plains of sand/silt are often bare of any sessile mega-benthic taxa (such as coral and macroalgae) these habitats do support smaller infaunal species and surface-dwelling echinoderms and filter feeders such as hydroids.

A baseline sediment assessment of the Mardi Project identified that of the Contaminants of Potential Concern (CoPC) analysed, only arsenic and nickel (95% UCL of mean) concentrations exceeded the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018). However, these levels are consistent with previous sediment quality studies undertaken in the Pilbara region and are considered naturally elevated ambient background levels (DEC, 2006). All sediment samples collected within the dredge footprint recorded no PASS (O2 Marine, 2019a). Therefore, baseline sediment results indicate that dredge sediments reflect natural background conditions and are suitable for onshore disposal.



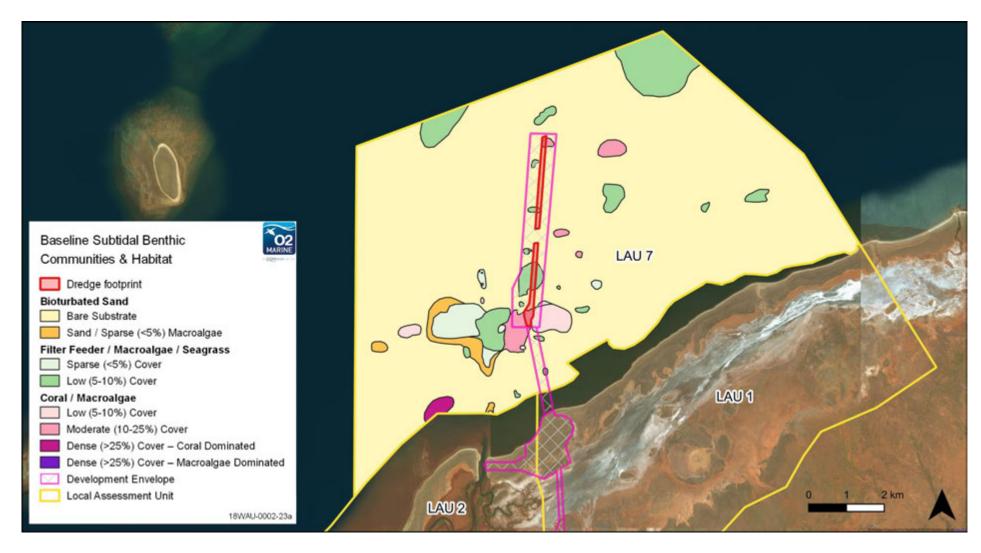


Figure 5. Project Subtidal Benthic Community Habitats (O2 Marine 2019b).



2.6. Marine Water Quality

Nearshore waters typical of this region are characterised by variable turbidity and high sedimentation rates, with associated highly variable light regimes and seawater temperatures. Offshore waters exhibit fewer extremes in the water quality, but still display occasional high levels of sedimentation and turbidity, low light and variable seawater temperatures (Pearce et al, 2003).

Light, turbidity, seawater temperature and sedimentation rates are typically weather dependent and show a strong seasonal transition from the dry to the wet seasons. Large daily tidal ranges (>5 m), strong winds (gusts >50 km/h) and increased wave activity (such as associated with cyclonic activity) can impact background conditions resulting in increased turbidity (in the form of increase suspended sediment concentration (SSC) due to coastal runoff and wind/wave driven sediment resuspension. In summary, waters in the vicinity of the project area are subject to naturally elevated levels of turbidity and a reduced light climate heavily influenced by discrete weather events (Pearce et al, 2003).

O2 Marine (2020) identified the following from marine water quality baseline studies conducted at the Mardie Project study area.

- Salinity levels recorded a median value of 37.5 ppt, and appeared to be indicative of a sheltered bay, which was thought to be due to the influence of the Passage Islands which act as a natural barrier and appear to restrict mixing with lower salinity oceanic waters;
- > Turbidity and SSC were found to be higher at the inshore monitoring location than at the offshore location, which is consistent with other Pilbara water quality investigations (Jones et al. 2019; MScience 2009; Pearce 2003);
- Derived Daily light Integral (DLI) for the offshore location was highest during wet season and lowest during the dry season and correlated with seasonal change in solar elevation angle, which is a primary factor influencing the amount of available benthic light at the offshore location. DLI was low year-round at the inshore location. Factors influencing benthic light levels are different between the offshore and inshore areas. However, the lowest light levels corresponded closely with high SSC and turbidity levels, with the lowest values recorded during the passing of several Tropical Cyclones and low-pressure systems over the sampling period;
- The recently published WAMSI (Jones et al. 2019) SSC and DLI thresholds for possible and probable effects on coral were not found to be suitable as criteria for monitoring dredging effects in the offshore or inshore portion of the Mardie Project area. Frequent natural exceedances of SSC and DLI thresholds indicates that these thresholds are not appropriate for use as dredge monitoring criteria in the Mardie Project area. It is noted that Jones et al. (2019) recognises these potential limitations of the thresholds and advises that WAMSI is in the process of developing thresholds for turbid water coral communities. Once these new turbid water thresholds are available, they should be evaluated against the baseline data collected in this program and as part of the pre-dredging baseline to determine suitability for use in dredge monitoring; and
- > Laboratory analysis of marine water samples showed no evidence of contamination and the current allocation of maximum and high levels of ecological protection are appropriate for the marine waters of the Mardie Project area.

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2.7. Marine Fauna

O2 Marine undertook a detailed marine fauna review in relation to the Mardie Project. Full results are detailed in O2 Marine (2019d). In summary, five, conservation significant marine fauna (excluding turtles - discussed below) that are either 'known to occur' or have a 'high potential to occur' in the Mardie Project area are:

- Three marine mammals:
 - Humpback Whale;
 - Dugong; and
 - Australian Humpback Dolphin.
- > One marine reptile (excluding turtles):
 - Short-nosed Sea Snake; and
- > One Elasmobranch:
 - Green Sawfish

Humpback whales were considered to be transient and are only likely to use the Project area as a stopover point during the southern migration period (i.e. September). However, they have been observed previously within 5km of the Project and as such management measures should consider impacts to this species.

Dugong have been observed in the vicinity of the Project area. However, the project area is considered to be of limited value to dugong populations due to lack of important feeding and foraging habitat (i.e. seagrass meadows). This conclusion is supported by aerial surveys and vessel-based observations which identified Coolgra Point to the south and Cape Preston to the north as supporting greater number of dugong. Nevertheless, dugong may be present in the Project area, particularly between June -September and management measures should consider impacts to this species.

Australian Humpback dolphins have previously been recorded in the Project area and as such management measures should consider impacts to this and other dolphin species.

The Short-nosed sea snake has not been previously recorded in the Mardie Project area. This species is typically found in coral reef habitats, which in the waters of the Project area are largely confined to the nearshore islands with fringing coral reefs and/or isolated reef patches. It is therefore unlikely the project would disturb or alter the habitat of this species and therefore it is unlikely any impact is expected to occur to this species as a result of the project.

Two species of sawfish have been recorded in similar tidal creeks located to both the north and south of the Mardie Project area and appropriate management measures should be considered to avoid impacts to this species, including consideration of impacts to pupping in the tidal creeks between September to October.

In addition to conservation significant species, the Onslow Prawn Managed Fishery (OPMF) Fortescue Nursery Area was identified as a commercially important area which encompasses the entire Mardie Project area. Therefore, ongoing consultation with WAFIC is considered important to informing the development of any appropriate management strategies to mitigate impacts on this important nursery area.

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The extensive mangrove habitats of the Project area were recognised as the most important habitat feature of the Project area for marine fauna as these provide important nursery and feeding areas for a range of species, including fish, turtles, invertebrates and migratory birds. However, overall, the Mardie Project area was not considered to be of particular significance to any of the abovementioned conservation significant marine fauna species.

Pendoley Environmental Pty Ltd undertook December 2018 and February 2019 turtle studies to describe populations that use suitable mainland and island habitat in proximity to the proposed footprint of the Mardie Project (Pendoley 2019).

Results found that the abundance, species composition, and distribution of nesting turtles on undisturbed habitat was typical of the region; with flatback turtle nesting dominating offshore island habitat and relatively less activity on the mainland. The mainland coast adjacent to the project site was characterised by very low nesting activity relative to other mainland sites such as Mundabullangana, Onslow Back Beach, and Ashburton Delta (near Onslow) and may be a reflection of the nesting habitat geomorphology which is characterised by narrow, low energy, hot, dark coloured terrigenous based moderately coarse sediments, with limited primary dune development (Pendoley 2019).

The lack of any successful flatback nesting and the presence of a single hawksbill nest (albeit past the peak of the hawksbill nesting season) on the mainland, suggests this area is not currently a regionally important rookery (Pendoley 2019).

In regards to lighting impacts it was found that, while hatchling orientation generally coincided with the direction of the horizon glow from the Sino Iron facilities, it is unlikely that the relatively small spatial extent of the sky glow visible from the nesting beach influenced hatchling orientation over the 30 km distance (Pendoley 2019).

Mardie Minerals Pty Ltd Mardie Project: **Dredge Management Plan**



3. **Construction Works**

3.1. Scope of Works

The scope of construction elements of the Project includes:

- 1. Mobilisation and installation of a floating excavator and support barges;
- 2. Preparation of the dredge material disposal area;
- 3. Dredging of the Berth Pocket and transport of dredged materials to the dredge material disposal area;
- 4. Dredging of the approach channel and transport of dredged materials to the dredge material disposal area;
- 5. Dredged materials handling at the dredge material disposal area as required;
- 6. Pre- and post-dredge hydrographic Survey(s); and
- 7. Demobilisation and site clearance upon completion of the Works.

3.2. Sequence of Works

The project allows for all works to be carried out over 12 hours per day, 7 days per week, during suitable weather conditions. The planned project sequence is as follows, whereby the tasks listed below may occur concurrently or overlap if multiple work fronts are achievable.

- 1. Equipment preparation; Inspection; Certification;
- 2. Preparation of all relevant Project Management Plans;
- 3. Pre-dredge hydrographic survey and land survey for the disposal area;
- 4. Mobilisation of all plant and equipment;
- 5. Site set-up including construction of road, crossings and causeways;
- 6. Preparation of disposal area(s);
- 7. Commence and complete dredging of access channel and berth pocket, and disposal of dredged materials;
- 8. Progressive Hand-Over Hydrographic Surveys for each section;
- 9. Final land-survey of "as-placed" dredged materials;
- 10. Demobilisation and site clearing.

3.3. **Preliminary Construction Schedule**

Under the current project schedule, dredging construction activities are planned to commence as soon as practicable once all required internal and external approvals are granted. Dredging and onshore spoil disposal is proposed to be undertaken over a period of approximately 2 years (not continuous). An indicative project schedule is presented in **Table 4**.



Table 4. Preliminary project construction schedule

PROJECT SCHEDULE MILESTONE	ESTIMATED DURATION
Project Preliminaries	6 weeks
Mobilisation & Installation	12 weeks
Dredging and spoil disposal	60 - 80 weeks (weather dependent)
Final land survey	2 weeks
Demobilisation and site clearance	4 weeks

3.4. Pre and Post Dredge Hydrographic Survey(s)

Each identified dredge section (separable portion) within the contract will have an individual pre-dredge hydrographic survey performed to determine as accurately as possible the total volume which is to be removed. Upon completion of the Works in each section, a post-dredging hydrographic survey will be carried out to determine if the specifications for that section has been met.

Both surveys (pre- and post) will form part of the final hand-over documents and will serve to calculate the final volumes removed and the payment volume considering the maximum payable depth.

3.5. Dredging Methodology

A backhoe dredge will be used to deepen the proposed transhipment approach channel and the berthing pocket for the project. A backhoe dredge is essentially an excavator secured to a manoeuvrable barge (**Figure 6**).

During dredge operations the dredge vessel will be secured to the seabed. The excavator includes a 10m³ bucket, and it is expected that in optimal operating conditions, 50 buckets (at 80% full) will be excavated per hour (400m³/hr).

The dredging will occur during daylight hours over a 12-hour shift, with actual dredge operation times expected for 10 hours per day. Typically, three or more loader barges will be used in a 'loading, transit, unloading, transit' sequence to maximise efficiency of transporting dredge sediment from the dredge site to the disposal location.

A loader barge will pull along-side the dredge vessel and will be loaded direct from the excavator bucket. Once full, the loader barge will pull away and transport dredge sediment to the shore (whilst a secondary loader barge pulls alongside the dredge vessel for loading). On shore the dredge sediment will be unloaded and conveyed to the dredge material disposal area.





Figure 6. Example of a Backhoe Dredge proposed for Project dredging.

3.6. Dredge Plume Modelling

Baird Australia Pty Ltd was engaged to undertake dredge plume modelling in relation to the proposed dredge scope at Mardie. The objectives of the modelling were to:

- 1. Determine the location, extent and duration of a potential dredge plumes;
- 2. Model realistic sediment plume outputs over the proposed dredge period (dry season) relevant to the scale of the dredging (including potential worst-case impact scenarios) to guide appropriate management (discussed in this document); and
- 3. Assess the likely dredge plume impact in relation to turbidity on biota and BCH.

The modelling software used is the Delft3D model suite, an industry standard model system developed by Delft Hydraulics (now Deltares), in the Netherlands. The model consists of several modules capable of simulating the complex hydrodynamic processes in the nearshore environment and assessment of sediment plumes associated with the planned dredging activities (Baird 2020a).

The FLOW and WAVE modules were applied to recreate the environmental forces acting through the water column during the different dredge sequences, influenced by tides, wind and waves. The model utilised a combination of regional scale hydrodynamic and wave models for the north-west shelf (NWS) (**Figure 7**), and specific baseline data collected at Mardie by O2 Marine (O2 Marine 2020).



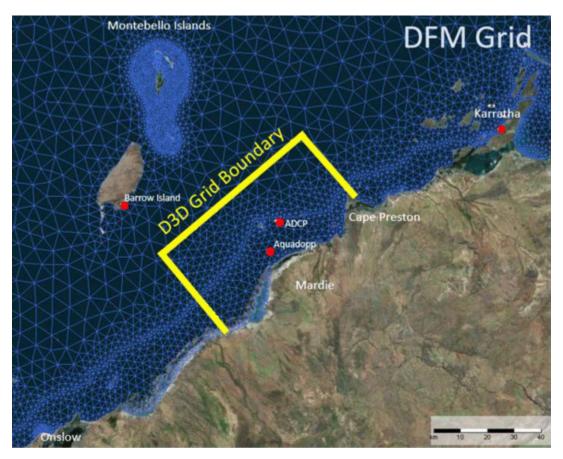


Figure 7. Area of Interest for Local Scale Model, overlain on Existing Regional Model Grid (Baird 2020b).

The dredging approach and methodology was defined by BCIM for incorporation into the dredge plume modelling process based on a backhoe dredge operating from a barge with a hopper alongside. Dredge rates adopted in the modelling process were based on a target production rate of 2,000m3 a day, with a sensitivity case examined based on an upper limit production rate of 2,500m3 a day. CMW (2019) provides a detailed geotechnical analysis of sediments within the dredge footprint, this information has informed understanding of the composition of the seabed material which will be dredged. The dredge material is very high in fine sediments (clays, silts) representing between 38% and 75% of the material by volume in sections of the channel. The required volume of dredging material was calculated through the footprint based on high resolution multibeam survey and requirements to achieve the target design depth which is -3.9m LAT in the channel and -6.7mLAT in the berth pocket.

Sediment plumes from dredging will be generated from 2 principal sources: mobilisation of fine sediments at the excavator bucket with each load and overflow water from the hopper barges. These have been input to the model as:

- > 4% by mass of total fine sediments (fine sand, clay and silt fractions) lost as the bucket comes up through the water column from the seabed.
- > 10% by mass of fines (< 62um) in suspension in the hopper discharging into the upper water column (conservative assumption).

The preparation of the time series inputs to the model cases were developed based on the dredging volume requirements and considering the geotechnical investigations and sediment sampling analysis of the seabed composition. Dredge sequences (SEC1 through to SEC7) were established along the



proposed dredge footprint, with the model simulating the dredge program running over two consecutive years of dry season conditions. Modelled best and worst case scenarios (and associated zones of impact) for the different dredge sequences are shown in **Figure 8**, **Figure 9** and **Figure 10**.

The dredge plume impacts are most pronounced inshore associated with dredging of large volumes of material over a comparatively small spatial area (SEC1 - 5). For the offshore sections of the channel (SEC6 & SEC7) the dredging requirements are spread out over a much larger area and the dredge plumes impacts significantly less. Additionally, the fines content is much higher inshore than offshore (up to 75% inshore compared with 38% through the offshore sections of the channel).

The Environment Protection Authority spatially based zonation scheme to describe the predicted extent, severity and duration of impacts associated with the Mardie project dredging have been determined through the processing and assessment of the dredge plume model results. Based on guidance from the WA Marine Science Institute (WAMSI) in relation to *possible* and *probable* coral mortality thresholds (Fisher *et. al.* 2019), the model identified zones of predicted likely best and worst-case scenarios for both the Zone of High Impact (ZoHI) and Zone of Moderate Impact (ZoMI) for all dredge sequences combined (**Figure 11**). It is noted that for the offshore portion of the dredging footprint (Transhipment approach channel) the boundaries of the ZoMI best and worst case are coincident.

Mardie Minerals Pty Ltd Mardie Project: **Dredge Management Plan**



Figure 8 shows calculated dredge plume impact areas for inshore dredge sequence SEQ1 to SEQ3. Left Image: Modelled dredge plume impact ZoMI and ZoHI based on target production rate 2,000m3/day ('Best Case'). Right Image: Modelled dredge plume impact areas ZoMI and ZoHI based on upper limit production rate of 2,500m3/day ('Worst Case').

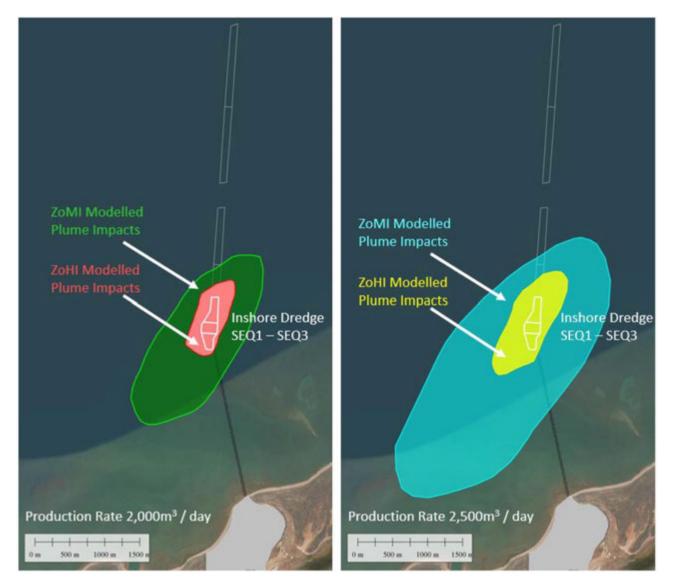


Figure 8 Calculated plume impact areas for inshore Section SEQ1 to SEQ3, best and worst case (Baird 2020b).



Figure 9 shows calculated dredge plume impact areas for inshore Section SEQ5 to SEQ6. Left Image: Modelled dredge plume impact ZoMI and ZoHI based on target production rate 2,000m3/day (best case). Right Image: Modelled dredge plume impact areas ZoMI and ZoHI based on upper limit production rate of 2,500m3/day (worst case).

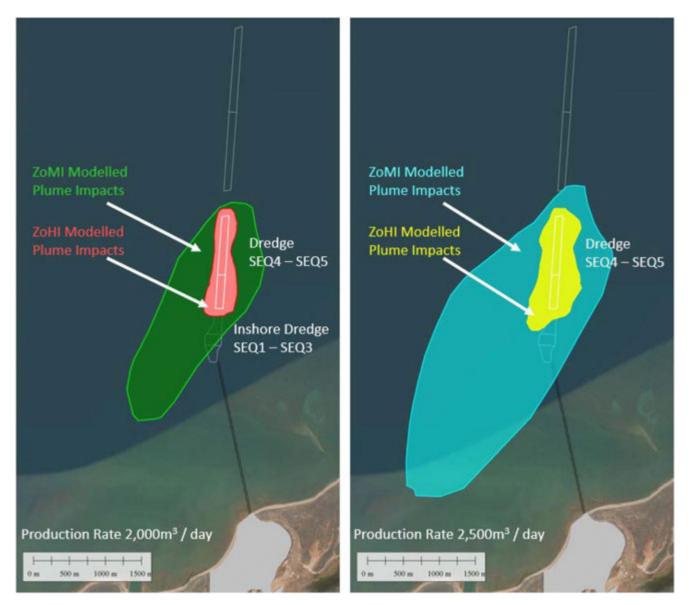


Figure 9 Calculated plume impact areas for inshore Section SEQ5 to SEQ6, best and worst case (Baird 2020b).



Figure 10 shows calculated Zones of Impact for offshore dredging in Sequence 6 and Sequence 7. Left image: Offshore dredging location. Middle Image: Modelled dredge plume impact ZoMI and ZoHI for offshore sections based on upper limit production rate (2,500m3/day). Right image: Adopted ZoMI and ZoHI extents are shown as polygons based on adopting a minimum distance from edge of channel. ZoHI is 25m from channel, ZoMI is 150m from channel. Actual modelled results are shown spatially contained within the respective bounds.

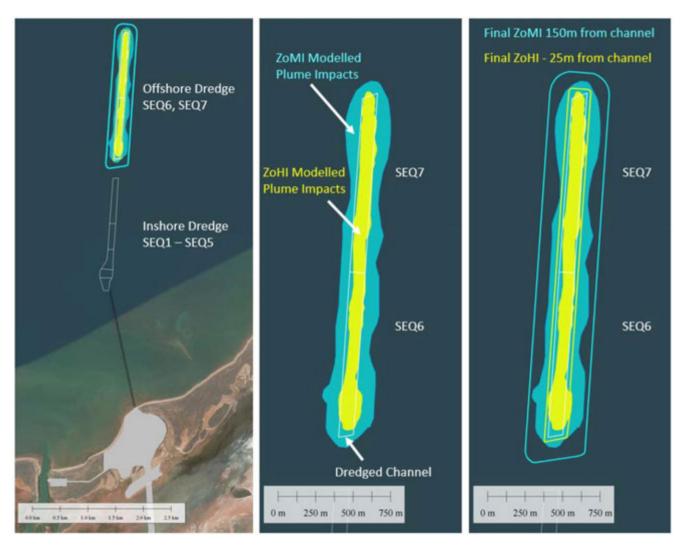


Figure 10 Calculated zones of impact for offshore dredging in Sequence 6 and Sequence 7 (Baird 2020b).



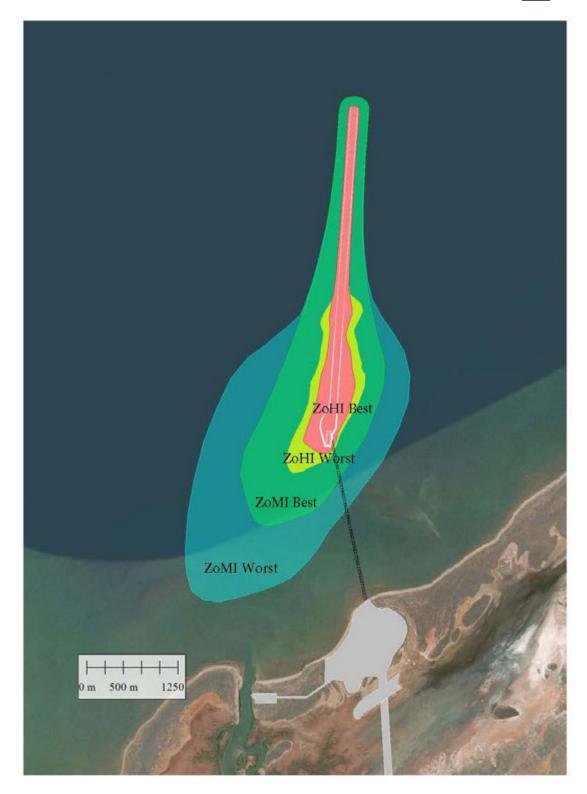


Figure 11. Calculated overall Zones of Impact (ZoMI and ZoHI) for best and worst case scenarios (Baird, 2020b)

3.7. Onshore Spoil Disposal

Dredge material will be unloaded from the loader barges at the shoreline and transported to a predetermined spoil disposal area, where the spoil will be utilised to construct land-based components for the project (including bunds and pads, windrows, transit routes and ramps etc).



4. Roles and Responsibilities

Table 5. Project Roles and Responsibilities

Position	Responsibility
	 Overall responsibility for implementation of this DMP. Overall responsibility for complying with all relevant legislation, standards and guidelines. Ensures dredging activities are conducted in an environment safe for both site personnel and the public. Reports on environmental performance for the project to relevant DMAs and to the Key Stakeholders. Responsible for the implementation of the environmental monitoring programs and inspections. Prepares environmental monitoring reports. Responsible for environmental compliance reporting in accordance with Ministerial Conditions (pending). Responsible for reporting all environmental non-compliance incidents in accordance with Ministerial Conditions (pending).
	 Prepares and implements an environmental management plan in accordance with the requirements of this DMP. Implements the management actions of this DMP. Ensures adequate training of all staff within its area of responsibility. Ensures all equipment is adequately maintained and correctly operated. Responsible for reporting all environmental incidents to Proponent Environmental Advisor within 24 hours in accordance with incident reporting procedures.
	 Comply with the requirements of this DMP. Comply with all legal requirements under the approvals documents and relevant Acts. Exercise a Duty of Care to the environment at all times. Report all environmental incidents.

Mardie Minerals Pty Ltd Mardie Project: **Dredge Management Plan**



5. Environmental Factors and Objectives

The key environmental factors and objectives to be managed under this DMP have been derived from the Statement of Environmental Principles, Factors and Objectives (EPA 2018), which outlines objectives aimed at protecting all environments (Themes) including: Sea, Land, Water, Air and People (**Table 6**).

Correspondence provided by the EPA, dated 13 June 2018 (case number CMS17264), outlines that of the environmental factors relevant to the proposal, three factors under theme 'Sea' are of potential significance and are relevant to the dredging scope. As a result, project specific Environmental Protection Outcomes (EPOs) and Management Targets (MT) have been derived for these three factors: Benthic Communities and Habitats; Marine Environmental Water Quality; and Marine Fauna (**Table 7**).

Table 6. Factors and Objectives (EPA 2018).

Theme	Factor	Objective	
Sea	Benthic Communities and Habitats	To protect benthic communities and habitats so that biological diversity and ecological integrity are maintained.	
	Coastal Processes	To maintain the geophysical processes that shape coastal morphology so that the environmental values of the coast are protected.	
	Marine Environmental Quality	To maintain the quality of water, sediment and biota so that environmental values are protected.	
	Marine Fauna	To protect marine fauna so that biological diversity and ecological integrity are maintained.	
Land	Flora and Vegetation	To protect flora and vegetation so that biological diversity and ecological integrity are maintained.	
	Landforms	To maintain the variety and integrity of distinctive physical landforms so that environmental values are protected.	
	Subterranean Fauna	To protect subterranean fauna so that biological diversity and ecological integrity are maintained.	
	Terrestrial Environmental Quality	To maintain the quality of land and soils so that environmental values are protected.	
	Terrestrial Fauna	To protect terrestrial fauna so that biological diversity and ecological integrity are maintained.	
Water	Hydrological Processes	To maintain the hydrological regimes of groundwater and surface water so that environmental values are protected.	
	Inland Waters Environmental Quality	To maintain the quality of groundwater and surface water so that environmental values are protected.	
Air	Air Quality	To maintain air quality and minimise emissions so that environmental values are protected.	
People	Social Surroundings	To protect social surroundings from significant harm.	
	Human Health	To protect human health from significant harm.	



 Table 7.
 Potential Environmental Impacts, Environmental Protection Outcomes and Management Targets for Mardie Project.

Environmental Factor	EPA Objective	Potential Environmental Impact Pathway	Environmental Protection Outcome (EPO)	Management Target	Management Measures
Benthic Communities and Habitats	To protect BCH so that biological diversity and ecological integrity	Direct loss of BCH through dredging (capital and maintenance).	No irreversible loss of BCH outside of the worst-case ZoHl. Refer to Figure 11	No irreversible loss of BCH outside of the best-case ZoHI. Refer to Figure 11	
	are maintained.	Indirect impacts on BCH associated with changes to water quality (increased suspended sediment and/or sedimentation).	 No irreversible loss of BCH outside of the worst-case ZoHI. Refer to Figure 11 No negative change from the baseline state of BCH outside of the worst-case ZoHI and ZoMI. Refer to Figure 11 	No negative change from the baseline state of BCH outside of the best-case ZoHI and ZoMI Figure 11.	Table 8
		Indirect impacts on BCH associated with leaks or spills of hydrocarbons or chemicals.	No irreversible loss, or serious damage to BCH outside of the worst-case ZoHI. Refer to Figure 11Figure 11Error! Reference source not found.	Manage vessel bunkering, chemical storage and spill response to minimise impacts to the marine environment.	
		Indirect impact to BCH health due to Introduced Marine Pests (IMP).	No irreversible loss, or serious damage to BCH resulting from IMP introduced through project vessels.	 Manage project vessels activities to prevent IMP impacts on the environment. 	
Marine Environmental Quality	To maintain the quality of water, sediment and biota so that environmental values are protected.	Contamination of water resulting from a vessel/hydrocarbon spill (i.e. bunkering operations).	• N/A.	Manage vessel bunkering, chemical storage and spill response to minimise impacts to the marine environment.	Table 9



Environmental Factor	EPA Objective	Potential Environmental Impact Pathway	Environmental Protection Outcome (EPO)	Management Target	Management Measures	
		Disturbance of contaminants and Potential Acid Sulphate Soils (PASS) during marine construction activities (dredging).	• N/A.	Assess and manage marine sediment PASS to maintain the quality the marine and land environment.		
Marine Fauna	To protect marine fauna so that biological diversity and ecological integrity are maintained.	 Disturbance, Injury or death of marine fauna as a result of dredge operations. 	• N/A.	Manage dredge operations so no injury or death of marine fauna occurs.		
		Injury or death of marine fauna due to vessel movement (strike).		Manage vessel speed so no injury or death of marine fauna occurs as a result of vessel strike.	Table 10	
		Indirect impacts on marine fauna habitat through decreased water quality.		Manage dredge activities to minimise turbid plumes as to not impact marine fauna habitats.		
		Disturbance, Injury or death from contaminated water from hydrocarbon spills.		Manage vessel bunkering, chemical storage and spill response to minimise impacts to marine fauna.		
		Introduced Marine Pests (IMP) translocation from construction or operational vessels.		All relevant vessels to comply with Commonwealth Department of Agriculture and Water Resources – Australian Ballast Water Management Requirements.		



6. Management

The potential environmental impacts identified above in **Table 7**, have been assigned monitoring and management actions to measure compliance against the EPOs¹ and MT. Management measures for each environmental factor (EPA, 2018) are detailed below.

6.1. Benthic Communities and habitats

Management proposed to minimise potential impacts on the environmental factor 'Benthic Communities and Habitat' are described in Table 8.

 Table 8.
 Management actions to minimise impacts on Benthic Community Habitats

Environmental Factor	Benthic Communities and Habitats
Activity	Capital Dredging and Maintenance Dredging
Potential Impacts	Direct loss of BCH through dredging (capital and maintenance).
	Indirect impacts on BCH associated with changes to water quality (increased suspended sediment and/or sedimentation).
	Indirect impacts on BCH associated with leaks or spills of hydrocarbons or chemicals.
	Indirect impact to BCH health due to Introduced Marine Pests (IMP).

Management Targets	Mana	gement Actions		Environmental Performance		
	Item	Actions	Responsibility	Reporting/Evidence	Timing	Contingency
No irreversible loss of BCH outside of the best-case ZoHI.	6.1	Undertake a HAZID risk assessment with all parties to ensure potential impacts on	Proponent / Contractor	Minutes of HAZID	Prior to commencement of dredging.	N/A - Completed

¹ EPOs identified in Table 7 are not presented in the following tables as it is assumed that if the MT is achieved then the corresponding EPO will also be achieved.



Management Targets	Management Actions			Environmental Performance		
	Item	Actions	Responsibility	Reporting/Evidence	Timing	Contingency
		BCH are known and understood.				
	6.2	Utilise a satellite- based vessel monitoring system on dredge vessel to ensure no works outside the approved disturbance area.	Contractor	 Inspection of satellite-based vessel monitoring system. Daily dredge logs submitted to the proponent throughout construction. 	 Prior to and during dredge operations. Weekly throughout construction 	 Cessation of dredging activities; and Maintenance of tracking system.
No negative change from the baseline state of BCH outside of the best-case ZoHI and ZoMI	6.3	Monitor dredge operations (duration, intensity, overflow rates etc) to minimise and control SSC where possible.	Contractor	Daily dredge logs submitted to the proponent throughout construction.	Weekly throughout construction	Modify or cease dredging activities if required.
	6.4	Undertake biannual BCH assessments within the ZoMI and ZoI to determine potential impacts from dredge related turbid plumes.	Contractor	BCH Assessment Report including data (photographs/video)	Biannually (wet and dry season).	Determine source of impact and modify dredge operations if required.
	6.5	Implement the Marine Water Quality Monitoring Program (MWQMP), refer Section 7.1	Contractor/ Proponent	Telemetered Water Quality Data (i.e. NTU) Water Quality Report	Data recorded hourly provided daily. Monthly	 Determine source of impact and modify dredge operations if required.
	6.6	Undertake plume validation monitoring with Aerial Multisectoral Imagery	Proponent	Plume Validation Report	 At Start of Dredging. Quarterly during dredging, and Following a Level 2 management trigger (Table 13) 	Investigate other data sources to validate plume model (e.g. MODIS imagery).



Management Targets	Management Actions			Environmental Performance		
	Item	Actions	Responsibility	Reporting/Evidence	Timing	Contingency
Manage vessel bunkering, chemical storage and spill response to minimise impacts to the marine environment.	6.7	Develop and implement project specific management procedures: Chemical Storage and Handling Procedure. Vessel Bunkering Procedure. Shipboard Oil Pollution Emergency Plan (SOPEP).	Contractor	Approved Management Procedures/Plans	Prior to commencement of work.	 Develop and implement management procedures Update procedures where necessary.
	6.8	 All project vessels to maintain adequate spill response equipment on board. All crew to be trained in emergency spill response. 	Contractor	 Pre work inspection Monthly Inspections Crew training logs 	 Prior to commencement of works Monthly during dredge operations Refresh training regularly throughout project 	 Source spill response equipment. Train all vessel crew.
Manage project vessels activities to prevent IMP impacts on the environment.	6.9	All relevant vessels should comply with Commonwealth Department of Agriculture and Water Resources – Australian Ballast Water Management Requirements, the National Biofouling Management Guidelines for commercial vessels.	Contractor	Vessel management procedures.	Prior to vessel entering Australian Waters or moving from one Australian port to the project site.	Vessel are not to mobilise to project site without approved IMP documentation.
	6.10	All vessels that mobilise to the project	Contractor	A copy of the Vessel Check report is to be	Prior to dredge entering Australian	Vessel are not to mobilise to project site



Management Targets	Management Actions			Environmental Performance		
	Item	Actions	Responsibility	Reporting/Evidence	Timing	Contingency
		site are required to complete the WA Department of Fisheries (DoF's) 'Vessel Check' risk assessment (https://vesselcheck.fis h.wa.gov.au)		submitted to PPA for assessment along with any supporting documentation including antifoul certificates and inspection reports.	Waters or moving from one Australian port to the project site.	without approved IMP documentation.



6.2. Marine Environmental Quality

Management proposed to minimise potential impacts on the environmental factor 'Marine Environmental Quality' are described in Table 9.

Table 9. Management actions to minimise impacts on Marine Environmental Quality

Environmental Factor	Marine Environmental Quality
Activity	Capital Dredging and Maintenance Dredging
Potential Impacts	 Contamination of water resulting from a vessel/hydrocarbon spill (i.e. bunkering operations). Disturbance of contaminants and Potential Acid Sulphate Soils (PASS) during marine construction activities (dredging).

Management Targets	Management Actions			Environmental Performance		
Taryers	Item	Actions	Responsibility	Reporting/Evidence	Timing	Contingency
Manage vessel bunkering, chemical storage and spill response to minimise impacts to the marine environment	7.1	Develop and implement project specific management procedures: Chemical Storage and Handling Procedure. Bunkering Procedure. 3. Shipboard Oil Pollution Emergency Plan (SOPEP).	• Contractor	Approved Management Procedures	Prior to commencement of work.	 Develop and implement management procedures Update procedures where necessary.
	7.2	All vessel equipment to be designed and operated to prevent spills and leaks through the provision of in-built safeguards such as,	Contractor	Monthly Inspections Vessel management procedure	Monthly	 Rectify any equipment that is damaged or missing as soon as practicable. Dredge operations not to commence prior to



Management -	Mana	gement Actions		Environmental Perfor	Environmental Performance		
Targets	Item	Actions	Responsibility	Reporting/Evidence	Timing	Contingency	
		but not limited to, relief valves, overflow protection, and automatic and manual shut-down systems.				development and approval of vessel management procedures.	
	7.3	The proponent is to be notified immediately in the event of a hydrocarbon spill of any volume. An incident report will be submitted for each spill.	Contractor	Verbal communication Incident Report	Immediately verbal communication. Incident report submitted within 24 hrs of incident.	Dredge operations to cease until spill investigation is complete, and or Proponent has given authority to proceed.	
Assess and manage marine sediment PASS to maintain the quality the marine and land environment.	7.4	Undertake a sediment investigation to investigate PASS in dredge sediment. environment.	Proponent	Assessment included in referral support document.	Completed	NA - Completed	



6.3. Marine Fauna

Management proposed to minimise potential impacts on the environmental factor 'Marine Environmental Quality' are described in Table 10.

Table 10. Management actions to minimise impacts on Marine Fauna

Environmental Factor	Marine Fauna
Activity	Capital Dredging and Maintenance Dredging
Potential Impacts	 Disturbance, Injury or death of marine fauna as a result of dredge operations. Injury or death of marine fauna due to vessel movement (strike). Indirect impacts on marine fauna habitat through decreased water quality. Disturbance, Injury or death from contaminated water from hydrocarbon spills. Introduced Marine Pests (IMP) translocation from construction or operational vessels.

Management	Management Actions			Environmental Performance		
Targets	Item	Actions	Responsibility	Reporting/Evidence	Timing	Contingency
Manage dredge operations so no injury or death of marine fauna occurs.	8.1	Implement a soft start procedure prior to activating below surface operations.	Contractor	Daily dredge logs.	Each occasion, prior to activating cutter head.	Dredge operations not to commence unless a soft start procedure has been implemented.
	8.2	 All project vessels are to have at least one crew member trained as a Marine Fauna Observer (MFO) on board at all times. 	Contractor	Training certificate.	Prior to commencement of dredging.	Dredge operations not to commence unless at least one crew member is a trained MFO.
	8.3	MFO logs to be complete during all dredge operations.	Contractor	MFO logs. Monthly Environmental Monitoring Report.	 Daily whilst dredge operations are occurring. Reported monthly. 	 Investigate why MFO logs were not complete, and ensure adequate staff and



Management	Management Actions			Environmental Performance		
Targets	Item	Actions	Responsibility	Reporting/Evidence	Timing	Contingency
						resources are in place to fulfil requirement.
	8.4	Dredge operations are to cease if: Whales or dugongs are observed within 100 m of the dredge vessel. Dolphins, sawfish or turtles are observed and at risk within 50 m of the dredge vessel.	• Contractor	MFO logs, Daily dredge logs.	For the duration of dredging.	Investigate why dredge operations were not ceased and apply required correction actions.
	8.5	 Report any injured or deceased marine mega fauna (whale, dugong, sawfish, turtle or dolphin) on the project site to the Proponent. 	Contractor	Verbal/written communication Incident Report	Immediately upon observationWithin 72 hours of incident	 Investigate fauna death and apply required corrective actions and or modifications to dredge operations.
Manage vessel speed so no injury or death of marine fauna occurs as a result of vessel strike.	8.6	All construction vessels to operate at a safe speed as to avoid interaction with marine fauna at all times within project boundaries.	Contractor	Vessel GPS monitoring system	Continuous throughout vessel operations.	 Investigate why vessel was recorded in excess for the defined speed limit and amend vessel operations and activities as appropriate.
	8.7	All project vessels are to have at least one crew member trained as an MFO on board at all times.	Contractor	Training certificate.	Prior to commencement of dredging.	Crew to undertake MFO training



Management	Management Actions		Environmental Performance			
Targets	Item	Actions	Responsibility	Reporting/Evidence	Timing	Contingency
Manage dredge activities to minimise turbid plumes as to not impact marine fauna habitats.	8.8	Implement the Marine Water Quality Monitoring Program (MWQMP), refer Section 7.1	Contractor/ Proponent	Telemetered Water Quality Data (NTU) Water Quality Report	Data recorded hourly provided daily.Monthly	Determine source of impact and modify dredge operations if required.
Manage vessel bunkering, chemical storage and spill response to minimise impacts to marine fauna	8.9	 Develop and implement project specific management procedures: Chemical Storage and Handling Procedure. Bunkering Procedure. Shipboard Oil Pollution Emergency Plan (SOPEP). 	• Contractor	Approved Management Procedures	Prior to commencement of work.	 Develop and implement management procedures Update procedures where necessary.
	8.10	All vessel equipment to be designed and operated to prevent spills and leaks through the provision of in-built safeguards such as, but not limited to, relief valves, overflow protection, and automatic and manual shut-down systems.	Contractor	Vessel management procedure Monthly Inspections	 Prior to commencing dredging. Monthly 	 Rectify any equipment that is damaged or missing as soon as practicable. Dredge operations not to commence prior to development and approval of vessel management procedures.
	8.11	The proponent is to be notified immediately in the event of a hydrocarbon spill of any volume. An incident report will be submitted for each spill.	Contractor	Verbal communication Incident Report	 Immediately verbal communication. Incident report submitted with 24 hrs of incident. 	Dredge operations to cease until spill investigation is complete, and or Proponent has given authority to proceed.



Management Targets	Management Actions			Environmental Performance		
	Item	Actions	Responsibility	Reporting/Evidence	Timing	Contingency
All relevant vessels to comply with Commonwealth Department of Agriculture and Water Resources – Australian Ballast Water Management Requirements.	8.12	All relevant vessels should comply with Commonwealth Department of Agriculture and Water Resources – Australian Ballast Water Management Requirements, the National Biofouling Management Guidelines for commercial vessels.	Contractor	Vessel management procedures.	Prior to vessel entering Australian Waters or moving from one Australian port to the project site.	Vessel are not to mobilise to site without approved IMP documentation.
	8.13	All vessels that mobilise to the project site are required to complete the WA DoF's 'Vessel Check' risk assessment (https://vesselcheck.fish.wa.gov.au)	Contractor	 A copy of the Vessel Check report is to be submitted to PPA for assessment along with any supporting documentation including antifoul certificates and inspection reports. 	Prior to dredge entering Australian Waters or moving from one Australian port to the project site.	Vessel are not to mobilise to project site without approved IMP documentation.



7. Environmental Monitoring

7.1. Marine Water Quality Monitoring Program

7.1.1. Monitoring Rationale

The Marine Water Quality Monitoring Program (MWQMP) is to be implemented to ensure the EPOs for Benthic Community Habitats, Marine Environmental Quality and Marine Fauna are met.

Marine dredging activities have the potential to increase suspended sediment and sedimentation in marine waters. This change in water quality has potential to indirectly impact BCH by reducing light penetration through the water column and smothering of biota due to sedimentation.

To assist the design of the MWQMP and to select suitable monitoring locations, a validated hydrodynamic model undertaken at the project area by BCIM (Baird 2020) was used to model sediment plumes generated by dredge operations within the proposed dredge footprint. A brief presentation of the model results is presented in **Section 3.6** and full report is provided in **Appendix B**.

The proposed dredge footprint consist of two key zones, the offshore (Shipping channel) and the nearshore (marine precinct, berth pocket), hereinafter referred to respectively as Zone A and Zone B (**Figure 12**).

The model result show that the dredge plume impacts are most pronounced with dredging occurring at the nearshore (Zone A), which is associated with dredging large volumes of material over a comparatively small spatial area with a high proportion of fine content in the sediment. For the offshore section of the channel (Zone B), the dredging requirements are spread out over a much larger area and the dredge plumes impacts significantly less due to sediments possessing a much high grain size and quicker settling rate (Baird 2020). Moreover, the model shows a preferential plume direction along a north-east to south-west axis, with dredge plume impacts elongated to the southwest driven by the stronger flood tides in comparison to ebb tide.

The MWQMP was developed with the assumption that dredging will be undertaken sequentially through Zone A and Zone B (i.e. two separate monitoring phases): Phase 1 monitoring will be undertaken during the dredging of Zone A and phase 2 monitoring during the dredging of Zone B.

The proposed monitoring locations have been selected based on the predicted plume distribution for Zone A and Zone B and aligned along the predicted plume direction north-east to south-west axis. The location of each site will be moved to optimise the monitoring during phase 1 and phase 2 as shown in **Figure 13** and **Figure 14**.

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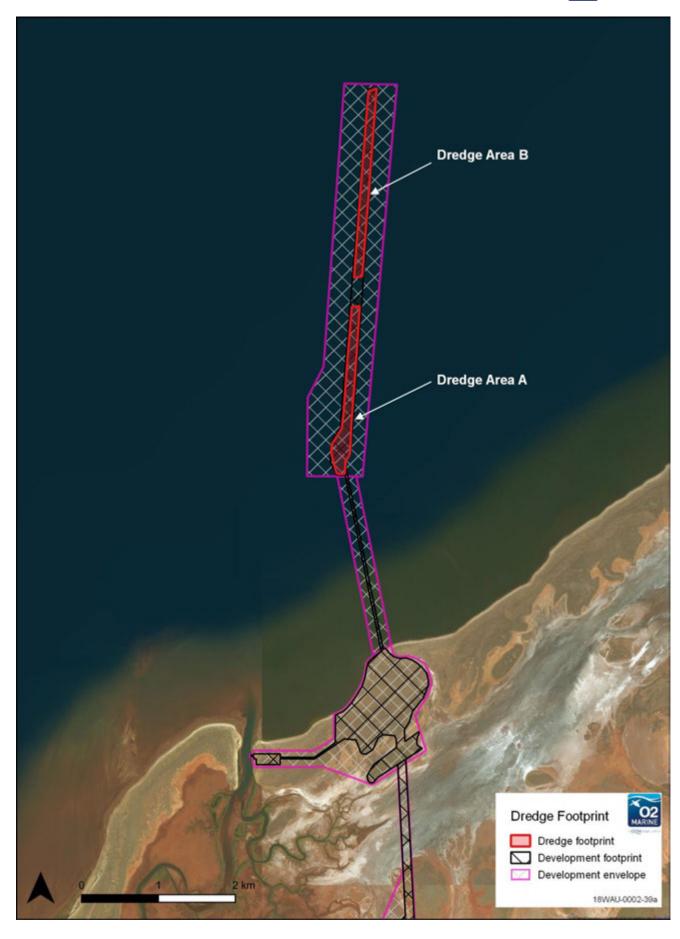


Figure 12. Proposed Dredging footprint of Dredge Zones A and B.



7.1.2. Predicted Zone of Impact and Thresholds

The model was used to develop "best-case" and "worst-case" zonation for each of the two key dredging zones (A and B), refer **Figure 13** and **Figure 14**. The best-case and worst case were derived using WAMSI threshold limit for Suspended Sediment Concentration (SSC) derived for corals (Fisher et. al. 2019) as shown in **Table 11** and **Figure 11**. The modelled SSCs were assessed against a combination of the 7, 14 and 28-day thresholds, which were applied across the model domain throughout the construction period. This resulted in the definition of likely best and worst-case Zones of High Impact (ZoHI) (irreversible loss) and Zone of Moderate Impact (ZoMI) (recoverable impact).

While the WAMSI threshold are considered appropriate to develop the modelled suspended sediment concentration to define the different zones of potential impact for dredging, these thresholds have been developed in an off-shore low turbidity environment and therefore are not considered to be suitable to be used as trigger thresholds for a dredging program in a inshore environment with high turbidity levels such as the Mardie Project. Therefore, to monitor the effects of dredging activities of the project and to trig management actions, project specific threshold for SSC will be derived relative to turbidity (NTU) baseline conditions of the project area.

Prior the commencement of dredging, a site-specific calibration of SSC vs Turbidity (NTU) with an R² >0.5 shall be derived. The site-specific nature of calibrations has been emphasised by a number of previous studies including Fisher et. al. (2019), Sternberg et. Al. (1986,1991) and today many of the best practice guidelines for the analysis of suspended sediment state the need for site specific calibrations, see for example Judd (2012).

The calibration coefficient will be applied to the real time NTU data allowing post conversion to SSC and monitoring of established triggers.

Trigger values for monitoring will be derived in accordance with the WMSI recommendation for coral monitoring using 12 months of baseline data which will be collected within 24 months prior the commencement of the dredging.

Table 11. Threshold Limits for Modelled Suspended Sediment Concentration used to define ZoMI and ZoHI regions through the dredge program (from Fisher et. al., 2019)

Threshold	Running Mean Period	ZoMI Threshold (>SSC)	ZoHl Threshold (>SSC)
5	7 day	14.7 mg/l	24.5 mg/l
Running Mean (SSC)	14 day	11.7 mg/l	18.0 mg/l
(000)	28 day	9.3 mg/l	13.2 mg/l

7.1.3. Telemetered In-situ Water Quality Monitoring.

Telemetered In-situ instruments will be installed to provide continuous one-hour interval water quality data throughout the dredge program. This data will be transmitted to an online data portal, to enable live updates allowing responsive monitoring and management. Each water quality sensor will be weighted to the seabed and positioned approximately 0.5m above the seabed. Each station will be tethered to a special designed telemetry marker boy (with navigation lighting) containing a battery and 3G/satellite telemetry components. Monitoring stations will be designed to be relocated as required based on dredge location.

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Monitoring Locations & Frequency

In-situ monitoring stations will be installed either side (east and west) of dredge operations along the predicted plume southwest-northeast axe to monitor potential plume impacts on BCH. Due to the spatial extent of the dredge footprint (Zone A and Zone B) the monitoring program will be undertaken in two phases (i.e. Phase1 & 2) and the monitoring sites will be re-located in relation to the area interested by the dredging. Impact monitoring stations and corresponding reference site locations for Zone A and Zone B are identified below in **Table 12** and **Figure 13** and **Figure 14** respectively.

Monitoring stations located at the ZoMI/ZoI best case scenario boundary location will be used to monitor EPO's and MT's associated with recoverable impacts on BCH. While stations at the ZoMI/ZoI worst-case scenario location will be used to monitor EPO's and MT's associated with no negative change of BCH from baseline conditions. Note that in relation to Dredge Zone B (Figure 12), the ZoMI/ZoI best and worst case scenarios are spatially comparable, and therefore only monitoring of the ZoMI/ZoI worst case (no negative change) scenario is required to be monitored.

Monitoring stations will be installed 8 weeks prior to commencement of dredging and will removed no less than 30 days post dredge completion.

Table 12. Indicative Water Quality Monitoring Stations for Dredge Zone A and B.

Dredge Zone	Station ID	Impact Assessment
	ZoMW-A	Zone of Moderate Impact (recoverable impacts on BCH)
	ZoME-A	Zone of Moderate Impact (recoverable impacts on BCH)
Zone A	ZoIW-A	Zone of Influence (no negative change from baseline state)
	ZoIE-A	Zone of Influence (no negative change from baseline state)
	RW-A	Reference Site
	RE-A	Reference Site
	ZoIW-B	Zone of Influence (no negative change from baseline state)
Zone B	ZoIE-B	Zone of Influence (no negative change from baseline state)
	RNW-B	Reference Site
	RNE-B	Reference Site

7.1.4. Parameters and Procedures

Each monitoring station will measure continuous turbidity (NTU) data throughout the dredging program. The derived coefficients from the SSC/NTU calibration will be used to convert NTU to SCC to allow comparison against WAMSI thresholds. Turbidity data will be downloaded daily using the telemetry system incorporated within the instrument buoy.

Turbidity sensors will be calibrated during regular maintenance and in accordance with manufacturer specifications to ensure accurate datasets are acquired.



7.1.5. Data analysis

The likelihood of a link between dredging and water quality decline will be assessed in terms of the following factors:

- Correct instrument function and operation;
- Locations of and status of dredging activities in relation to the site(s) at the time of the exceedance;
- Hydrodynamic conditions, for example wind, tide, wave and swell state at the time of the exceedance; and
- Assessment against background conditions (reference site) and extreme weather events in the region.



Table 13. Environmental Protection Outcomes, Management Targets and Trigger Levels for protection of BCH from dredging in Zone A.

	ZONE A						
Monitoring Location: ZoMI Monitoring Location: ZoMI/ZoI Boundary							
Monitoring sites lo	cated on ZoMI/ZoI best-case predicted impact boundary	Monitoring sites located on ZoMI/ZoI worst-case predicted impact boundary					
Early Warning:	Trigger Level 1 For any period of 14 or more consecutive days: - 24 hr rolling median (NTU) exceeds 80 th percentile of baseline data*; AND - Median NTU of an impact site exceeds 80 th percentile of reference site data.	Early Warning:	Trigger Level 1 For any period of 7 or more consecutive days: - 24 hr rolling median (NTU) exceeds 80 th percentile of baseline data*; AND - Median NTU of an impact site exceeds 80 th percentile of reference site data.				
Management Target: Recoverable Impact on BCH	Trigger Level 2 For any period of 14 or more consecutive days: - 24 hr rolling median (NTU) exceeds 95 th percentile of baseline data*; AND - Median NTU of an impact site exceeds 95 th percentile of reference site data	Management Target: No negative change in BCH from baseline state	Trigger Level 2 For any period of 14 or more consecutive days: - 24 hr rolling median (NTU) exceeds 80 th percentile of baseline data*; AND - Median NTU of an impact site exceeds 80 th percentile of reference site data.				
Environmental Protection Outcome: Recoverable Impact on BCH	Trigger Level 3 For any period of 14 or more consecutive days: - 24 hr rolling median (NTU) exceeds 99 th percentile of baseline data*; AND - Median NTU of an impact site exceeds 99 th percentile of reference site data.	Environmental Protection Outcome: No negative change in BCH from baseline state	Trigger Level 3 For any period of 14 or more consecutive days: - 24 hr rolling median (NTU) exceeds 95 th percentile of baseline data*; AND - Median NTU of an impact site exceeds 95 th percentile of reference site data.				

^{*}Trigger values (NTU) will be derived from 12-month site specific baseline data recorded prior to dredging.



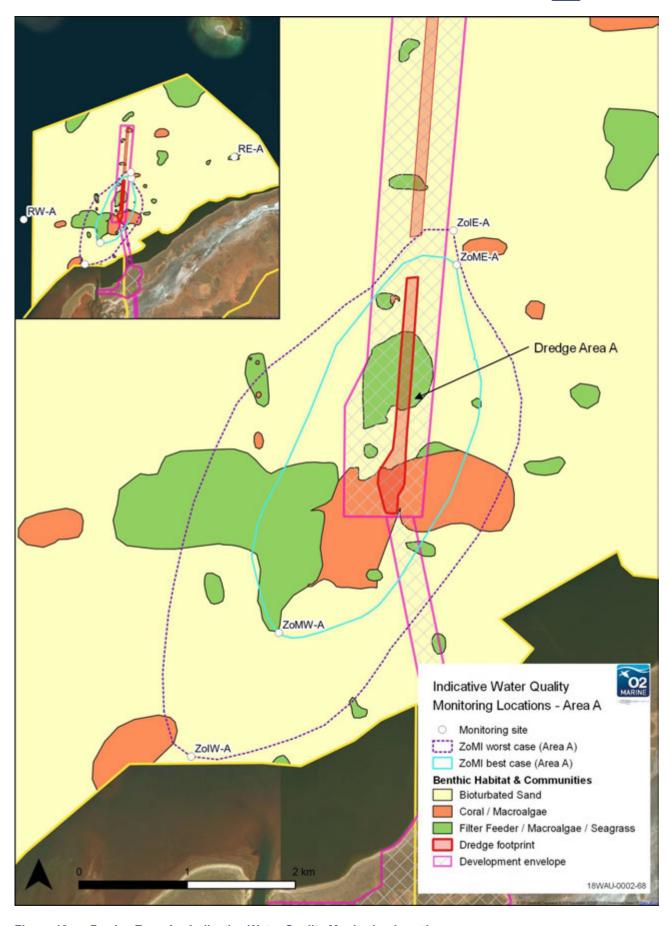


Figure 13. Dredge Zone A – Indicative Water Quality Monitoring Locations



Table 14. Environmental Protection Outcomes, Management Targets and Trigger Levels for protection of BCH from dredging in Zone B.

ZONE B						
	Monitoring Location: ZoMI/ZoI Boundary					
Monito	oring sites located on ZoMI/ZoI worst-case predicted impact boundary					
Early Warning:	Trigger Level 1					
No negative change in BCH from baseline state	For any period of 7 or more consecutive days:					
	- 24 hr rolling median (NTU) exceeds 80 th percentile of baseline data*;					
	- Median NTU of an impact site exceeds 80 th percentile of reference site data.					
Management Target:	Trigger Level 2					
No negative change in BCH from baseline state	For any period of 14 or more consecutive days:					
	- 24 hr rolling median (NTU) exceeds 80 th percentile of baseline data*;					
	- Median NTU of an impact site exceeds 80 th percentile of reference site data.					
Environmental Protection Outcome:	Trigger Level 3					
No negative change in	For any period of 14 or more consecutive days:					
BCH from baseline state	- 24 hr rolling median (NTU) exceeds 95 th percentile of baseline data*;					
	- Median NTU of an impact site exceeds 95 th percentile of reference site data.					

^{*} Trigger values (NTU) will be derived from 12-month site specific baseline data recorded prior to dredging.



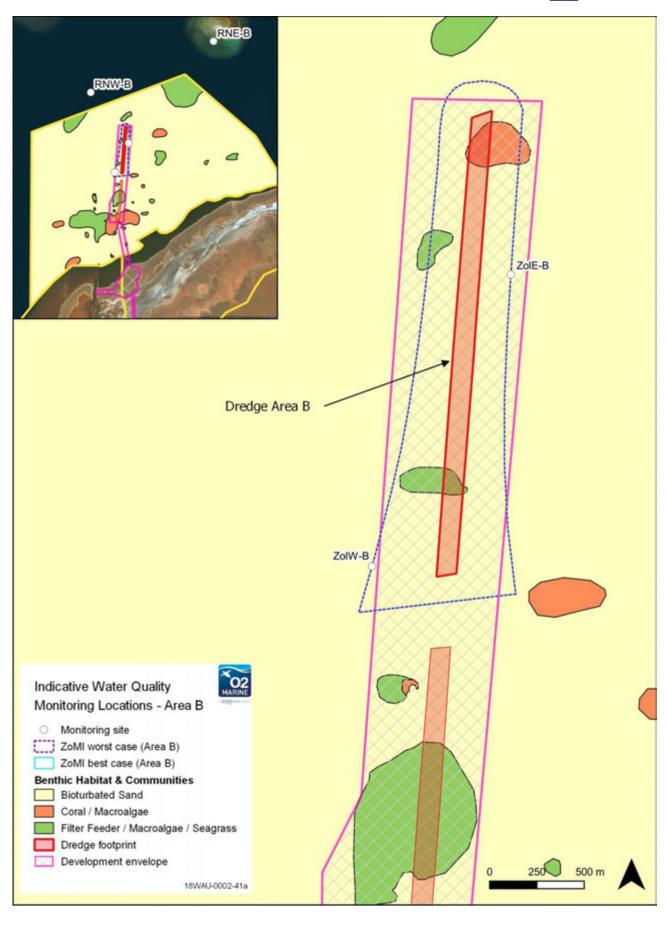


Figure 14 Dredge Zone B – Indicative Water Quality Monitoring Locations



7.1.6. Tiered Management Framework

A Tiered Management Framework (TMF) has been developed based on monitoring and reporting against the three trigger levels to ensure EPOs and MTs for protection of BCH are achieved during dredging. The TMF presented in (**Figure 15**) will be implemented by the Proponent/Contractor.



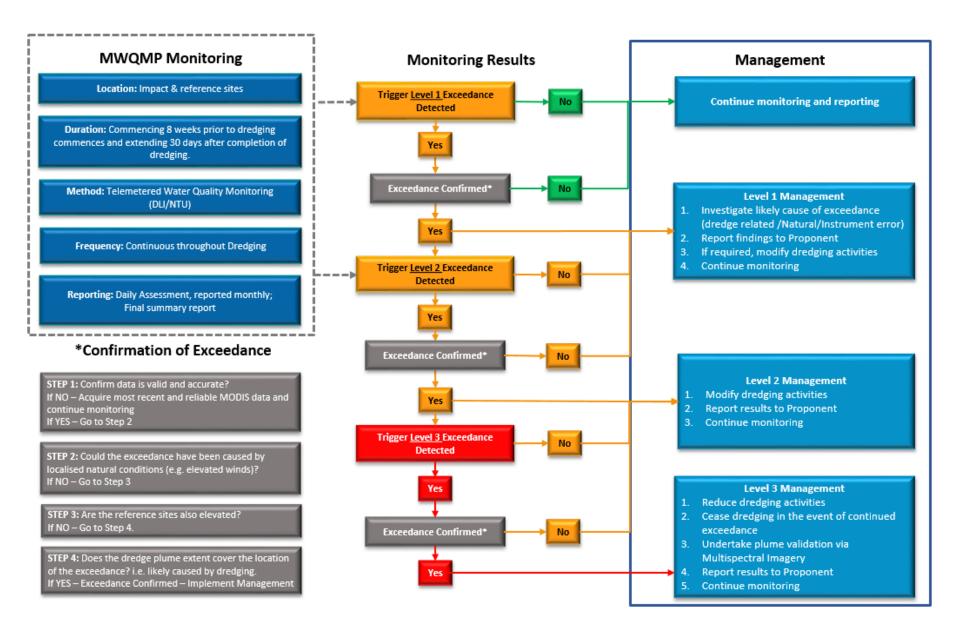


Figure 15. Tiered Management Framework for Marine Water Quality Monitoring



7.1.7. Aerial Plume Validation

Aerial multispectral imagery will be used to quantitatively assess and validate plumes models. High spatial resolution multispectral imagery validated with real-time Total Suspended Solids (TSS) samples will be captured via Unmanned Aerial Vehicle (UAV) at the start of dredging and on a quarterly basis during dredge operations. This data will allow assessment of TSS levels from dredge plumes, which are not likely to be visible via broad scale MODIS imagery due to the method of dredging and expected small scale plumes. This data will increase the accuracy of impact assessment on BCH and will help inform the predictive plume model. Multispectral imagery verification will also be implemented in the event that a Level 3 Trigger exceedance is breached (**Figure 15**). A dredge plume validation report will be prepared following each survey event.



7.2. Benthic Community Habitat Monitoring

7.2.1. Baseline BCH Survey

Subtidal BCH surveys were undertaken across the project area in March, October and December 2018, and February and March 2019 (O2 Marine 2019b). These surveys captured a pre-construction characterisation of BCH within the dredge footprint and the broader project area. In general, BCH within the dredge footprint largely is comprised of bare substrate, with small interspersed areas of low-density filter feeders, macro algae and/or seagrass. A moderate cover of coral/macroalgae was recorded immediately to the North of the dredge channel and south of the berth pocket.

7.2.2. Biannual BCH Condition Surveys

To verify ongoing BCH health and to confirm the extent of predicted recoverable impacts to subtidal BCH and evaluate the effectiveness of the MWQMP, bi-annual BCH surveys are proposed to be undertaken. **Figure 16** presents the indicative BCH monitoring locations at:

- Four (4) locations within the ZoMI (ZM1, ZM2, ZM3 and ZM4) to assess recoverable impacts.
- Four (4) locations within the ZoI (ZI1, ZI2, ZI3 and ZI4) to assess no change from baseline state, and
- Three (3) reference locations.

Both a wet season (November to April) and a dry season (May to October) survey will be undertaken to account for any seasonal variation. Survey methodology (diver or drop camera) will be confirmed with WAMSI prior to project commencement.

The bi-annual survey program will continue throughout dredging and for 12 months post-dredging or, if required, until subtidal BCH impacted as a result of dredging is considered to have recovered to a predredging condition.

Indicative BCH monitoring sites focus predominately on coral BCH where possible with sites also selected within Filter Feeder/Macroalgae/Seagrass BCH where coral BCH is not present.

7.2.3. Reporting

BCH Condition Reports will be prepared following each Biannual BCH survey. Each Condition Report will include:

- Summary of data collected during the survey;
- Comparison of BCH condition with baseline;
- Discussion regarding any observed impacts on subtidal BCH and the likelihood that impacts are attributable to dredging; and
- Recommendations for additional management / remediation if required.



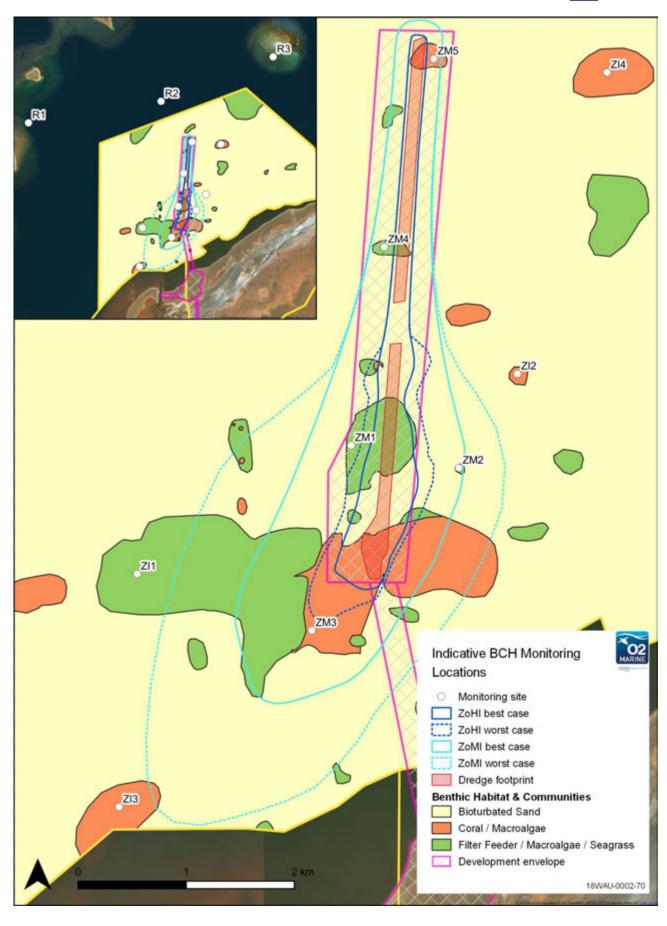


Figure 16. Indicative BCH Monitoring Locations.



7.3. Marine Fauna Monitoring

Table 10 above outlines the monitoring and management actions required to protect marine fauna from project construction activities. The key actions are:

- 1. All project vessels are to have at least one trained MFO on board at all times;
- 2. All project vessels are to maintain a safe speed as to safely avoid interaction with marine fauna at all times;
- 3. The dredge vessel will maintain a daily MFO log during all dredge operations (refer Appendix A);
- 4. The daily MFO logs will be compiled and submitted as part of the monthly Environmental Monitoring Report and
- 5. All incidents of injured or deceased marine fauna will be reported to the Proponent immediately, with an incident report submitted 72 hours after initial observation.

Mardie Project: Dredge Management Plan



8. Reporting

8.1. Compliance Reporting

To be updated upon EPA assessment.

8.2. Additional Reporting

A summary of the additional reports that are expected to inform compliance reporting commitments (Section 8.1) are listed in **Table 15**.

Table 15. Reporting Requirements throughout Dredging Scope.

Name of Report	Content	Timeframe	Responsibility	Recipient
Pre-Dredging Benthic Community Habitat Survey Report	Results and discussion of pre- dredge benthic habitat survey. Recommendations for suitable MWQMP monitoring locations.	Prior to commencement of dredging.	Proponent	
Annual Benthic Community Habitat Survey Report	Results and discussion of bi- annual BCH surveys during dredge activities.	Two months following completion of the second biannual survey.	Proponent	
Post Dredging Benthic Community Habitat Survey Report	Results and discussion of post- dredge benthic habitat survey. Describe BCH status and any further management required.	Three months following completion of dredging.	Proponent	
Marine Environmental Monitoring Report	Monthly summary of telemetered water quality data. Discuss any management actions implemented during period.	Monthly.	Proponent	
Dredge commencement Plume Verification Report	Results of plume verification with multispectral camera at commencement of dredging.	Within first month of dredging	Proponent	
Quarterly Plume Verification Report	Results of quarterly aerial plume verification with multispectral camera.	Quarterly following dredge commencement	Proponent	
Reactive Plume Verification Report	Results of reactive aerial plume verification with multispectral camera. Following a level 2 management target exceedance.	Two weeks following level 2 management target exceedance	Proponent	
Final Marine Water Quality Monitoring Report	Summary of all water quality data collected over the construction period. Discussing trends, exceedances and implemented management actions.		Proponent	
Marine Fauna Observer Logs	Logs continuous monitoring for Marine Fauna during dredge operations. Outlines necessary	Daily during dredge operations	Contractor	

Mardie Project: Dredge Management Plan



Name of Report	Content	Timeframe	Responsibility	Recipient
	management actions where required.			
IMP Risk Assessment	Department of Fisheries 'Vessel check risk assessment', copy of Vessel Check report, supporting documentation including antifoul certificates and inspection reports. Statement from lead inspector on marine pest status of the vessel.	Within 72 hours of inspection.	Contractor	
Vessel Quarantine Report	Checklist of vessel components checked during vessel inspection. Statement from lead inspector.	Within 14 days of inspection or risk assessment.	Contractor	

Mardie Minerals Pty Ltd Mardie Project: **Dredge Management Plan**



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Appendix A Example Marine Fauna Observation Log

MFO LOG

- Every day requires at least one entry. Either a sighting or an entry to note 'no sightings'.
- 2. All cells require information when logging a marine fauna sighting.
- 3. Species if species is known state species, otherwise state type of marine fauna.
- 4. Direction of animal to source record using cardinal points (N, NE etc)
- 5. Codes for mitigation response: SD = shutdown, SL = slow dredge operations SH = shift dredger or NR = no response required.

Date	MFO Name	Time of sighting	Vessel position (lat/long)	Species	Total no. of animals	Adults	Calf	Distance to source (m)	Direction of animal from source	Mitigation response	Lost production time
03/08/18	John Smith	09:12	21.64 S 115.11 E	Dugong	1	1	0	30	NW	SL	9:12 – 9:22 10 minutes
04/08/18	John Smith - No sightings										



Appendix B Dredge Plume Modelling Report - Mardie Project

18WAU-0002 / R190047 Mardie Minerals Pty Ltd

Mardie Project: Dredge Management Plan



Mardie Project

Dredge Plume Modelling Report

14 April 2020 | 12979.101.R4.Rev0



baird.com

Mardie Project

Dredge Plume Modelling Report

Prepared for: Prepared by:



BCI Minerals Level 1 15 Rheola Street West Perth, WA 6005

Contact: Neil Dixon Phone: +61 8 6311 3400



Baird Australia Pty Ltd as Trustee for the Baird Australia Unit Trust ACN 161 683 889 | ABN 92 798 128 010

For further information, please contact Jim Churchill at +61 8 6255 5090 jchurchill@baird.com www.baird.com

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В	30/03/2020	Final	Issued with updates Based on review of Production Rates	JC	SG	JC
0	14/04/2020	Final	Issued for Release – Client Comments Addressed	JC	SG	JC

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12979.101.R4.Rev0 Page i

Executive Summary

The Mardie Project is a greenfields high-quality salt project proposed in the Pilbara region of Western Australia. Baird Australia Pty Limited (Baird) have been engaged by Mardie Minerals, a wholly owned subsidiary of BCI Minerals Limited (BCIM) to develop a hydrodynamic modelling program to support the environmental approvals process to assess:

- Modelling of dredge plumes to inform the preparation of a Dredging and Spoil Disposal Management Plan (DSDMP); and
- Modelling of mixing and dilution of bitterns discharge into the marine environment to inform the preparation of a Environmental Quality Plan (EQP).

The dredging requirements through project footprint will require approximately 800,000m³ of sediment to be removed from the seabed for disposal onshore. The dredging approach and methodology was defined by BCIM for incorporation into the dredge plume modelling process based on a backhoe dredge operating from a barge with a hopper alongside. Dredge rates adopted in the modelling process are based on a target production rate of 2,000m³ a day, with a sensitivity case examined based on an upper limit production rate of 2,500m³ a day. Sediment plumes from dredging are generated in the model from two principal sources: mobilisation of fine sediments at the excavator bucket with each load and overflow water from the hopper barges.

An established Delft3D hydrodynamic model (Baird 2020) was used as a basis for the dredge plume modelling program. The Delft3D Online Sediment model (Online-MOR) has been activated in the model to investigate the transport of fine sediments released through the dredging program in four representative fractions – fine sand, silt, fine silt and clay. There is a detailed geotechnical investigation and sediment sampling program which has informed understanding of the composition of the seabed material which will be dredged. The dredge material is very high in fine sediments (clays, silts) representing as much as 75% of the material by volume in sections of the channel. The required volume of dredging material was calculated through the footprint based on high resolution multibeam survey and requirements to achieve the target design depth which is -3.9m LAT in the channel and -6.7mLAT in the berth pocket.

The modelling process simulates dredge plume generation from their source and examines the fate of fine sediments in suspension, as suspended sediment concentration (SSC) both spatially and vertically through the water column in 3D. Sediment plumes are driven in the model by the hydrodynamic forcing (water levels, winds, waves, currents) with erosion, resuspension and deposition of the dredge material permitted in the model based on bed shear stress.

The Environment Protection Authority spatially based zonation scheme to describe the predicted extent, severity and duration of impacts associated with dredging for the Mardie project have been determined through the processing and assessment of the dredge plume model results. The Zone of High Impact (ZoHI) and Zone of Moderate Impact (ZoMI) have been determined by analysing model results as running mean values of modelled SSC against possible and probable coral mortality thresholds applying the method presented in Fisher et al (2019, WAMSI dredging node). The ZOMI and ZOHI for the Mardie project are presented spatially in Section 5 for application in the DSDMP.



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Dredge Plume Modelling Report



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1. Introduction

1.1 Background

Mardie Minerals Pty Ltd, a wholly owned subsidiary of BCI Minerals Limited (BCIM), seek to develop the Mardie Project (the proposal), a greenfields high-quality salt project in the Pilbara region of Western Australia. Baird Australia Pty Limited (Baird) have been engaged by BCIM to address two study scopes associated with the Definitive Feasibility Study (DFS) and environmental approvals for the Mardie Project. The two study scopes are:

- Modelling of dredge plumes to inform the preparation of a Dredging and Spoil Disposal Management Plan (DSDMP); and
- Modelling of mixing and dilution of bitterns discharge into the marine environment to inform the preparation of a Environmental Quality Plan (EQP).

The following report presents the dredge plume modelling. The dredge plume modelling program has been completed adopting the validated hydrodynamic model presented in Baird (2020).

Details on the Mardie Project and Baird's scope of engagement are presented in the following sections.

1.2 Project Overview

The proposal is a solar salt project that utilises seawater and evaporation to produce raw salts as a feedstock for dedicated processing facilities that will produce a high purity salt, industrial grade fertiliser products, and other commercial by-products. Production rates of 4.0 Million tonnes per annum (Mtpa) of salt (NaCl), 100 kilo tonnes per annum (ktpa) of Sulphate of Potash (SoP), and up to 300 ktpa of other salt products are being targeted, sourced from a 150 Gigalitre per annum (GLpa) seawater intake. To meet this production, the following infrastructure will be developed:

- Seawater intake, pump station and pipeline;
- Concentrator ponds;
- Drainage channels;
- Crystalliser ponds;
- Trestle jetty and transhipment berth/channel;
- Bitterns disposal pipeline and diffuser;
- Processing facilities and stockpiles;
- Administration buildings;
- Accommodation village,
- Access / haul roads;
- Desalination plant for freshwater production, with brine discharged to the evaporation ponds; and
- Associated infrastructure such as power supply, communications, workshop, laydown, landfill facility, sewage treatment plant, etc.

Seawater for the process will be pumped from a large tidal creek into the concentrator ponds. All pumps will be screened and operated accordingly to minimise entrapment of marine fauna and any reductions in water levels in the tidal creek.

Concentrator and crystalliser ponds will be developed behind low permeability walls engineered from local clays and soils and rock armoured to protect against erosion. The height of the walls varies across the project and is matched to the flood risk for the area.

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Potable water will be required for the production plants and the village. The water supply will be sourced from a desalination plant which will provide the water required to support the Project. The high salinity output from the plant will be directed to a concentrator pond with the corresponding salinity.

A trestle jetty will be constructed to convey salt (NaCl) from the salt production stockpile to the transhipment berth pocket. The jetty will traverse the intertidal zone for approximately 3.6 km before extending into the ocean for a further 2.4 km. The jetty will not impede coastal water or sediment movement, thus ensuring coastal processes is minimal.

Dredging of approximately 800,000 m³ will be required to ensure sufficient depth for the transhipper berth pocket at the end of the trestle jetty, as well as along a 4.5 km long channel out to deeper water. The dredge spoil is inert and will be transported to shore for use within the development.

The production process will produce a high-salinity bittern that, prior to its discharge through a diffuser at the far end of the trestle jetty, will be diluted with seawater to bring its salinity closer to that of the receiving environment.

The Project was referred to the Department of Water and Environmental Regulation – Environmental Protection Authority (DWER-EPA) Services and the Level of Assessment (LOA) was set at Public Environmental Review (PER). The EPA determined on 13 June 2018 that there were seven preliminary key environmental factors related to the Project, with Benthic Communities and Habitat (BCH) and Marine Environmental Quality (MEQ) being relevant to this Scope of Works (SOW). BCI are currently finalising the Environmental Scoping Document (ESD) with the DWER and Department of the Environment and Energy (DoTEE), with potential BCH and MEQ impacts and risks associated with the SOW being:

- 3.6GL/a of Bitterns disposal (salinity) at discharge location;
- Localised reduction in water quality around the bitterns outfall location;
- Direct disturbance / removal of benthic communities and habitat:
- Direct loss and degradation of marine fauna habitat;
- Marine fauna injury or fatality as a result of vessel strike or contact with dredge equipment;
- Changes to water quality due to intertidal dredging including:
 - Increased sedimentation resulting in settlement and smothering of habitat;

Baird Australia (Baird) have been engaged by BCIM to deliver a numerical modelling study which will provide the basis to support the environmental approvals for the Mardie project.

1.3 Dredge Plume Modelling Scope

This report provides a detailed summary of the inputs, assumptions and outputs from the dredge plume modelling scope. Baird were engaged by BCIM to assess the dredge plume impacts associated with the planned dredging program for the project. The established hydrodynamic model (Baird 2020) was used as a basis for the dredge plume modelling program. The tasks for the modelling as detailed in Baird's engaged scope for BCIM are as follows:

- 1. Attend an inception meeting and discussion with BCIM on their proposed dredging program and methodology for definition in the modelling scope.
- 2. Prepare a summary of the metocean, water quality, bathymetric data and dredging methodology to define the key inputs for the dredge plume modelling. The metocean summary has been drawn from the hydrodynamic modelling study (Baird, 2020)
- 3. The hydrodynamic model with wave effects (Baird, 2020) has been applied to model the generation, transport and fate of dredge plume(s) from the dredging activities. The hydrodynamic modelling completed by Baird includes:
 - Adopting the calibrated coupled 2D/3D model as specified in Baird (2020);
 - 2D and 3D modelling of the representative dry season (winter) period of the dredging campaign;

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- Wave effects from offshore swell and local sea conditions included with coupling to the SWAN wave model as specified in Baird (2020).
- 4. Dredge Plume Modelling has been undertaken with the Delft3D Online Sediment model to include coupled wave and hydrodynamic forcing described above. The tasks undertaken for the dredge plume modelling include:
 - Classification of dredging plume composition and specification of modelled sediment fractions including physical parameters;
 - Schematisation of dredge plan and preparation of time series inputs for the Delft3D model; and
 - Time series modelling of the dredging programme.
- 5. Deliverables

The results from the dredge plume modelling have been analysed and presented in the following outputs:

- The location, extent and duration of a potential dredge plume extent over the course of the dredging programme;
- Potential worst-case impact scenarios to guide appropriate management techniques in the DSDMP; and
- Definition of the likely dredge plume impact areas based on threshold suspended sediment concentration (SSC) limits which may impact on light intensity for biota and BCH.

The model outputs have been adopted in the development of the DSDMP to determine environmental monitoring and management measures to be implemented during dredging activities to achieve defined Environmental Protection Objectives (EPOs). The DSDMP is being prepared by O2Marine.

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2. Background Information

2.1 Key Reports

The background reports referenced in the development of the hydrodynamic model and application in the dredge plume modelling program are outlined in this section.

2.1.1 Site Specific Reports Prepared for the Mardie Project

- CMW (2019), Mardie Salt Project Jetty and Port Facilities Factual Geotechnical Report, Mardie WA.
 Report prepared for Mardie Minerals, 30 October 2019.
- EGS Survey (2019), Mardie Salt Project Geophysical Survey BCI Minerals SURVEY REPORT, EGS PROJECT REF: AU025918, Prepared for O2Marine 21 January 2019.
- O2Marine (2018), Mardie Project Progress Report #1 for Metocean Data Collection, REPORT No.: R1800106, ISSUE DATE: 22 Oct 2018.
- O2Marine (2019), Mardie Project Progress Report for Metocean Data Collection, R1800132 ISSUE DATE: 15th January 2019.
- RPS (2017), Mardie Salt Project, Preliminary Storm Surge Study, Prepared for BCI.
- Surrich and EGS (2019), Detailed Bathymetry data provided by the Mardie project ,
 Surrich_EGS_Datasets_Merged_Mardie_Creek_MGAZ50_1m_Shoal_Final_GRIDDED_DepthPos_A HD.
- TAMS (2019), Dive Operations Field Report, Report prepared for BCI Minerals detailing Dive operations and Core Samples collected on site 15th July - 30th August 2019.

2.1.2 Western Australian Marine Science Institution (WAMSI) Dredging Node

- Fisher R, Jones R, Bessell-Browne P, (2019). Effects of dredging and dredging related activities on water quality: Impacts on coral mortality and threshold development Report of Theme 4 Project 4.9, prepared for the Dredging Science Node, Western Australian Marine Science Institution, Perth, Western Australia, 94 pp.
- Kemps H and Masini R (2017) Estimating dredge source terms a review of contemporary practice in the context of Environmental Impact Assessment in Western Australia. Report of Theme 2 Project 2.2, prepared for the Dredging Science Node, Western Australian Marine Science Institution. Perth, Western Australia, 29pp.
- Mills D (2019) Predicting and measuring the characteristics of sediments generated by dredging.
 Synthesis Report of Theme 2 prepared for the Dredging Science Node, Western Australian Marine Science Institution, Perth, Western Australia, 12 pp.
- Sun C, Shimizu K, Symonds G (2016) Numerical modelling of dredge plumes: a review. Report of Theme 3 Project 3.1.3, prepared for the Dredging Science Node, Western Australian Marine Science Institution, Perth, Western Australia, 55 pp.
- Sun C, Lowe R, Fearns P, Ghisalberti M, Branson P (2019), WAMSI Dredging Science Node Theme 3
 I Synthesis Report: Characterisation and prediction of dredge-generated sediment plume dynamics
 and fate, prepared for the Dredging Science Node, Western Australian Marine Science Institution,
 Perth, Western Australia.

2.1.3 Key EPA Documents

- EPA (2016a), Statement of Environmental Principles, Factors and Objectives, EPA, Western Australia.
- EPA (2016b), Environmental Impact Assessment (Part IV Divisions 1 and 2) Administrative Procedures 2016.
- EPA (2018a), Environmental Impact Assessment (Part IV Divisions 1 and 2) Procedures Manual, EPA, Western Australia.

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- EPA (2016c), Environmental Factor Guideline Marine Environmental Quality, EPA, Western Australia.
- EPA (2016d), Environmental Factor Guideline Benthic Communities and habitat, EPA, Western Australia.
- EPA (2016e), Environmental Factor Guideline Marine Fauna, EPA, Western Australia.
- EPA (2018b), Instructions on how to prepare Environmental Protection Act Part IV Environmental Management Plans.
- EPA (2016f), Technical Guidance Protecting the Quality of Western Australia's Marine Environment, EPA, Western Australia.
- EPA (2016g), Technical Guidance Environmental Impact Assessment of Marine Dredging Proposals, EPA, Western Australia.

2.1.4 Other Policy and Guidance

- DoE (2006), Pilbara Coastal Water Quality Consultation Outcomes Environmental Values and Environmental Quality Objectives, Department of Environment (DoE), Government of Western Australia, Marine Series Report No. 1.
- MScience (2009). Wheatstone LNG Development: Baseline Water Quality Assessment Report November 2009. MSA134R3. Statement/Environmental Review and Management Programme for the Proposed Wheatstone Project - Appendix Q7.
- ANZECC & ARMCANZ (2000), Australian and New Zealand Guidelines for Fresh and Marine Water Quality (Australian and New Zealand Environment and Conservation Council (ANZECC) & Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ).

2.2 Measured Data Sources

The key measured data sources which have been applied in the Dredge Plume model program are summarised in Table 2.1.

Table 2.1: Data Summary - Key Datasets

Dataset	Description	
Sodiment Sampling	Detailed geotechnical core samples with sediment sampling from seabed areas adjacent the proposed dredging footprint were reported in CMW 2019.	
Sediment Sampling	Sediment sampling results were collected at locations west of the proposed dredging footprint by O2 Marine reporting Particle Size Distribution (PSD) for the dredge material (O2 2018b,2019b).	
	In August 2019 a high-resolution bathymetric survey using a Multibeam Echosounder was completed to define the seabed level of the revised channel infill, transhipment route and proposed cyclone mooring site (Surrich and EGS 2019).	
Bathymetry Ordered Highest to lowest priority	In November 2018 a Class A survey was completed to define the seabed level for the proposed access channel route and berth pocket in high resolution. Bathymetry was provided in a Digital Elevation Model (DEM) as reported in EGS 2019.	
	In September 2018 low resolution bathymetry survey was collected by O2Marine and provided as DEM covering the proposed dredge corridor and surrounds.	

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Dataset	Description		
	Hydrographic Charts (soundings and contours):		
	 AUS742 - Australia - North West Coast - Western Australia - Rosemary Island to Barrow Island 		
	 AUS743 - Australia - North West Coast - Western Australia - Barrow Island to Onslow 		
	Offshore ADCP:		
	 Approximately 16km offshore in 11.2m depth (MGA50 391,362 7,685,272) 		
	 8 Deployments covering the period 5 April 2018 – 9 July 2019 		
Baseline Metocean Data	 Wave height and direction, Current speed and direction, Water Level 		
Daseline Metocean Data	Inshore Aquadopp:		
	 Approximately 4km offshore in 5.9m depth (MGA50 388,514 7,673,522) 		
	 4 Deployments covering period 8 November 2018 – 8 July 2019 (deployment in 2018 dry season had instrument failure). 		
	Current speed and direction, Water Level		
Baseline Water Quality	 Offshore (ADCP) Location: Light, Temperature, turbidity (TDS) Inshore (Aquadopp) Location: Temperature, pH, salinity (EC), Dissolved oxygen (DO) 		

The location of the measured metocean data is shown in Figure 2.1.





Figure 2.1: Measured Data Locations

3. Dredging Method

3.1 Project Location and Dredging Requirements

3.1.1 Project Location Summary

The local setting and metocean conditions for the Mardie project location are described in detail in Baird (2020). A brief summary follows.

The Mardie project location experiences a semi-diurnal tide (two highs and two lows a day) with a tidal range of 5.185 m (LAT to HAT) and mean sea level at 2.75m LAT. The mean tide range is 3.6m in springs and 1m in neaps.

The inner shelf region is very wide along the Mardie section of the coast, and consequently the near shore bathymetry is very shallow, with water depths of approximately 5m (below LAT) at a distance of 10km offshore. A series of offshore islands and reefs are located immediately offshore of the Mardie coast (Passage Islands). Due to the alignment of the island and reef features of the Passage Islands the majority of incoming tidal flow on the flood tide is directed through the opening between Scholl Island and Mardie Island to the north of the project site. At this offshore location, between the islands, the tidal flow is directed along a general north-south axis whilst closer inshore at the project marine facility location, the tidal flows align along a northeast-southwest axis in the ebb and flood tide.

The measured currents at the marine precinct area show:

- Depth averaged peak current speed of 0.3ms⁻¹ 0.5ms⁻¹ in springs and 0.2ms⁻¹ 0.3ms⁻¹ in neaps
- Current direction (direction to) consistent in Ebb 40° 70° and Flood 220° 250°
- The flood speeds are generally stronger than the ebb current speed

In general, wave conditions are dominated by locally generated sea conditions within the range of 0.5m to 1m (significant wave height) at short wave periods (peak periods < 5 s).

3.1.2 Project Footprint and Dredging Requirements

The project footprint extends across the tidal flats at Mardie with the settling ponds approximately 5km inland and the port facility (berth pocket, loader, trestle jetty) located approximately 2.4km offshore as shown in Figure 3.1.

A trestle jetty, with a conveyer-based system to transport processed salt to the ship loader at the port over the intertidal areas, will be located on the eastern side of the berth pocket. The berth pocket has a maintained depth of -6.7m LAT, around which, there is a turning circle area and marine operations area dredged to a depth of -3.9m LAT. A navigation channel 100m wide will be dredged through the natural seabed north of the berth, over a distance of approximately 4.5km to a design depth of -3.9m LAT. The design of the navigation channel and berth pocket are shown in Figure 3.2 with the surrounding seabed bathymetry.

The design of the berth pocket, marine precinct and channel alignment has been optimised based on the dredging requirements, length of trestle jetty and design vessel requirements.

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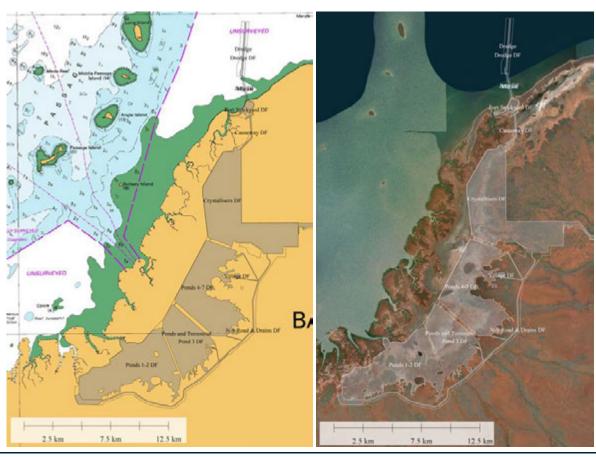


Figure 3.1: Mardie Project Footprint (underlain by Hydrographic Chart AUS743)

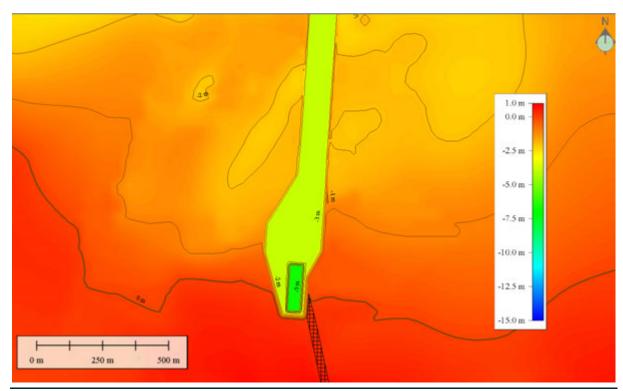


Figure 3.2: Configuration of Berth Pocket and Navigation Channel (Datum mLAT)



Around the berth pocket the natural seabed depth is shallow with water depths approaching 0m LAT. The dredging requirements and volumes are weighted to the nearshore section of the dredge footprint, with the berth pocket (-6.7m LAT) and marine precinct/ navigation channel (-3.9m LAT) requiring significant dredging of the natural seabed. Offshore, the dredging requirements to get to design depth through the channel areas require approximately 1m of dredging below the natural seabed. This is discussed further in Section 3.6.

The intended method for the dredge program is for a backhoe dredger on a barge to operate through the dry season months, extracting sediment from the seabed and depositing it into hoppers alongside (Figure 3.3). The hoppers are to transfer the dredged material to the onshore area for re-use on site. The program will commence from inshore and complete the berth pocket and marine precinct and then proceed with dredging requirements offshore progressing along the offshore channel footprint.

An over dredge allowance of 0.5m is included in the dredge program and incorporated into the modelled volumes. For areas where the natural seabed is already at the design depth along the channel (-3.9m LAT) no over dredge is undertaken.



Figure 3.3: Example of Backhoe Dredge (TAMS, 2020)

3.2 Dredging Approach and Methodology

The dredging methodology was defined by BCIM for incorporation into the dredge plume modelling process as summarised in Table 3.1.

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Table 3.1: Dredging Method - Summary Statement

Dredge Design	Channel	Berth Pocket		
Total Length	4,500m	210m x 40m		
Design Depth	-6.65m AHD (-3.9m LAT)	-9.45m AHD (-6.7m LAT)		
Design Width	90m at Floor	40m at Floor		
Batters	1V:5H	1V:5H		
Over Dredge Allowance		in all areas being dredged (ie not el is already at design depth).		
Dredge Volume	735,000m ³	75,000m ³		
Dredge Volume Total	Approximately 810,000r	m ³ (including over dredge)		
Dredge Method				
Dredge Plant	Long reach excavator / Backhoe on Barge			
Production Rates – Basis	Based on Contractor Submissions (Advice L Huck BCIM) Dredging to be completed in Dry Season Months (April to October)			
Excavation Rate	Target Rate = 100m³/hr, Maximum Rate = 125m³/hr Target Rate = 2,000m³/day, Maximum Rate = 2,500m³/day			
Operational Constraints	Excavator Reach is not Constrained by Tide Level and no downtime is assumed in the model for environmental issues.			
Operating Hours	20hr non-stop dredging (2x 10 hr shifts). 4hr stopped (0400-0800)			
Dredge spoil disposal method	Spoil placed in hopper barge and disposed onshore Hoppers will be overfilled and there will be overflow of fines in suspension from the hopper into the water column			

Sediment plumes will be generated during the channel dredging at different scales. The sediment plume generation sources are summarised in Table 3.2 for the dredging activities with relevant assumptions adopted in the modelling based on literature and studies as referenced.

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Table 3.2: Model Assumptions - Plume Generation Sources from Dredging Activities

Plume Source	Approach to define plume generation in model				
	Sediment plumes from dredging will be generated from 2 principal sources:				
Sediment Plume Sources	1. Mobilisation of fine sediments at the excavator bucket with each load: and				
	2. Overflow water from the hopper barges				
Material Loss from Bucket	4% by mass of total fine sediments (fine sand, clay and silt fractions) lost as the bucket comes up through the water column from the seabed to the Hopper barge on surface. Of the load input into the model, 40% is input at the seabed, 30% mid depth and 30% at the surface				
Material Loss from Hopper Overflow	An assumption that 10% by mass of fines (< 62um) in suspension is discharging from overflow at top of water column (conservative assumption i.e. worst case). Input to model from the top of the water column.				

3.3 Construction Schedule

A construction schedule has been developed based on target production rates of 2,000m³ a day. The schedule aims to complete the requirements of the project over dry season months in 2 successive years and incorporates a range of assumptions for the plant and equipment (eg production rates, working hours) as shown in Table 3.3. The proposed schedule has been implemented in model simulations developed from a range of local information including survey data and geotechnical information.

The dredging requirements are considered in 7 individual sections along the dredge footprint (dredge sequences shown in Figure 3.4). Within each dredge sequence, the sediment composition of dredge spoil is determined from available geotechnical information (CMW 2019) closest to each respective section. The dredge volume in each section is then calculated in terms of sand, silt and clay components and assigned to plume sources in the numerical model based on the assumed dredging method of long reach excavator and hopper discussed in the sections to follow.

Table 3.3: Proposed Dredging Schedule Adopted in Model Program

Activity	Dredge Assumption Time - Target Production		
Sequence 1 – Berth Pocket	2,000m³ /day x 58 days 116,000m³ Total	Month 1 - Month 2, Year 1	
Sequence 2 and 3 – Marine Precinct	2,000m³ /day x116 days 232,000m³ Total	Month 3 - Month 6, Year 1	
Sequence 4 and 5 – Channel Section North	2,000m³ /day x114 days 228,000m³ Total	Month 1 - Month 4, Year 2	
Sequence 6 and 7 – Offshore Channel Section	2,000m³ /day x109 days 218,000m³ Total	Month 5 - Month 8, Year 2	

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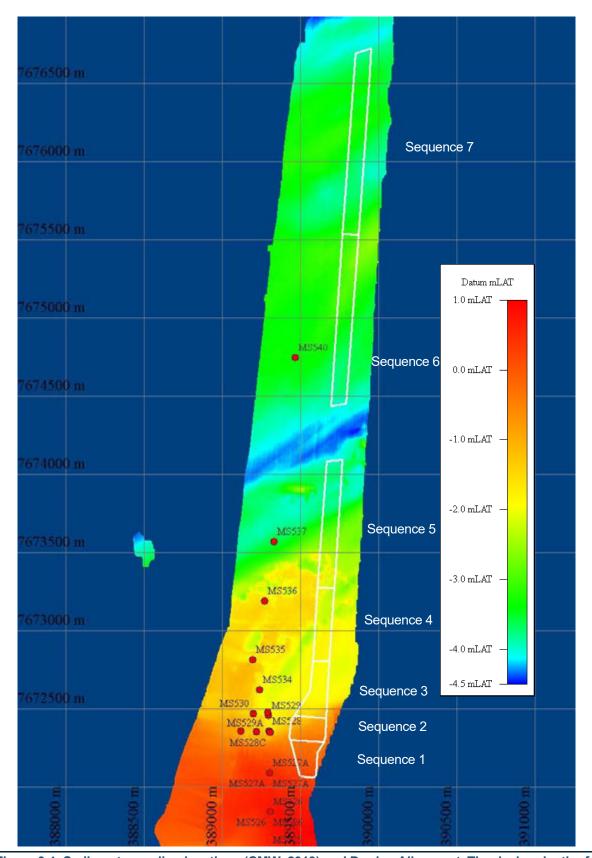


Figure 3.4: Sediment sampling locations (CMW, 2019) and Dredge Alignment. The design depth of the channel is -3.9mLAT and the berth pocket design depth is -6.7mLAT.



3.4 Sediment Classifications in Model

There is a detailed geotechnical investigation and sediment sampling program which has informed understanding of the composition of the seabed material which will be dredged (CMW2019).

The sediment classifications considered in the modelling are based on the range of sizes described in Table 3.4. The dredge plume modelling examines fine cohesive sediments (clays, silts) and also considers non-cohesive fine sand. The sediment classifications larger than fine sand are not included in the sediment plume modelling. It is assumed that these will fall out of suspension and be deposited at the seabed rapidly a short distance from their source.

Table 3.4: Summary of Sediment Classes in Model (from Wentworth Scale)

Sediment Class	Size Range (µm)	Model Assumptions
Gravel, Cobbles	>2mm	Not considered in the model. Assumed that these
Medium to Coarse Sand	0.25mm – 2mm	larger sediments will fall to the seabed locally from the source location.
Fine sand	62µm – 0.25mm	Modelled as non-cohesive sediment with Median Sediment D_{50} = 125 μ m
Coarse Silt	16μm to 62μm	Modelled as cohesive sediment, Settling Velocity 1.7mm/s
Fine Silt	2μm to 16μm	Modelled as cohesive sediment, Settling Velocity 0.06 mm/s
Clay	< 2µm	Modelled as cohesive sediment, Settling Velocity 0.004 mm/s

A key determinant of the dredge plume dispersion and settlement in the model is the settlement rate parameter for the fine fractions. According to Stoke's Law, the settling rate of particles is affected by the gravitational force exerted on the particle, the density of the particle relative to the density of the medium, and the viscosity (resistance to flow-settling) of the medium.

For the modelled fine fractions, the following settlement rate has been adopted:

- Coarse Silt = 1.7 mm/s
- Fine Silt = 0.06 mm/s
- Clay = 0.004 mm/s

These values fall within the ranges of settling velocity adopted in similar modelling studies as noted in Sun et. al., 2016.

3.5 Dredge Material - Sediment Sampling and Analysis

The sediment sample locations collected through the alignment of the transhipment channel are shown in Figure 3.4 based on locations reported in CMW (2019). The sediment samples are taken from various depths under the seabed from boreholes extracted from locations approximately 250m west of the channel alignment. The boreholes are considered to represent the sediment conditions of the dredged material in the channel.

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There are seven dredge sequences shown as white polygon areas in Figure 3.4. The sequences are distinct areas considered along the dredging footprint in which the sediment composition and volume has been assessed and input into the model to determine the dredge plume impacts. Within each of the areas the volume of sediment removed varies between 112,000m³ and 116,000m³.

The dredge sequences commence at the most inshore location and progress offshore. Sequence 1 (SEQ1) is the first section that is dredged in the model simulations and the region covers the berth pocket area. The SEQ1 section is completed in the model (approximately 8 weeks of dredging) and the next section of the channel in SEQ2 commences. At the start of SEQ2, the bathymetry is updated in the model to represent the completed SEQ1 section and hydrodynamics in the model run are based on interaction with the partially completed dredged channel and footprint in SEQ1.

Within each of the dredge sequences SEQ1 through to SEQ7 offshore, the particle size distribution of the dredged material for application in the model has been calculated based on the measured geotechnical data. This process is summarised in Table 3.5 and Figure 3.4 outlining the samples that have been considered for each of the sections and the calculation of the respective sediment fractions (clay, silt, sand). It is noted that for the sand fraction, only fine sands (62µm - 0.25mm) are included in the dredge plume modelling. It is assumed that medium and coarse sand particles (0.25mm - 2mm) will fall to the seabed close to the source. The PSD have been examined in each sample to define the representative proportion of fine sand to include in the model, which is generally about one third of the total sand.

Table 3.5: Sediment Composition of dredged material by Zone - based on CMW 2019

	Sediment Composition					
Dredge Zone	Ref. Sample	Depth of Sample Below Seabed	Clay %	Silt %	Sand %	Gravel %
SEQ1	MS527A MS527A Average	2.4m to 2.5m 4.0m to 4.2m Applied in Model	18 18 18	24 16 20	11 53 32	47 13 -
SEQ2	MS528 MS529 MS529A MS531 Average	1.2m to 1.5m 1.0m to 1.5m 1.2m to 1.35m 2.7m to 3.0m Applied in Model	36 34 46 17 33	37 34 36 33 35	17 26 14 25 21	10 6 4 25
SEQ3	MS534 MS529 MS529A MS535 Average	0.4m to 0.7m 1.0m to 1.5m 1.2m to 1.35m 1.5m to 1.8m Applied in Model	40 34 46 48 42	26 34 36 31 32	30 26 14 18 22	4 6 4 3
SEQ4	MS534 MS535 MS536 Average	0.4m to 0.7m 1.5m to 1.8m 1.6m to 2.0m Applied in Model	40 48 34 41	26 31 44 34	30 18 19 22	4 3 3
SEQ5	MS536 MS537 Average	1.6m to 2.0m 0.0m to 0.5m Applied in Model	34 31 33	44 39 42	19 26 23	3 4 -
SEQ6 and SEQ7	MS537 MS540 Average	0.0m to 0.5m 0.0m to 0.3m Applied in Model	31 4 17	39 4 21	26 62 44	4 31 -

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An overview of the incorporation of the CMW 2019 sediment sampling results into the model is provided as follows:

- The boreholes are considered to represent the sediment conditions of the dredged material in the dredge areas. Boreholes closest the dredge sections (SEQ1 to SEQ7) at depths consistent with the planned dredge program were used as the basis for calculations with the average calculated for each representative section in the model as shown in Table 3.5
- The sediment samples show that the fines content is very high through the dredge footprint. The fines
 (clay + silt) material represents 38% of dredged material in SEQ1 at the berth pocket area and the
 fines content increases to between 68% to 75% of the dredged material in SEQ2, SEQ3, SEQ4 and
 SEQ5. In the most offshore dredge areas, the sediments in SEQ6 and SEQ7 are similar to the SEQ1
 section with a fines content of 38%.

To illustrate the application of the geotechnical information, the core sample from borehole 529A used to define the sediment composition in SEQ2 and SEQ3 is shown in Figure 3.5. The upper layers in the core are very high in clay and silt, to a depth of approximately 2.5m below the seabed. The sediment sample reported from 1.2m to 1.35m in the core showed there was 46% clay and 36% silt. It is noted that the lower section of the core sample in Figure 3.5, shows a distinct change in the sediment composition to gravel. For the dredging along the SEQ2 and SEQ3 sections the required depth of dredging below the seabed is within 2.5m of the surface and the dredged material in the model assumes a high fines content (ie gravel is not encountered).



Figure 3.5: Core Sample for site MS529-A (TAMS, 2019). Cores at 1m length are shown as recovered from the seabed. Sediment sampling from the core was extracted from 1.2m – 1.35m below the surface and showed very high fines content of 82% (CMW, 2019).

3.6 Calculation of Dredging Volumes

The analysis of the required volume of dredging was calculated through the transhipment channel and berth pocket dredge footprint based on the target design depth (Table 3.1) and the natural seabed levels with an allowance for over dredging of 0.5m. The calculation was completed through a GIS based analysis utilising the high resolution multibeam bathymetry dataset collected through the transhipment corridor in 2019 (Surrich and EGS, 2019).

The natural seabed level is shown in Figure 3.4 based on multibeam bathymetry data collected in 2019.

A transect along the channel centreline through the offshore Sequence 6 and Sequence 7 areas is shown in Figure 3.6. The natural seabed level along the transect varies between -3.9m LAT and -2.9m LAT. Along this offshore section the target depth of the navigation channel is 1m or less below the natural seabed.

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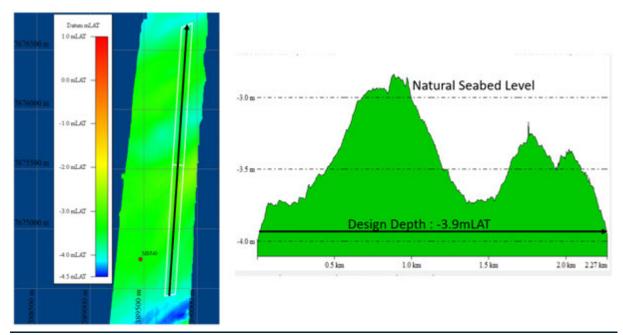


Figure 3.6: Natural Seabed Level through offshore dredged channel alignment (SEQ6 to SEQ7). The natural seabed is generally within 1m of the design channel depth of -3.9mLAT.

A transect along the channel centreline through the inshore Sequence 1 to Sequence 5 areas is shown in Figure 3.6. The transect shows that the natural seabed level in Sequence 1 is 0m LAT to -0.5mLAT. In this section the design depth of the channel (-3.9mLAT) as well as the berth pocket (-6.7mLAT) will require significant dredging. In Sequence 2 the natural level of the seabed falls to -1mLAT, which will still require dredging to go 3m below the natural seabed to reach design depth. In Sequence 3 and Sequence 4, the natural seabed is at approximately -2m LAT. The design depth of the channel will be around 2m below this natural seabed. For the Sequence 5 section the natural seabed deepens to design depth over a distance of approximately 800m.

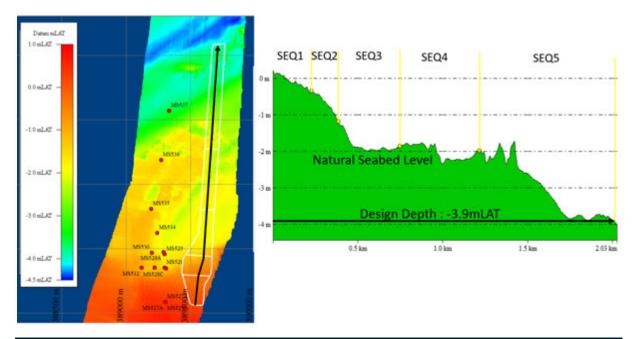


Figure 3.7: Natural Seabed Level through inshore dredged channel alignment (SEQ1 to SEQ5). The natural seabed through the sections is shown against the design channel depth of -3.9mLAT.

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4. Dredge Plume Model Setup

4.1 Model System

Hydrodynamic, wave and sediment transport models have been developed for the Mardie project to model dredge plume development and dispersal. The model system is used for predicting the likely extent, severity, and persistence of environmental impacts by the proposed dredging activity. For this project the Delft3D modelling system (Deltares, 2020) has been adopted. Delft3D is an industry leading integrated modelling suite, which simulates two-dimensional (in either the horizontal or a vertical plane) and three-dimensional flow, sediment transport and morphology, waves, water quality, and ecology and can handle the interactions between these processes. The model has been applied in many similar studies of dredging impacts at sites around Australia with modules for investigation of far-field water quality, mid-field water quality, ecological modelling, and cohesive and non-cohesive sediment transport (Sun et al 2016).

4.1.1 Hydrodynamic Model (Delft3D FLOW-WAVE-FLOW)

The hydrodynamic and wave models established for the Mardie project are detailed in Baird (2020) with components summarised in brief as follows:

- 1. A regional scale hydrodynamic model extending across the northwest of Australia using Delft-Flow Flexible Mesh (D-Flow FM) model. The model is driven by tidal constituents along its open boundaries with bathymetry defined from hydrographic chart data and local scale bathymetry sources where available. For this project, winds and atmospheric pressure have been sourced from the NCEP Climate Forecast System (CFSR). The climatic conditions were then applied spatially in D-Flow FM and updated hourly across the regional model in conjunction with the tides, so their influence was captured in the determination of hydrodynamic forces acting in the domain.
- 2. A local scale Delft3D hydrodynamic model is established over the Mardie area with boundary conditions defined by the Regional model (Figure 4.1).
- 3. The local model is setup in a domain decomposition grid arrangement to optimise the efficiency of the model performance. The outer grid extends along the shoreline approximately 70km with a cross shore extent of approximately 45km. The outer grid is setup on a 200m grid size. For the dredge plume analysis, a smaller domain sized at 40m resolution describes the dredge footprint including the channel and marine precinct of the port. Inshore dredge sequences SEQ1 through SEQ5 are assessed on one 40m grid and the offshore dredge sequences SEQ6 and SEQ7 use a separate 40m domain centred over the offshore channel extent (Figure 4.2).
- 4. A SWAN wave model was developed to cover the local scale domain with the following attributes:
 - The model is setup with an outer grid domain extending across the hydrodynamic grid, with a grid size of 400m. A nested grid of 40m grid size over the transhipment channel and port facility area is nested within.
 - The wave conditions inside the SWAN model develop under the local wind forcing applied in the model. Swell conditions are applied at the boundary based on the measured data from the offshore ADCP.
 - Wave conditions are updated in the local hydrodynamic model every 2 hours using Delft3D coupled FLOW-WAVE-FLOW module.

The validation of the hydrodynamic model against available measured data is presented in Baird (2020) for neap and spring tide periods through the wet season and dry season period. The validation shows good validation metrics calculated for water level, depth averaged current velocity and direction at both the inshore and offshore measurement sites for Mardie. The SWAN wave model has been validated against the measured data from the offshore measurement location showing good agreement to wave height, direction and period.

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Figure 4.1: Upper plot – Regional Hydrodynamic Model Domain (DFM). Lower plot – Local scale Delft3D model developed for Mardie Project with boundary conditions defined from the Regional model. Measured data was available for model validation from the ADCP and Aquadopp Locations.





Figure 4.2: Local Delft3D Hydrodynamic Model grid setup applied for dredge plume modelling. Domain Decomposition Grids - Outer grid (yellow, grid resolution 200m x 200m) and Inner grids (green, grid resolution 40m x 40m).

4.1.2 Sediment Transport Model - Delft3D Morphology Module (Online-MOR)

The Delft3D Online Sediment model (Online-MOR) is used to investigate the transport and fate of sediments released into the water column through the dredging program. The sediment transport module is part of the Delft3D suite developed by Deltares in the Netherlands and designed to simulate sediment transport of non-cohesive (sandy) or cohesive (silt) sediments under combined processes of wave propagation, currents and morphological developments in coastal, river and estuarine areas (Deltares 2020).

The Delft3D model system is one of the passive plume models reviewed in Sun et al 2016 and the model has been applied in similar dredging studies completed in Western Australia and many locations globally. The passive plume dispersal is managed through three separate model components, namely a hydrodynamic model, a sediment transport model and surface wave model. The validated Delft3D hydrodynamic and wave model system outlined in Section 4.1.1 has been adopted as the platform for hydrodynamics and waves, with the sediment transport module (Online-MOR) activated to investigate the release of sediments from dredge plume sources (backhoe operation and hopper overflow) and examine the diffusion, dispersion and resuspension processes of the plume.

The sediments released through the dredging program are assessed in the model in four sediment fractions – fine sand, coarse silt, fine silt and clay. The following ranges are used:

- 1. Fine Sand represents sediment sizes in the range 0.062 mm to 0.25 mm (62 μ m-250 μ m) with a median value of 0.125 mm adopted in the model
- 2. Coarse Silt represents sediment sizes in the range 0.016 mm to 0.062 mm (16-62 μm)
- 3. Fine Silt represents sediment sizes in the range 0.002 mm to 0.016 mm (2-16 μ m)
- 4. Clay represents sediment sizes in the range <0.002mm (<2 μm)

Sediment size larger than 0.25mm is not included in the model. Any gravel, medium or coarse sand that is lost from the backhoe bucket or hopper barge is assumed to settle immediately to the seabed within the immediate vicinity of the dredging area.

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4.2 Representative Seasonal Scenarios Modelled

The modelling program for the Dredge Plume Modelling phase is based on scenario modelling. The scenario modelling approach has been adopted to optimise the model run times, as continuous modelling of environmental conditions through the full duration of the dredging campaign would be impractical due to the long run times of the model system (Baird, 2020).

The dredging is planned to be completed over the dry season months (i.e. outside of cyclone season) over successive years. In developing the scenario approach, modelling cases of four weeks duration have been selected that are representative of the dry season at Mardie:

The period selected as representative of the dry season period was 4 July – 1 August 2018.

The modelling applies the representative dry season period to examine the influence of the metocean conditions (winds and waves climate) on the dredge plumes generated. It is noted that the dry season period selected exhibit the general characteristics of winds and waves from the long-term records available at the location (Baird, 2020).

The model is forced by hydrodynamic conditions for the representative dry season period (Baird 2020). through each of the seven dredge sequences. The time taken to dredge each of the sequences is approximately 2-months in the model. The dredge plumes are represented as modelled SSC of the respective sediment fractions (fine sand, silt, fine silt, clay).

The dredge plumes are driven in the model by the hydrodynamic forcing (water levels, winds, waves, currents) with erosion, resuspension and deposition of the dredge material permitted in the model based on bed shear stress. It is noted that the layer of sediment at the existing seabed is not erodible in the model.

4.3 Model Setup

4.3.1 Schematisation of dredge method

It is intended the dredging program will achieve a target production rate of 2,000m³ a day over a 20-hour shift period (20-hours dredging, 4-hours stopped).

The preparation of the time series inputs to the model were developed based on the dredging volume requirements along the sections of the transhipment channel under the assumption that $2,000 \, \text{m}^3$ a day was dredged every day, during 2×10 -hour shifts. This resulted in the total volume of $810,000 \, \text{m}^3$ distributed across seven dredge sequences summarised in Figure 3.4. The modelled point of discharge moves through the transhipment footprint area based on the dredging requirements (volumes of dredge material / rate of production) for each of the seven respective dredging sequences to simulate the dredging process.

The model outcomes were used to assess dredge plume impacts associated with the target production rate of 2,000m³ a day and an upper limit production rate of 2,500m³ a day in the analysis presented in Section 5.

4.3.2 Summary of Model Parameters

An overview of the key model settings and characteristics is provided in Table 4.1.

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Table 4.1: Delft3D Dredge Plume Model Settings

Feature	Description
Grid size / type	Domain Decomposition (DD) - Regular Grids at 200m and
Grid Extent	Outer Grid: 45km x 70km
3D sigma layer model	5-vertical sigma layers with layer thicknesses of 20% all the way through the water column.
Vertical Datum	Mean Sea Level (m MSL) which is approximately Australian Height Datum (AHD)
Horizontal eddy diffusivity coefficient	Across the DD Grids 200m / 40m: 25 / 5 m ² /s
Horizontal eddy viscosity coefficient	Across the DD Grids 200m / 40m: 25 / 5 m ² /s
Vertical eddy viscosity / diffusivity	k-ε turbulence closure model
Time step (2D model)	0.25 mins (15 secs)
Time step (3D sigma-layer)	0.1 mins (6 secs)
Bed friction	Chezy 55m ^{1/2} /s
Sediments Specific Density	2650 kg/m ³
Fine Sand	D50 = 0.125mm, Dry Bed Density 1600kg/m ³
Silt	Settling Velocity 1.7mm/s, Dry Bed Density 500kg/m ³
Fine Silt	Settling Velocity 0.06mm/s, Dry Bed Density 500kg/m³
Clay	Settling Velocity 0.004mm/s, Dry Bed Density 500kg/m ³
Van Rijn's reference height factor	1
Threshold sediment thickness	0.005 m
Critical Bed Shear Stress for Sedimentation	0.1 N/m ²
Critical Bed Shear Stress for Erosion	0.5 N/m ²
Background Suspended Sediment	Modelled as zero. Background SSC is added into model results in post processing (refer Section 5)
Mapping Output	60-minute output for every point on the DD grids through the full duration of model. 5 vertical layers of water column

4.3.3 Sediment Discharge Volumes

The sediment sampling results were analysed in detail to determine the time series sediment discharge in the model by relative sediment fraction. The release by sediment fraction is summarised Table 4.2 to Table 4.7 for dredge Sequence 1 to Sequence 7 respectively.

From the table summaries, the dredge plume source rates are highest in SEQ2, SEQ3, SEQ4 and SEQ5 in the range of 9.9m³/hr to 10.8m³/hr of fines released into the water column whilst the dredger is in operation 20hrs per day. The fines content reduces in the offshore sections SEQ6 and SEQ7 and around the berth pocket in SEQ1 with only about 6m³/hr of fine sediments released into the water column whilst dredging.

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Table 4.2: Sediment Discharge Rates by Fraction for Sequence 1

	Fine Sand (m³/hr)	Silt (m³/hr)	Clay (m³/hr)	Total (m³/hr)
Assumed PSD	11%	20%	18%	-
Dredge Rate (m³/hr)	11	20	18	49 (out of 100 Total Production Rate)
Bucket Loss @ 4% (m³/hr)	0.5	0.8	0.7	2.0
Overflow Loss @ 10% of Total (m³/hr)	NA	2.0	1.8	3.8
Total (m³/hr)	0.5	2.8	2.5	5.8

Table 4.3: Sediment Discharge Rates by Fraction for Sequence 2

	Fine Sand (m³/hr)	Silt (m³/hr)	Clay (m³/hr)	Total (m³/hr)
Assumed PSD	7%	35%	33%	-
Dredge Rate (m³/hr)	7.0	35	33	75 (out of 100 Total Production Rate)
Bucket Loss @ 4% (m³/hr)	0.3	1.4	1.3	3.0
Overflow Loss @ 10% of Total (m³/hr)	NA	3.5	3.4	6.9
Total (m³/hr)	0.3	4.9	4.7	9.9

Table 4.4: Sediment Discharge Rates by Fraction for Sequence 3

	Fine Sand (m³/hr)	Silt (m³/hr)	Clay (m³/hr)	Total (m³/hr)
Assumed PSD	7%	32%	42%	-
Dredge Rate (m³/hr)	7	32	42	81 (out of 100 Total Production Rate)
Bucket Loss @ 4% (m³/hr)	0.3	1.3	1.7	3.3
Overflow Loss @ 10% of Total (m³/hr)	NA	3.2	4.2	7.4
Total (m³/hr)	0.3	4.5	5.9	10.7

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Table 4.5: Sediment Discharge Rates by Fraction for Sequence 4

	Fine Sand (m³/hr)	Silt (m³/hr)	Clay (m³/hr)	Total (m³/hr)
Assumed PSD	7%	34%	41%	-
Dredge Rate (m³/hr)	7.4	33.7	40.7	81 (out of 100 Total Production Rate)
Bucket Loss @ 4% (m³/hr)	0.3	1.4	1.7	3.4
Overflow Loss @ 10% of Total (m³/hr)	NA	3.4	4.0	7.4
Total (m³/hr)	0.3	4.8	5.7	10.8

Table 4.6: Sediment Discharge Rates by Fraction for Sequence 5

	Fine Sand (m³/hr)	Silt (m³/hr)	Clay (m³/hr)	Total (m³/hr)
Assumed PSD	7%	42%	33%	-
Dredge Rate (m³/hr)	7.4	42	33	82 (out of 100 Total Production Rate)
Bucket Loss @ 4% (m³/hr)	0.3	1.7	1.3	3.3
Overflow Loss @ 10% of Total (m³/hr)	NA	4.2	3.3	7.5
Total (m³/hr)	0.3	5.9	4.6	10.8

Table 4.7: Sediment Discharge Rates by Fraction for Sequence 6 and 7

	Fine Sand (m³/hr)	Silt (m³/hr)	Clay (m³/hr)	Total (m³/hr)
Assumed PSD	15%	21%	17%	-
Dredge Rate (m³/hr)	14.5	21.1	17.2	53 (out of 100 Total Production Rate)
Bucket Loss @ 4% (m³/hr)	0.6	0.9	0.7	2.2
Overflow Loss @ 10% of Total (m³/hr)	NA	2.1	1.7	3.8
Total (m³/hr)	0.6	3.0	2.4	6.0

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5. Modelling Outcomes

5.1 General Plume Behaviour

For the nearshore region of the dredging footprint (marine precinct, berth pocket), the general tidal currents are aligned along a north-east to south-west axis for the ebb and flood tides (Section 3.1.1). As a result, the dredge plumes are directed along this axis, with dredge plume impacts elongated to the southwest driven by the stronger flood tides in comparison to ebb tide.

The dredge plume impacts are most pronounced inshore from dredging of the sections SEQ1 to SEQ5 (Figure 3.4). This is due to the large volume of material being dredged at the seabed over a comparatively small spatial area. For the offshore sections of the channel (SEQ6 and SEQ7) the dredging requirements are spread out over a much larger area and the dredge plumes impact are significantly less. Additionally, the fines content is much higher inshore than offshore (up to 75% inshore compared with 38% through the offshore sections of the channel). Finally, the offshore current direction is more aligned with the general channel alignment and as a result the plume is often directed along the dredge footprint reducing impacts to regions outside of the main channel.

5.1.1 Spatial Extents of Modelled Dredge Plumes

5.1.1.1 Modelled Dredge Plume – Nearshore Section

Time series spatial mapping of the modelled plume for the inshore dredging at SEQ2 is shown in Figure 5.1 for the upper surface layer and Figure 5.2 for the seabed layer. The modelled dredge plume is shown at 2-hour intervals and a comparison of the surface and seabed layers from the model shows the surface layer experiences comparatively higher SSC within the immediate dredge channel footprint due to the influence of the overflow of fines from the hopper. At approximately 500m distance from the channel outlines the SSC from the surface layer and bed layer are consistent in Figure 5.1 and Figure 5.2. The depth averaged current velocity is shown in the spatial plots with the dredge plume entrained into the current. The current direction is shown to be changing through the spatial mapping plots, initially directed offshore (ebb tide) and then moving onshore (flood tide). The very high region of modelled SSC (>50mg/L) is seen from the dredging source within the confines of the channel, extending beyond the channel extents and decreasing at a distance from the channel as the plume disperses (Figure 5.1). The dredge plume area of influence extends a considerable distance to the southwest outside of the channel footprint on the flood tide.

5.1.1.2 Modelled Dredge Plume - Offshore Section

Time series spatial mapping of the modelled plume for offshore section SEQ6 is shown in Figure 5.3. The modelled dredge plume is shown at 2-hour intervals for the upper layer of the water column which experiences the highest SSC as a result of overflow from the hopper of fines. The plume is directed by the current velocity shown in Figure 5.3 based on depth averaged current direction. The current direction is shown to be changing through the spatial mapping plots, initially directed offshore (ebb tide) and then moving onshore (flood tide). The very high region of modelled SSC (>50mg/L) is generally contained within the confines of the channel with a rapid decrease in SSC level modelled outside of the channel. It is clear the plume impacts (SSC) outside of the channel at any time during the dredging is directly related to the direction of the tidal current. When dredging, modelled SSC is high at the location of the dredge and hopper in the model at up to 100mg/L. This high level of SSC is shown within the confines of the channel in Figure 5.3. Moving from the source and along the axis of the current direction, the modelled SSC in the plume reduces quickly. Generally, within 100m of the channel bounds the SSC reduces to 20mg/L or lower. Away from the main current direction on the lee side of the dredge plume the modelled SSC is almost at background.

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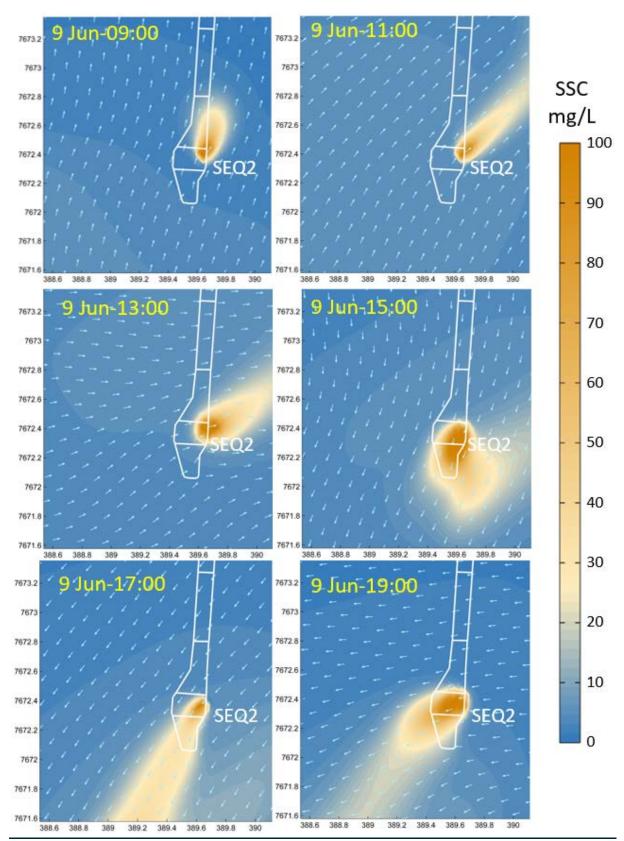


Figure 5.1: Modelled dredge plume results for SEQ2 showing modelled SSC in the upper water column (surface) at 2-hour intervals.



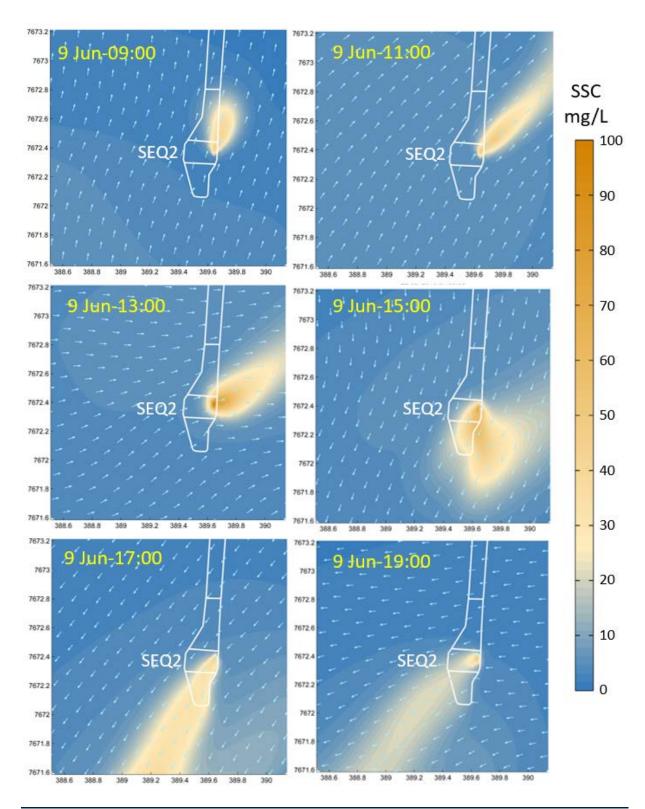


Figure 5.2: Modelled dredge plume results for SEQ2 showing modelled SSC in the lower water column (above seabed) at 2-hour intervals.



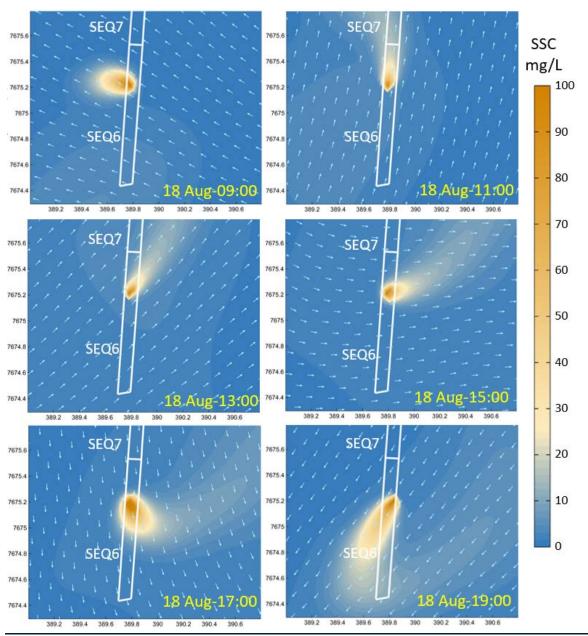


Figure 5.3: Modelled dredge plume spatial results for dredging in SEQ6 showing modelled SSC (mg/L) at 2-hour intervals with the dredge operating. Dredge plumes are shown for the upper water column where SSC is at its highest concentration.

5.2 Modelled Time Series Data through the Dredge Program

The modelled dredge sequences were compiled to provide a continuous time series of the dredging program for detailed analysis.

5.2.1 Modelled Time Series Year 1 – Inshore Areas

An example of the time series data from the dredge plume model in year one of the dredge program at inshore locations is shown in Figure 5.4. The modelled SSC from the sediment fractions (fine sand, silts, clays) are combined at each timestep in each respective vertical layer of the water column (5-layer 3D model). The modelled SSC is excess above background (mg/L) and the highest SSC through the water column at each location at each timestep is adopted in the time series plots in Figure 5.4.

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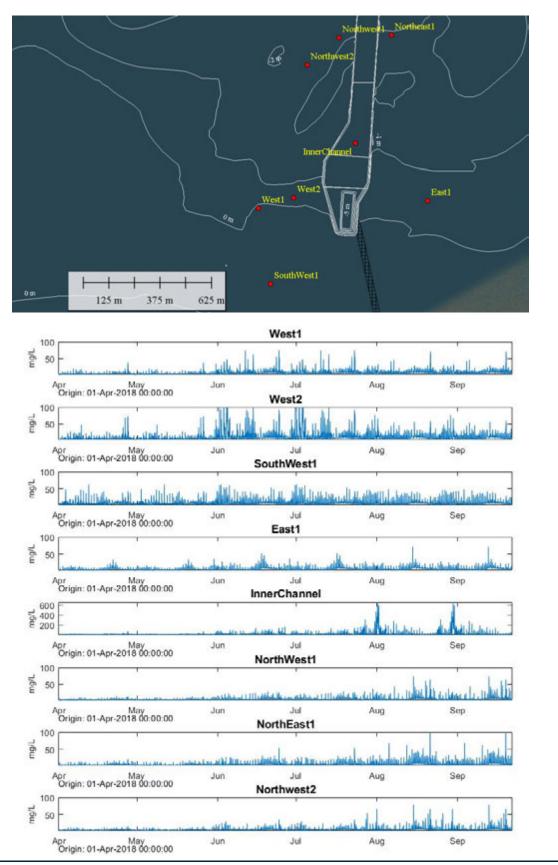


Figure 5.4: Modelled Suspended Sediment Concentration (mg/L) above background for locations around the Marine Precinct in Year One of dredging program (target dredging rate 2000m³/day).

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Analysis of the time series data from the first year of modelled dredge program indicates:

- The dredging is completed in the SEQ1 area over the April to May period, with modelled SSC in these months highest in West 1, West 2 and Southwest1 locations. The SSC reduces markedly between the West2 and West1 locations showing the dispersion of the SSC at a distance from the dredge plume source. At the same three locations the SSC increases in the June to September period as the SEQ2 and SEQ3 regions are dredged in the model which contain a higher fines content vs SEQ1.
- For the East1 location the SSC level is generally consistent through the dredging campaign and lower than SSC on the west side of the channel. This is likely due to the alignment of the plume and concentration along the NE-SW axis of the general current direction.
- The Inner Channel location SSC is far higher magnitude compared to locations outside the channel
 due to the proximity to the dredge operations. The SSC values peak when the SEQ3 is dredged in
 August and September adjacent the reporting location.
- Locations Northwest 1, Northwest 2 and Northeast 1 show consistent SSC outcomes which peak in the August and September months as SEQ3 is dredged in close proximity.

For year one of the dredge program, the 99th percentile SSC values were calculated and are shown in Figure 5.5 as excess above background. The spatial plot does not represent a single moment in time, rather it shows the 99th percentile value in each grid cell over the approximate 6-month model period. The 99th percentile SSC values are very high in the dredged footprint (100mg/L to 300mg/L) and reduce away from the dredged channel to a value of 50mg/L or less within 500m. Within 1km of the dredged footprint the 99th percentile SSC has generally reduced below 20mg/L. The concentrated plume area in Figure 5.5 shows elongation to the southwest of the 50mg/L concentration (green) due to the tidal current axis and stronger flood tides noted previously in Section 3.1.1.

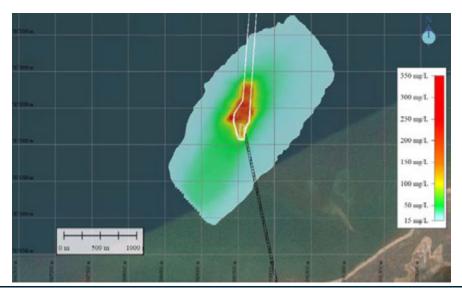


Figure 5.5: Modelled value of 99th percentile SSC through the first year dredging period. Values represent excess above background SSC (15mg/L to 350mg/L)

5.2.2 Modelled Time Series Year 2 – Offshore Areas

An example of the time series data from the dredge plume model in year two during dredging of the offshore areas of the channel is shown in Figure 5.6. Analysis of the time series data shows that the magnitude of the SSC offshore is lower than that modelled for the inshore locations (Figure 5.4). As the dredging is completed moving north over the scheduled dredging program, the peak SSC occurs through the offshore reporting locations when the dredger is in close proximity, however outside of these times the SSC is generally low.

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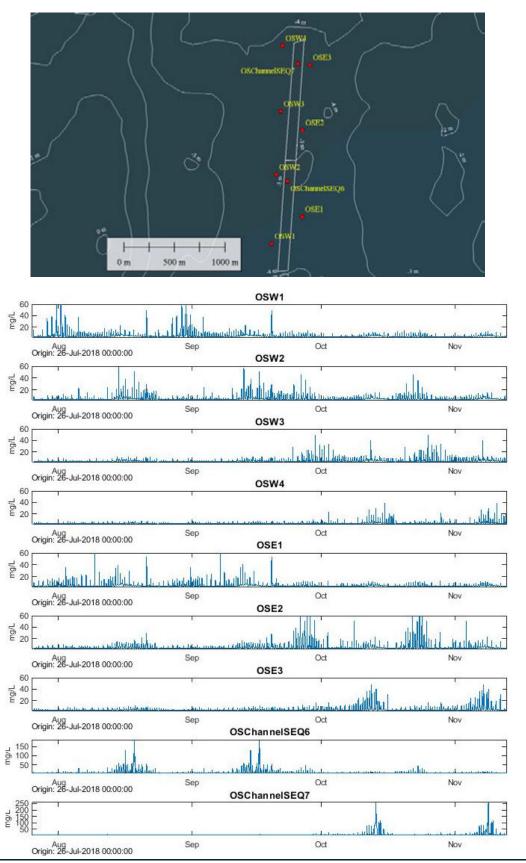


Figure 5.6: Modelled Suspended Sediment Concentration (mg/L) above background for locations in the offshore section of the dredged channel (based on target dredging rate 2000m³/day).

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5.3 Background Suspended Sediment Concentration

The Dredge Plume model simulations were executed with no background suspended sediment concentration (SSC). The model results represent excess above the background SSC.

Natural background SSC at Mardie will vary due to a range of factors. For the analysis of the model results and predicted extent, severity and duration of dredging impacts a background SSC was applied in the post processing of results based on analysis of historic MODIS imagery (MODIS, 2020) for the nearshore coastal waters around Onslow (MS Science, 2009). The analysis of the modelled data has been undertaken adopting a median background (50th percentile, P50) SSC value of 3.2mg/L.

5.4 Zones of Impact Calculation

The EPA has developed a spatially based zonation scheme for proponents to use as a common basis to describe the predicted extent, severity and duration of impacts associated with their dredging proposals (EPA, 2016g). The scheme consists of three zones that represent different levels of impact:

- 1. Zone of High Impact (ZoHI) is the area where impacts on benthic communities or habitats are predicted to be irreversible. The term irreversible means 'lacking a capacity to return or recover to a state resembling that prior to being impacted within a timeframe of five years or less'. Areas within and immediately adjacent to proposed dredge and disposal sites are typically within zones of high impact.
- 2. Zone of Moderate Impact (ZoMI) is the area within which predicted impacts on benthic organisms are recoverable within a period of five years following completion of the dredging activities. This zone abuts, and lies immediately outside of, the zone of high impact. The outer boundary of this zone is coincident with the inner boundary of the next zone, the Zone of Influence.
- 3. Zone of Influence (ZoI) is the area within which changes in environmental quality associated with dredge plumes are predicted and anticipated during the dredging operations, but where these changes would not result in a detectible impact on benthic biota. These areas can be large, but at any point in time the dredge plumes are likely to be restricted to a relatively small portion of the Zone of Influence.

5.4.1 Calculation Method for Zones of Impact

The calculation of the ZoMI and ZoHI areas from the dredge plume modelling has been completed based on analysis of the running mean of modelled SSC against possible and probable coral mortality thresholds, from the method presented in the recent work by Fisher et. al. (2019) and Jones et. al. (2019) from the Dredging Science Node of the WAMSI.

The time series dredge plume mapping output of suspended sediment is analysed spatially to calculate the running mean of SSC at 7-day, 14-day and 28-day periods across the grid over the dredge program. At each model grid point location, the modelled SSC value is defined at one-hour timestep through the dredging program. At each time step the SSC is calculated based on the combined total of all sediment fractions (clay, silt, sand). The results from the model are in 5 vertical layers through the water column and the level in the water column where the highest SSC occurs is adopted. The stratification of the plume is most pronounced adjacent the generation source with the SSC approaching uniform distribution through the water column at a distance away in the model.

The calculated running means were assessed against 7-day, 14-day and 28-day threshold limits for corals based on advice from O2Marine and work presented in Fisher et. al. (2019) as shown in Table 5.1. The ZoHI and ZoMI regions were categorised as those locations where the modelled running mean crossed the respective 7-day, 14-day or 28-day threshold at any point in the dredging program.

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Table 5.1: Threshold Limits for Modelled Suspended Sediment Concentration used to define ZoMI and ZoHI regions through the dredge program (from Fisher et. al., 2019)

Threshold Type	Running Mean Period	ZoMI Threshold (>SSC)	ZoHI Threshold (>SSC)
Running Mean (SSC)	7 day	14.7 mg/L	24.5 mg/L
	14 day	11.7 mg/L	18.0 mg/L
	28 day	9.3 mg/L	13.2 mg/L

5.4.2 Best Case and Worst-Case Scenarios

The following conditions were analysed from the model results to determine ZoHI and ZoMI:

- The 'best case' scenario for dredge plume impacts is defined as the case where expected dredge production rate is achieved throughout the duration of the dredge program. The assumption is based on 2 x 10hr shifts per 24-hour period where 2,000m³ / day is dredged. The dredge operates 7 days a week):
- The 'worst-case' scenario for dredge plume impacts is defined as the case where an upper limit dredge production rate is achieved throughout the duration of the dredge program. The assumption is based on 2 x 10hr shifts per 24-hour period where 2,500m³ / day is dredged. The dredge operates 7 days a week);

The mapping output from the model was made available on a 60-minute time interval from 5 vertical layers. The SSC was analysed in all five model layers and the highest SSC through the water column at each location on the model output grid was adopted in the analysis at each timestep. As discussed in Section 5.1.1.1 the SSC is notably higher in the upper water column around the hopper overflow, when compared to the seabed, becoming more uniform at a distance away from the dredge footprint.

Running mean values of modelled SSC were calculated (7-day, 14-day and 28-day) and analysed against possible and probable coral mortality thresholds applying the method presented in Fisher et. al. (2019). This analysis has determined the zones of impact that will be used in the environmental monitoring and management program.

5.4.3 Analysis Steps

The process for calculating the ZoMI and ZoHI regions has utilised a custom Matlab algorithm which applies the following steps:

- 1. The dredge model output is a spatial grid on a 60-minute timestep. The grid points store the SSC value through the water column based on the combined sediment fractions from dredge plumes (total SSC from fine sand, silt, fine silt and clay).
- 2. The model is in 3D with the mapping at 5 vertical layers from the surface to seabed (units mg/L). The highest modelled SSC through the 5 layers of the water column in the model is adopted at each timestep in the analysis;
- 3. Modelled outcomes represent excess above background. Background SSC is added to the dredge plume model results adopting a P50 value of 3.2mg/L.
- 4. The algorithm calculates the SSC running mean over a 7-day, 14-day and 28-day period at every individual model grid location from the modelled time series data. This is done for year one and year two of the dredge program separately
- 5. Analysis of the calculated running mean against the 7-day, 14-day and 28-day thresholds (Table 5.1) is used to define the spatial extent of the ZoMI and ZoHI areas (based on Fisher et. al., 2019). The calculated ZoMI and ZoHI region is defined as a polygon area bounding the point where any of the 7-day, 14-day or 28-day running mean thresholds is exceeded during the dredge program;

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- 6. The 'Best Case' ZoMI and ZoHI is assessed for model results developed for the expected dredging production rate of 2,000m³/day. The 'Worst Case' is based on an upper limit production rate of 2,500m³/day.
- 7. For the ZoHI, the spatial extent adopts a minimum distance from the dredged channel of 25m. For the ZoMI a minimum distance from the dredged channel of 150m is applied. These distances have been set as a conservative basis for including consideration of the coarse sand fractions assumed to fall out of suspension close to the source of dredging.

An example of the analysis of running mean SSC against the 7-day, 14-day and 28-day thresholds is presented in Figure 5.7 based on the target production rate of 2,000m³ a day. The locations analysed are the points shown in Figure 5.4 as 'West1', 'Inner Channel1' and 'East1'. From the analysis of Figure 5.7:

- West1 location is categorised as ZoMI as the 14-day and 28-day moving average cross the possible coral mortality threshold but stay just below the probable threshold in all categories;
- InnerChannel location is categorised as ZoHI as the 7-day,14-day and 28-day moving average cross
 the probable coral mortality threshold for all categories. The very high SSC spikes in August and
 September are associated with the close proximity of the dredging to the reporting location during
 completion of SEQ3; and
- At the East1 location, the calculated 7-day and 14-day running mean does not reach the respective coral mortality threshold. However, the 28-day running mean just reaches the 28-day threshold value and as a result this location is within the ZoMI.

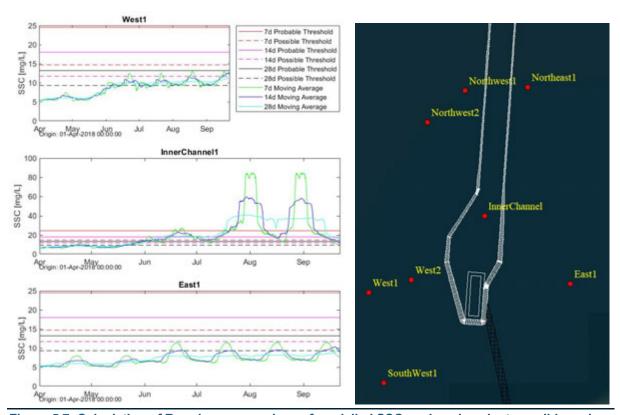


Figure 5.7: Calculation of Running mean values of modelled SSC analysed against possible and probable coral mortality thresholds (based on Fisher et. al., 2019). Analysis shown for the target dredge rate of 2000m³ a day.

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5.5 Final Calculated Zones of Impact

5.5.1 Inshore Dredging – Sequence 1 to Sequence 3

The modelled dredge plume impact regions are shown in Figure 5.8 for the inshore dredge sequence SEQ1, SEQ2 and SEQ3 covered in the first dry season period. This represents the analysis of 6 continuous months of dredging. The spatial extent of the zones of impact are shown for the target production rate of 2,000m³/day ('best case') and upper limit 2,500m³/day production rate (ie 'worst case').

- For the ZoHI the modelled impact region under the 2,000m³/day target production case extends over a spatial area of 0.5km² and is a minimum 60m to maximum 180m from the edge of the dredged channel. Under the modelled 2,500m³/day upper limit production case the ZoHI extends over a spatial area of 0.8km² and is a minimum 100m to maximum 390m from the edge of the channel
- For the ZoMI the modelled impact region under the 2,000m³/day target production case extends over a spatial area of 2.5km² with a minimum 330m to maximum 1.4km distance as measured from the edge of the dredged channel. Under the modelled 2,500m³/day upper limit production case the ZoMI region is 6.2km² with a minimum 460m to maximum 2.7km distance measured from the edge of the dredging. The plume extent is elongated along the southwest axis.

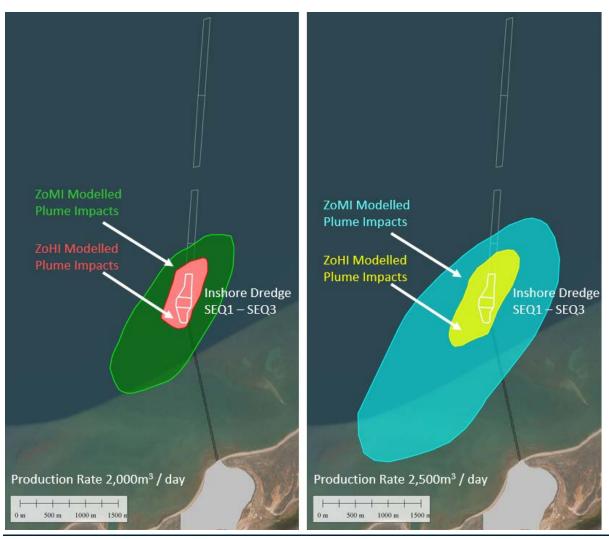


Figure 5.8: Calculated dredge plume impact areas for inshore Section SEQ1 to SEQ3. Left Image: Modelled dredge plume impact ZoMI and ZoHI based on target production rate 2,000m³/day ('Best Case'). Right Image: Modelled dredge plume impact areas ZoMI and ZoHI based on upper limit production rate of 2,500m³/day ('Worst Case').

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5.5.2 Inshore Dredging – Sequence 4 to Sequence 5

The modelled dredge plume impact regions are shown in Figure 5.8 for the inshore dredge sequence SEQ5 and SEQ6. This represents the analysis of 4 continuous months of dredging. The modelled spatial extent of the zones of impact are shown for the target production rate of 2,000m³/day ('best case') and the upper limit 2,500m³/day production rate (ie 'worst case').

- For the ZoHI the modelled impact region under the 2,000m³/day target production case extends over a spatial area of 0.5km² and is a minimum 60m to maximum 180m from the edge of the channel. Under the modelled 2,500m³/day upper limit production case the ZoHI extends over a spatial area of 0.8km² and is a minimum 100m to maximum 390m from the edge of the dredged channel
- For the ZoMI the modelled impact region under the 2,000m³/day target production case extends over a spatial area of 2.8km² and is a minimum 30m to maximum 1.9km from the edge of the channel. Under the modelled 2,500m³/day upper limit production case the ZoMI extends over a spatial area of 6.5km² and is a minimum 180m to maximum 3.1km from the edge of the channel. The plume extent is elongated along the southwest axis.

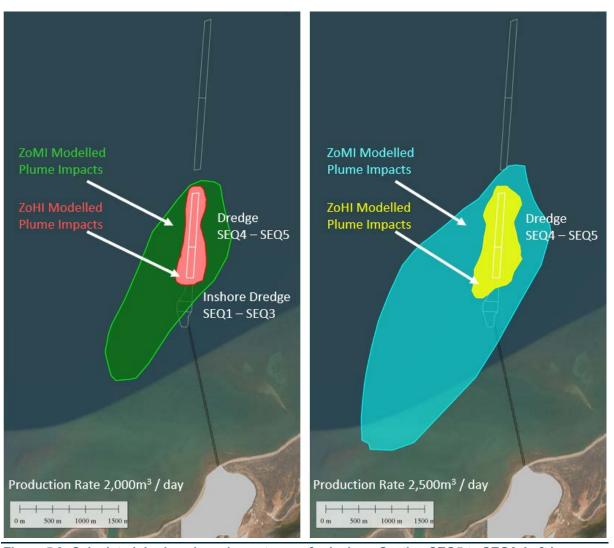


Figure 5.9: Calculated dredge plume impact areas for inshore Section SEQ5 to SEQ6. Left Image: Modelled dredge plume impact ZoMI and ZoHI based on target production rate 2,000m³/day (best case). Right Image: Modelled dredge plume impact areas ZoMI and ZoHI based on upper limit production rate of 2,500m³/day (worst case).

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5.5.3 Offshore Dredging – Sequence 6 to Sequence 7

For the offshore dredge sections Sequence 6 and Sequence 7 the calculation method for the zones of impact is presented in Figure 5.10. The modelled dredge plume impact regions are much reduced compared to the inshore dredge region as previously discussed in Section 5.1. The modelled spatial extent of the zones of impact is shown for the 2,500m³/day production rate (ie 'worst case') in Figure 5.10

- For the ZoHI the plume impacts are generally within 20m of the edge of the channel. The adopted ZoHI region is conservatively defined based on a 25m distance from the edge of the channel and shown as the yellow polygon.
- The ZoMI modelled dredge plume impact is shown in Figure 5.10 as a spatially varying region along the channel sections of SEQ6 and SEQ7. Conservatively the ZoMI extent adopted is defined by a blue polygon area 150m from the edge of the channel.

The modelled outcomes for the ZoMI and ZoHI under target production rate of 2,000m³/day 'best case' are smaller than the regions shown in Figure 5.10. Applying the conservative approach outlined above, the adopted extents of the ZoMI are defined at 150m from the edge of the channel and the ZoHI at 25m from the edge of channel.

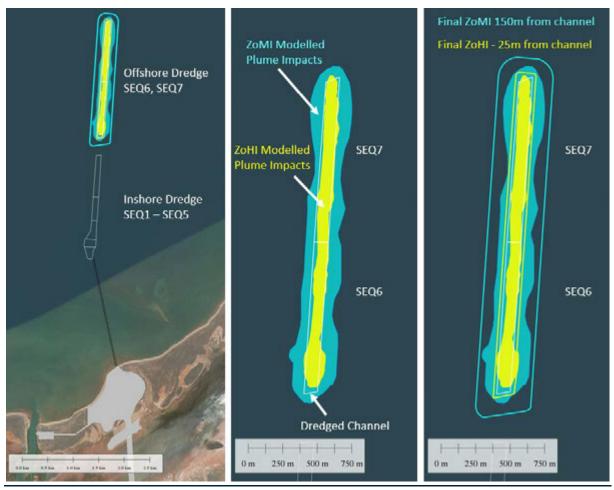


Figure 5.10: Analysis of Zones of Impact for offshore dredging in Sequence 6 and Sequence 7. Left image: Offshore dredging location. Middle Image: Modelled dredge plume impact ZoMI and ZoHI for offshore sections based on upper limit production rate (2,500m³/day). Right image: Adopted ZoMI and ZoHI extents are shown as polygons based on adopting a minimum distance from edge of channel. ZoHI is 25m from channel, ZoMI is 150m from channel. Actual modelled results are shown spatially contained within the respective bounds.

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5.5.4 Calculated Zones of Impact over Entire Dredge Campaign

The calculated zones of impact (ZoMI and ZoHI) have been compiled based on the complete dredging program. The spatial areas have been defined based on a polygon drawn around the extents defined in the presentations in Figure 5.8, Figure 5.9 and Figure 5.10. The zones of impact are presented in Figure 5.11 for the 'best case' (target 2,000m³/day production) and Figure 5.12 for the 'worst case' (upper limit 2,500m³/day production). A relative comparison of the spatial areas can be seen on the combined map in Figure 5.13:

- For the ZoMI the modelled impact region extends over a spatial area of 5.3km² for the best case to 9.7km² for the worst case; and
- For the ZoHI the modelled impact region extends over a spatial area of 1.2km² for the best case to 1.8km² for the worst case.

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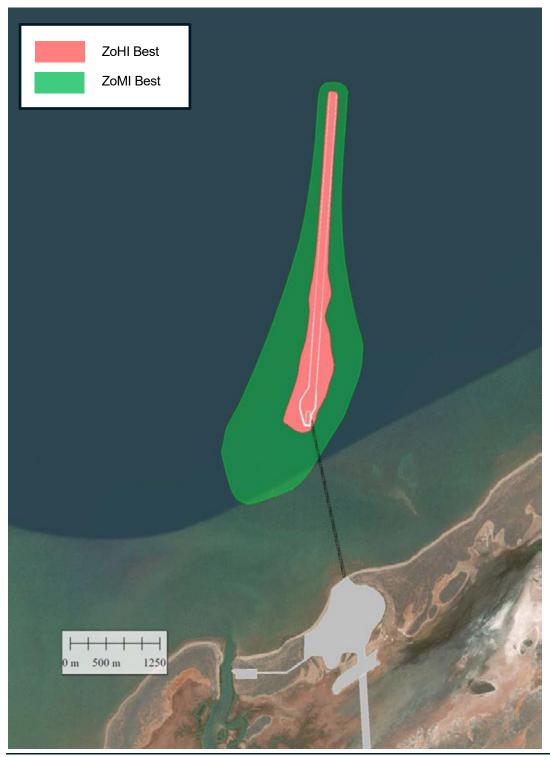


Figure 5.11: Calculated Zones of Impact for expected production rate scenario with a dredging rate of 2,000m³/day ('Best Case'). Full dredge program.



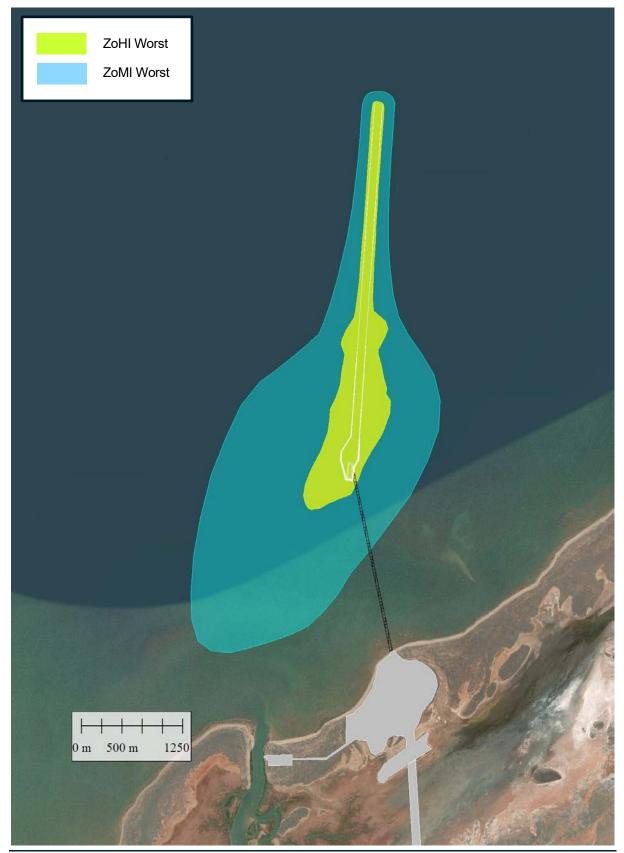


Figure 5.12: Calculated Zones of Impact for maximum production rate scenario with a dredging rate of 2,500m³/day ('Worst Case'). Full dredge program.

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Figure 5.13: Calculated Zones of Impact (ZoMI and ZoHI) for 'Best Case' and 'Worst Case' Scenarios. Full dredge program.



6. Conclusions

The Mardie Project is a greenfields high-quality salt project proposed in the Pilbara region of Western Australia. Baird Australia Pty Limited (Baird) have been engaged by Mardie Minerals, a wholly owned subsidiary of BCI Minerals Limited (BCIM) to develop a hydrodynamic modelling program to support the environmental approvals process to assess:

- Modelling of dredge plumes to inform the preparation of a Dredging and Spoil Disposal Management Plan (DSDMP); and
- Modelling of mixing and dilution of bitterns discharge into the marine environment to inform the preparation of a Environmental Quality Plan (EQP).

The dredging requirements through the project footprint will require approximately 800,000m³ of sediment to be removed from the seabed for disposal onshore. The dredging approach and methodology was defined by BCIM for incorporation into the dredge plume modelling process based on a backhoe dredge operating from a barge with a hopper alongside. Dredge rates adopted in the modelling process are based on a target production rate of 2,000m³ a day, with a sensitivity case examined based on an upper limit production rate of 2,500m³ a day.

An established Delft3D hydrodynamic model (Baird, 2020) was used as a basis for the dredge plume modelling program. The Delft3D Online Sediment model has been activated in the model to investigate the transport of fine sediments released through the dredging program in four representative fractions – fine sand, silt, fine silt and clay. There is a detailed geotechnical investigation and sediment sampling program which has informed understanding of the composition of the seabed material which will be dredged (CMW,2019). The dredge material is very high in fine sediments (clays, silts) representing between 38% and 75% of the material by volume in sections of the channel. The required volume of dredging material was calculated through the footprint based on high resolution multibeam survey (Surrich and EGS, 2019)) and requirements to achieve the target design depth which is -3.9m LAT in the channel and -6.7mLAT in the berth pocket.

Sediment plumes from dredging will be generated from 2 principal sources: mobilisation of fine sediments from the dredger bucket with each load and overflow water from the hopper barges. These have been input to the model as:

- 4% by mass of total fine sediments (fine sand, clay and silt fractions) lost as the bucket comes up through the water column from the seabed.
- 10% by mass of fines (< 62um) in suspension in the hopper discharging into the upper water column (conservative assumption).

The preparation of the time series inputs to the model cases were developed based on the dredging volume requirements and giving consideration to the geotechnical investigations and sediment sampling analysis of the seabed composition. Dredge sequences were established in the model to simulate the dredge program over two consecutive years of dry season conditions.

The modelling was completed without background concentration of SSC in the water column. For the analysis of the model results and predicted extent, severity and duration of dredging impacts a background SSC of 3.2mg/L was applied in the post processing of results based on P50 value of SSC analysed from historic MODIS imagery for the nearshore coastal waters around Onslow (MS Science, 2009).

For the nearshore region of the dredging footprint (marine precinct, berth pocket), the general tidal currents are aligned along a north-east to south-west axis for the ebb and flood tides (Baird, 2020). The dredge plumes are directed along this axis, with dredge plume impacts elongated to the southwest driven by the stronger flood tides in comparison to ebb tide. The dredge plume impacts are most pronounced inshore associated with dredging of large volumes of material over a comparatively small spatial area. For the offshore sections of the channel the dredging requirements are spread out over a much larger area and the

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dredge plumes impacts significantly less. Additionally, the fines content is much higher inshore than offshore (up to 75% inshore compared with 38% through the offshore sections of the channel).

The dredge plume model outcomes are examined as time series of SSC in Section 5. Analysis of the first year of the dredge program examining the 99th percentile SSC values shows these are very high in the dredged footprint (100mg/L to 300mg/L) and reduce away from the dredged channel to a value of 50mg/L or less within 500m. Within 1km of the dredged footprint the 99th percentile SSC has reduced below 20mg/L.

The Environment Protection Authority spatially based zonation scheme to describe the predicted extent, severity and duration of impacts associated with the Mardie project dredging have been determined through the processing and assessment of the dredge plume model results. The Zone of High Impact (ZoHI) and Zone of Moderate Impact (ZoMI) have been determined by analysing model results as running mean values of modelled SSC against possible and probable coral mortality thresholds applying the method presented in Fisher et. al. (2019).

The mapping output from the model was made available on a 60-minute time interval from 5 vertical layers through the water column. To analyse the modelled dredge plume impacts the SSC was combined from the 4 respective sediment fractions (fine sand, coarse silt, fine silt, clay) within each respective vertical layer. The highest SSC through the water column at each location on the model output grid was adopted at each timestep in the analysis. The 'best case' scenario for dredge plume impacts is defined as the case where expected dredge production rate of 2,000m³/day is achieved throughout the duration of the dredge program. The 'worst-case' scenario for dredge plume impacts is defined as the case where an upper limit dredge production rate of 2,500m³/day is achieved throughout the duration of the dredge program.

The final ZOMI and ZOHI for the Mardie project are presented spatially in Section 5 for application in the DSDMP.

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Appendix A

Summary of Final Mapping Datasets

Supplied Datasets

File	Filename
ZoMI Worst	MardieDredge2020_ZOMI_WorstCase_BgSSC_3.2mgL_2500m3dayProduction
ZoMI Best	MardieDredge2020_ZOMI_BestCase_BgSSC_3.2mgL_2000m3dayProduction
ZoHI Worst	MardieDredge2020_ZOHI_WorstCase_BgSSC_3.2mgL_2500m3dayProduction
ZoHI Best	MardieDredge2020_ZOHI_BestCase_BgSSC_3.2mgL_2000m3dayProduction

12979.101.R4.Rev0 Appendix A