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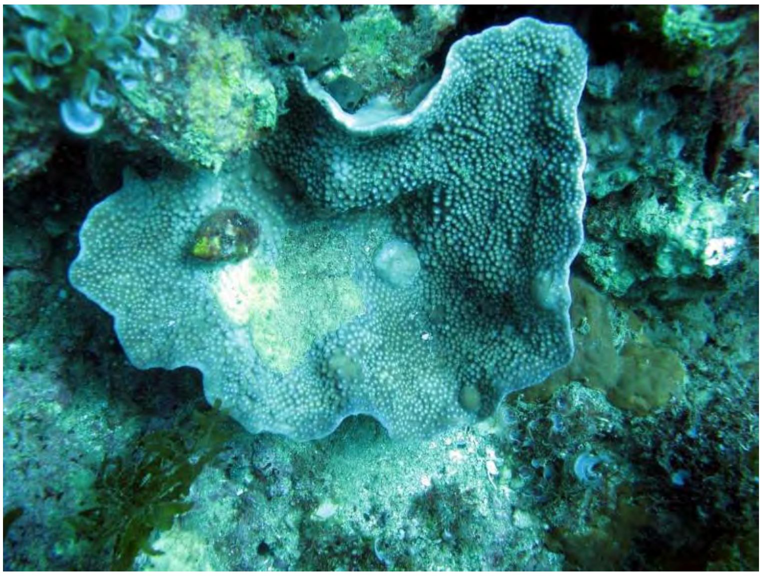
Port Hedland Outer Harbour Development



SUBTIDAL MARINE BENTHIC HABITATS IMPACT ASSESSMENT

- WV03759.150
- Revision 2
- 7 April 2011

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Sinclair Knight Merz
11th Floor, Durack Centre
263 Adelaide Terrace
PO Box H615
Perth WA 6001 Australia

Tel: +61 8 9268 4400
Fax: +61 8 9268 4488
Web: www.skmconsulting.com

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The sole purpose of this report and the associated services performed by Sinclair Knight Merz ("SKM") is to assess the impacts of the proposed Outer Harbour Development on the subtidal marine benthic habitats at Port Hedland, in accordance with the scope of services set out in the contract between SKM and the Client. That scope of services, as described in this report, was developed with the Client.

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Executive Summary

Background

BHP Billiton Iron Ore operates a port in the Port Hedland region of Western Australia. In recent times, BHP Billiton Iron Ore has experienced unprecedented demand for iron ore from overseas markets and is now embarking on a development program to cater for this increased demand. BHP Billiton Iron Ore is currently investigating a number of port development options, one of which is to develop an Outer Harbour at Port Hedland. The marine component of the proposed Outer Harbour Development will include dredging and the development of a new jetty/wharf structure, berths and ship loading infrastructure.

The proposed Outer Harbour Development has the potential to impact upon marine benthic primary producers (BPPs) such as hard corals, seagrasses and macroalgae both directly (infrastructure insertion, dredging) and indirectly (dredging and spoil disposal plumes).

The Environmental Protection Authority (EPA) recognises the importance of BPPs and benthic primary producer habitat (BPPH) in contributing to marine ecological functions and provision of environmental services (EPA 2004). Consequently, the EPA has produced Environmental Assessment Guideline No. 3, *Protection of Benthic Primary Producer Habitats in Western Australia's Marine Environment* (EPA 2009), and Environmental Assessment Guideline No. 7, *Marine Dredging Proposals* (EPA 2010), to provide advice on the considerations that must be addressed by any proponent of a development that may negatively impact upon the suite of environmental services and ecological functions supported by the BPPH.

Objectives

The objectives of this marine subtidal BPPH Impact Assessment are to:

- define the direct and indirect impacts related to the proposed Outer Harbour Development;
- predict the spatial extent of impacts to BPPH within State waters;
- calculate potential cumulative losses of BPPH within defined Local Assessment Units;
- evaluate direct and indirect losses and impacts against the EPA's EAG No. 3 and No. 7;
- consider the BPPH in a regional context to determine its ecological significance; and
- propose management strategies to minimise potential impacts to BPPH.

Methods

This report covers subtidal marine habitats and associated communities in State waters offshore from Port Hedland. All intertidal habitats along the coastline within the project footprint, including inshore from Finucane Island, are covered by a separate intertidal BPPH assessment report (SKM 2009i).

Predictive sediment plume modelling was undertaken by APASA to evaluate the extent of water quality perturbations resulting from dredging activities. Perturbations included increased total suspended solid concentrations and elevated sedimentation rates. In addition, threshold criteria based on tolerances of hard corals were applied to the modelling outputs such that impacts to benthic habitats and benthic communities could be determined.

A number of Local Assessment Units were proposed within State waters of the proposed Outer Harbour Development area. The LAUs and their boundaries were provided to the EPA Marine Branch Service Unit in January 2011 and were accepted. The LAUs relevant to this assessment are LAUs 7, 8, 9, 14, 17, 18 and the established Port Hedland Industrial LAU[1].

The proposed and predicted losses and impacts to BPPH have been assessed in each LAU. The assessment has considered direct and indirect losses arising from the proposed Outer Harbour Development, and indirect impacts to communities.

Outcomes

Direct loss of BPPH (7.6 ha; 2.5% of LAU 8) will occur during construction of the marine infrastructure, and indirect loss of BPPH due to elevated sedimentation rates is predicted to also occur close to the dredging activities (140.3 ha; 45.6% of LAU 8). When accounting for historical losses in the Port Hedland Industrial LAU (4.17 ha) and LAU 8 (15 ha) this amounts to a cumulative loss of 167.1 ha of BPPH within State waters for the proposed Outer Harbour Development, primarily due to indirect losses arising from sedimentation in the Zone of High Impact. The predicted indirect losses due to increases in sedimentation rates in the Zone of High Impact will not result in the loss of the underlying hard substrate on which BPP’s grow.

The ecological significance of the losses of BPPH arising from the proposed Outer Harbour Development is considered to be minimal. Hard corals were the most dominant BPP growing along the ridgelines that will be affected by dredging activities, and the dominant corals present are from the genus *Turbinaria* and from the families Faviidae and Poritidae. Based on the low species richness and abundance of corals and dominance of *Turbinaria*, coral communities that inhabit subtidal habitats in the Port Hedland region are high turbidity, high sedimentation adapted communities. In addition, the species and habitats affected are considered typical of the broader marine environment of the Pilbara region, and no new species have been recorded.

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[1] Previously known as the Port Hedland Industrial Area Management Unit, as identified in EPA (2001).

The nearest seagrasses are some 10 km to the south-west of the boundary of the Zone of Moderate Impact and lie within the Zone of Influence. No losses or impacts to seagrasses recorded within the proposed Outer Harbour Development area are predicted.

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1. Introduction

1.1. Project Overview

BHP Billiton Iron Ore operates a port in the Port Hedland region of Western Australia. The current port operations consist of processing, stockpiling and shiploading facilities at Nelson Point and Finucane Island (referred to as the Inner Harbour), located on opposite sides of the Port Hedland Harbour.

BHP Billiton Iron Ore is investigating a number of port development options to further extend capacity of its port operations, one of which is to develop an Outer Harbour at Port Hedland.

The proposed Outer Harbour Development is expected to provide an additional nominal export capacity of approximately 240 Mtpa of iron ore from to BHP Billiton Iron Ore's Port Hedland. The proposed expansion is planned to occur in stages.

The Outer Harbour Development will involve the construction and operation of landside and marine infrastructure for the handling and export of iron ore. Landside development will include:

- rail connections from the existing BHP Billiton Iron Ore mainline to proposed stockyards at Boodarie;
- rail loops at Boodarie;
- stockyards at Boodarie; and
- an infrastructure corridor (including conveyors, access roadway and utilities) from the stockyards to a transfer station on Finucane Island that connects to a marine jetty.

Key proposed marine structures and activities will include:

- an abutment, jetty and wharf;
- mooring and associated mooring dolphins;
- transfer station and deck;
- associated transfer stations, ore conveyors and ship loaders;
- dredging for berth pockets, basins and channels; and
- aids to navigation.

1.2. Study Objectives

The proposed Outer Harbour Development will have direct and indirect impacts on subtidal marine habitats in the Port Hedland offshore environment. As required by the *Environmental Protection*

Act, 1986, an assessment of the environmental impacts arising from the proposed project is to be made by BHP Billiton Iron Ore.

This document presents an assessment of the subtidal habitats and associated benthic communities that will or could be impacted by the proposed Outer Harbour Development, and an outline of the activities causing the impacts. All intertidal habitats along the coastline within the project footprint, including inshore from Finucane Island and in the tidal creeks of the Port Hedland region, are covered by a separate intertidal BPPH assessment report (SKM 2009i).

1.3. Structure of this Report

This report comprises the following:

- **Section 2**: an overview of the legislative and policy framework for assessment of environmental impacts to subtidal marine habitats;
- **Section 3**: a description of the proposed construction and operation activities;
- **Section 4**: a summary of the subtidal marine habitats within the project footprint;
- **Section 5**: predictions of the likely behaviour and spatial distribution of dredge and dredge spoil disposal plumes and water quality threshold setting and rationale;
- **Section 7**: interpretation of sediment plume modelling outputs;
- **Section 8**: approach to assessment of impacts to benthic communities and benthic habitats;
- **Section 9**: predicted impacts to benthic communities and benthic habitats arising from construction dredging and disposal activities;
- **Section 10**: predicted indirect effects to benthic communities and benthic habitats from construction of nearshore infrastructure; and
- **Section 10**: a summary of the environmental impact assessment provided in this document.

2. EPA Guidelines

The Environmental Protection Authority (EPA) issues Environmental Assessment Guidelines (EAGs) which assist in the protection and management of sensitive environments in Western Australia. There are two EAGs relevant to the environmental impact assessment undertaken in this report:

- EAG No. 3, *Protection of Benthic Primary Producer Habitats in Western Australia's Marine Environment*, provides guidance on assessing potential impacts, including cumulative irreversible loss and serious damage to, benthic primary producer habitats in Western Australia's marine environment; and
- EAG No. 7, *Marine Dredging Proposals*, has been designed to impart clarity and consistency to the information presented to the EPA for the environmental impact assessment of marine dredging proposals through the provision of a single assessment framework.

A brief summary of each EAG is provided in the sub-sections below.

2.1. Environmental Assessment Guideline No. 3

The geographic scope of EAG No. 3 covers all coastal waters of Western Australia, from the highest water mark to the intertidal zone associated with the mainland, islands and emergent reefs to the depth maxima for benthic primary producer habitats in the subtidal zone of these waters.

In applying the intent of EAG No. 3 and ensuring that impact assessment is undertaken as intended by the EPA, a clear understanding of a number of terms is required:

- Benthic primary producer habitats are functional ecological communities that inhabit the seabed within which algae (e.g. macroalgae, turf and benthic microalgae), seagrass, mangroves, corals or mixtures of these groups are prominent components. Benthic primary producer habitats also include areas of seabed that can support these communities.
- Loss of benthic primary producer habitat would commonly be associated with activities such as excavation or burial. In almost all cases, these activities directly modify benthic primary producer habitat so significantly that impacted habitat would not be expected to recover to the pre-impact state and therefore the impact is irreversible.
- Serious damage refers to damage to benthic primary producer habitat that is effectively irreversible or, where recovery is predicted, it is not predicted to occur within a 5-year timeframe.

2.2. Environmental Assessment Guideline No. 7

The direct and indirect impacts of dredging on benthic communities and habitats are the primary concerns of EAG No. 7. Specifically, the main focus of EAG No. 7 is:

- direct loss of benthic habitats and communities by removal or burial; and
- indirect impacts on benthic habitats and communities from the effects of sediments introduced to the water column by the dredging.

At a minimum, direct losses will occur within the footprints of dredged areas and some spoil grounds, and may extend to areas immediately surrounding infrastructure where acute or ongoing sediment-related impacts are expected to occur (e.g. sedimentation). Direct losses are considered irreversible unless a scientifically-sound case can be made for recovery within a timeframe of five years or less.

Indirect impacts generally occur as a consequence of the intensity, duration and frequency of sediment-related pressure imposed on benthic biota such as:

- Sediment in the water column (turbidity): reduces quality and quantity of light available at the seabed for photosynthesis, can clog feeding apparatus of filter feeders and deposit feeders and inhibit key ecological processes that occur in the water column (e.g. fertilisation of pelagic gametes, survivorship and competency of propagules).
- Sediment deposited on the benthos (sedimentation): smothers biota, can cause abrasion of exposed tissues, can alter sea bed load or produce other effects similar to those caused by turbidity.

3. Project Description

The proposed Outer Harbour Development will include the following key marine infrastructure and activities:

- an abutment (on Finucane Island), jetty and wharf;
- mooring and associated mooring dolphins;
- associated transfer stations, ore conveyors and shiploaders;
- berth pockets, basins and channels; and
- aids to navigation.

The marine infrastructure for the offshore loading facility will be constructed from Finucane Island in an approximately northerly direction with a new wharf constructed adjacent to the existing shipping channel. The marine infrastructure and activities are described in the following subsections and illustrated in **Figure 3-1**.

3.1. Marine Jetty

A steel piled jetty of approximately 4 km in length is proposed to be constructed from Finucane Island to the wharf. The jetty will support conveyors, maintenance services and a two lane roadway for vehicle access to the wharf. The jetty conveyors will be constructed to transfer ore material from the transfer station on Finucane Island to the transfer deck, then onto the wharf conveyors and into the shiploaders.

The passage of recreational water craft under the elevated jetty trestle will be permitted at controlled locations, for the purposes of safety.

3.2. Wharf Structure/Transfer Deck

The proposed wharf structure and associated berthing and mooring dolphins will be located approximately 4 km north of Finucane Island. The wharf will be approximately 2 km in length and will be designed to accommodate:

- shiploaders and shiploader rail system;
- access roadway and access walkways;
- maintenance bays;
- the conveyor systems;
- cyclone tie down facilities, and
- support services (including amenities, offices etc).

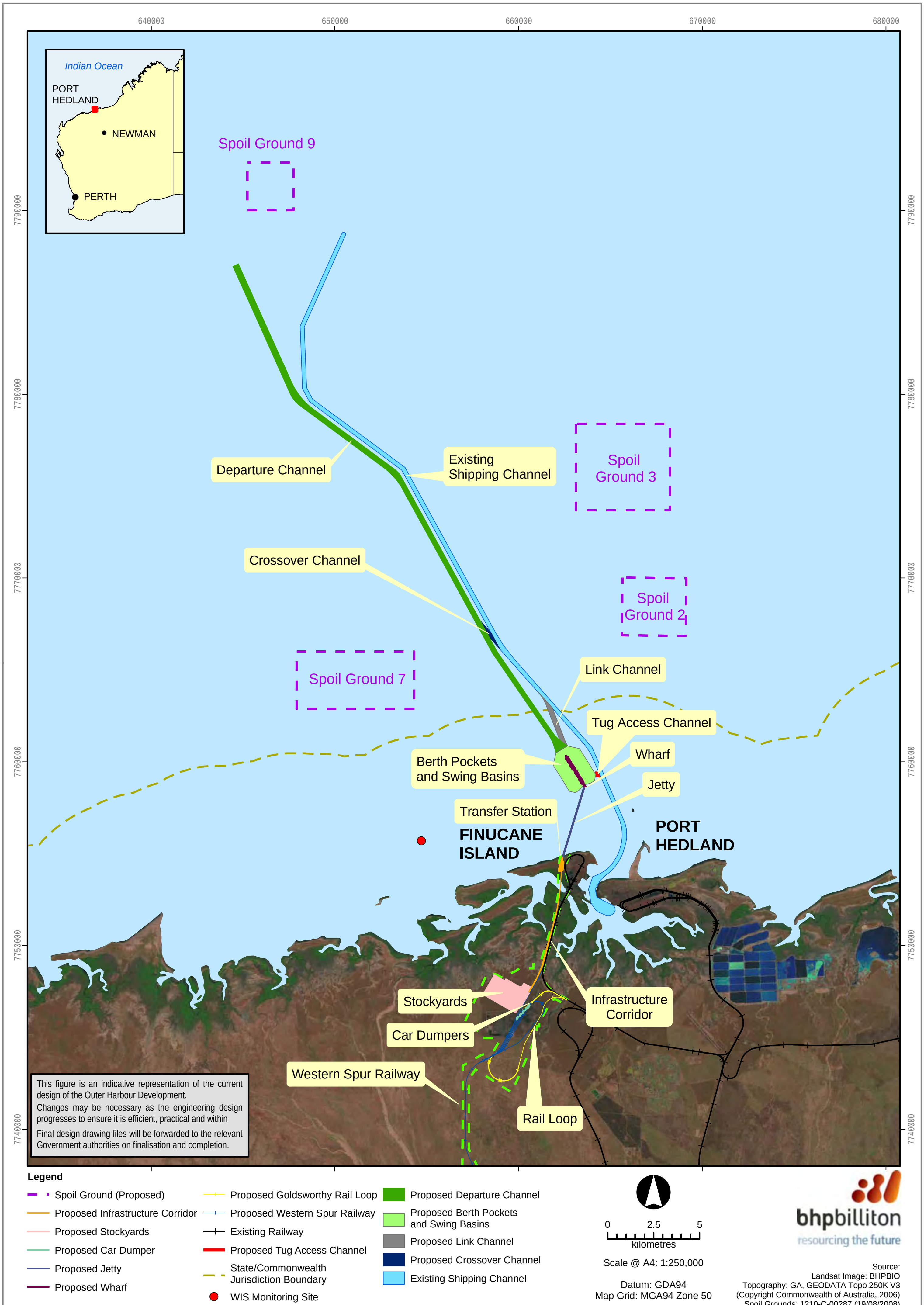


Figure 3-1 Port Hedland Outer Harbour Development Proposed Marine Infrastructure and Proposed Spoil Grounds

Each stage of wharf development consists of two berths. The proposed transfer deck will be located at the end of the jetty and will connect to the wharf structure. The transfer deck will provide services and support facilities for construction, operational and maintenance personnel.

3.3. Dredging and Spoil Disposal

The construction of the proposed Outer Harbour Development will require dredging to enable vessel access to the wharf and for loaded vessels to depart to deep water.

Dredging operations will create new berth pockets, swing/departure basins, a departure link channel to the existing shipping channel, a proposed departure channel, a cross-over link channel enabling access for departing, laden vessels from the Inner Harbour shipping channel into the new 34 km long departure channel and a tug access channel from the existing channel into the berth pockets.

The required depths will be approximately -22 m CD for the berth pockets, -23 m CD for the wharf footprint area, -11 m CD for the swing basins and -16 m CD for the departure basins, based upon a 250,000 Dry Weight Tonnes (DWT) vessel. The swing basins, departure basins, berth pockets and up to 3 km of the new departure channel will be located in State waters, with the remainder of the departure channel being in Commonwealth waters. The depths along the departure channel will range from approximately -15 m to -17 m CD.

The total volume of dredge spoil is estimated to be approximately 54 million cubic metres (Mm^3) of material, including over-dredging. The majority of material can be removed by a trailing suction hopper dredger (TSHD). A smaller percentage of the material is harder substrate and will require a cutter suction dredger (CSD). Based on the geotechnical studies completed to date there have been no areas identified in the dredging footprint that would necessitate blasting operations for material extraction. Dredging operations will involve a workforce of up to 160 persons and be conducted 24 hours per day, 7 days per week. It is proposed that dredging will occur in a staged manner, as follows:

- Dredging of berth pockets, eastern swing and departure basins, a tug access channel and a link channel to the existing channel to provide two loading berths.
- Dredging of the western swing and departure basins to provide two additional loading berths. This stage also includes the dredging works for the new 34 km departure channel and the crossover link channel.
- Dredging for the extension of the wharf with additional berth pockets and the swing and departure basins to accommodate another four loading berths.

The disposal of dredged material will be carried out in accordance with the Dredge and Spoil Disposal Management Plan. The suitability of a number of potential spoil locations has been investigated and there are three preferred offshore locations which have been identified as part of the application for a Commonwealth Sea Dumping Permit (SKM 2009a). A separate spoil ground selection phase study report to describe the history of the process has been undertaken (SKM 2009b). All of these offshore spoil grounds will be located in Commonwealth waters in depths greater than -10 m CD.

3.4. Construction of the Marine Infrastructure

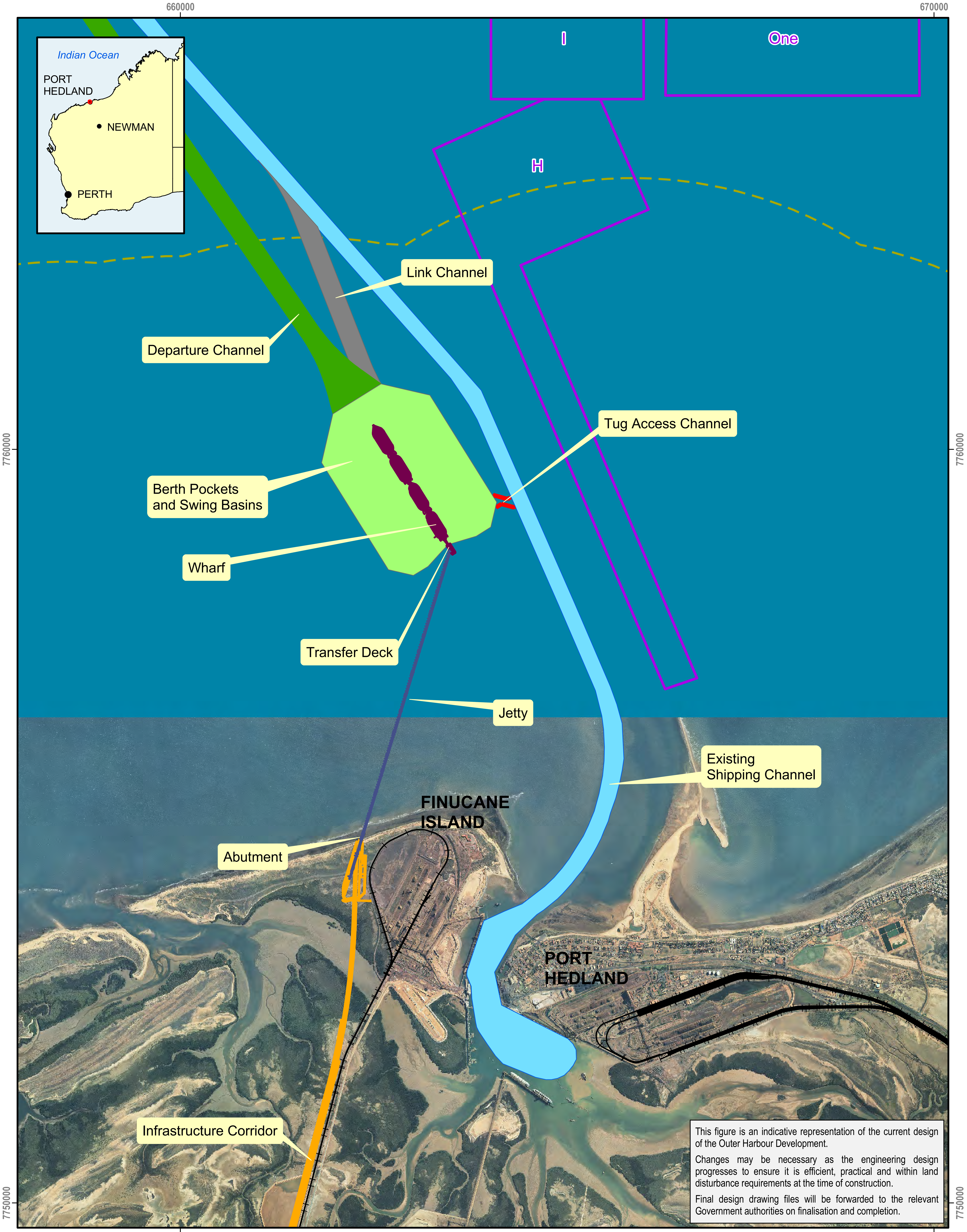
The construction of the proposed Outer Harbour Development is intended to be phased to match BHP Billiton Iron Ore's future operational and capacity requirements.

Construction of marine civil infrastructure will maximise the use of precast or prefabricated components. These components will be prepared offsite, shipped to Port Hedland and offloaded via a temporary offloading facility. Lay down areas on Finucane Island and at Boodarie will be utilised to temporarily store marine structures and equipment.

At the jetty abutment, a temporary platform consisting of a structural truss or frame and supported by the piles and crossheads will be utilised to drive successive piles and to install and erect the structures for the first 3 km of the jetty structure. Construction of the jetty trestle will involve jack up barges for piling. Jack up barges and cranes will be used for erecting and installing structures. Overall, a total of approximately 1,200 piles will be driven over a period of approximately 24 months for the jetty. The pile installation method may require some drilling.

Construction work is proposed 24 hours per day, 7 days per week, with favourable conditions. Piling activities will take place 24 hours a day, 7 days per week. It is proposed that physical piling is proposed to be 12 hours per day (7am to 7pm), 13 days per fortnight. Occasionally for safety reasons, there will be an allowance to continue piling activities up to 10 pm to accommodate the completion of a pile.

Approximately 40 to 50 marine vessels will be used including supply boats, tugs, barges and other marine craft that transport supplies, materials, equipment, consumables and personnel.



Legend

- Spoil Ground (Existing)
- Proposed Jetty
- Proposed Wharf
- Proposed Infrastructure Corridor
- Proposed Departure Channel
- Proposed Berth Pockets and Swing Basins
- Proposed Link Channel
- Existing Shipping Channel
- Proposed Tug Access Channel
- Existing Railway
- State/Commonwealth Jurisdiction Boundary

0 0.5 1 1.5
kilometres

Scale @ A4: 1:65,000

Datum: GDA94
Map Grid: MGA94 Zone 50

bhpbilliton
resourcing the future

Source:
Orthorectified Aerial Photograph: 06/2010 (BHPBIO)
Topography: GA, GEODATA Topo 250K V3
(Copyright Commonwealth of Australia, 2006)
Spoil Grounds: 1210-C-00287 (19/08/2008)
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Figure 3-2 Port Hedland Outer Harbour Development Proposed Jetty and Wharf

3.5. Project Schedule

The dredging involved in this project will be undertaken in three stages. Volumes of material to be dredged include over-dredge allowance of 1 m. The three stages and volumes from each area are as shown in **Table 3-1**.

▪ **Table 3-1: Outer Harbour Development Summary Schedule**

Dredge Area	Surface Area	Volume	Disposal Location Approximate Distribution
Basin and link to existing channel	2.25 km^2	22 Mm^3	50% Spoil Ground 3 50% Spoil Ground 7
Basin extension, new channel and cross-link to new channel	10.85 km^2	25 Mm^3	50% Spoil Ground 3 45% Spoil Ground 7 5% Spoil Ground 9
Basin extension	1.06 km^2	7 Mm^3	50% Spoil Ground 3 50% Spoil Ground 7
Total	**14.17 km^2**	**54 Mm^3**	

3.6. Operation of the Marine Infrastructure

Once completed, the proposed infrastructure will provide a nominal export capacity of approximately 240 Mtpa of iron ore. The marine loading facility will be capable of berthing and loading 250,000 DWT vessels with a design provision for 320,000 DWT vessels to berth and load in the future. Operational activities pertinent to benthic habitats include:

- maintenance dredging of the access channel and navigational facilities;
- vessel movement with associated propeller wash and sediment disturbance;
- loading of iron ore; and
- wastes, discharges and spills associated with vessels and infrastructure.

Maintenance dredging and disposal of dredged material will be raised on an as-needed basis, as the need for maintenance dredging arises. Therefore, the impacts of maintenance dredging are not considered in this impact assessment.

Impacts of vessel movements, loading of iron ore and wastes/discharges/spills may result in disturbances to the benthic communities. However it is not predicted that irreversible or indirect impacts to benthic habitats, as described by EAG No. 3 and EAG No. 7, will result from vessel movements. As such, consideration of the disturbances from these activities are addressed in **Chapter 10** of the PER/EIS and are not considered in the environmental impact assessment undertaken in this report.

4. Benthic Communities and Habitats

Provided below is a summary of the benthic habitats and communities observed and mapped within nearshore State waters of the footprint for the proposed Outer Harbour Development and the studies undertaken to define distribution of benthic habitats. Further detail on the existing marine environment, an overview of the benthic ecology of the region, and description of the surveys undertaken are provided in **Chapter 6** of the PER/EIS.

4.1. Studies Undertaken in Defining Benthic Habitat Distribution

Surveys conducted within and adjacent to the proposed Outer Harbour Development area ('study area') were used to describe benthic habitats are summarised in **Table 4-1**. The survey effort included a total of 734 discrete observations using a number of techniques (**Figure 4-1**).

- **Table 4-1: Marine Investigations within the Proposed Outer Harbour Development Area Providing Benthic Habitat Data**

Task Description	Number of Sites/Transects	Date/Period	Season
Towed video transects (offshore of Finucane Island)	3	July 2007	Winter
Towed video transects (West of current dredge footprint)	42	December 2007	Summer
Sediment sampling	213	December 2007 – September 2008	Various
Diver video transects (throughout study area)	52	January – May 2008	Summer, Autumn
Spot dives (Aborted diver video transects)	13	January – May 2008	Summer, Autumn
Towed video transects (throughout study area)	21	October 2008	Spring
Towed video transects (between Weerdee & Downes Island)	390	May 2009	Autumn
Total	**734**		

4.1.1. Towed Video

Surveys were conducted in winter 2007 (July), summer 2007 (December), spring 2008 (October) and autumn 2009 (May).

Figure 4-1 Location of Subtidal Investigations

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Winter

In July 2007, benthic video footage was captured in the near-shore environment adjacent to Finucane Island. Three transects of approximately 1 km in length each were filmed parallel to the coastline in depths of 0, 3 and 5 m below LAT.

Summer

The December 2007 survey captured 42 towed video transects ranging in length from 0.5 to 6 km, which focused on a now discounted dredge footprint and potential spoil grounds to the west of the current footprint. The survey also included nearby ridgelines in an effort to identify potential hard coral habitat monitoring sites. Survey observations were used to inform the habitat modelling process.

Spring

In October 2008, after completion of preliminary habitat modelling, 21 sites were visited for ground truthing purposes. The data points were quantitatively analysed for habitat composition and density. These sites were spread throughout the study area across a mixture of predicted topography and substrates. The sites were situated in areas with relatively low densities of field data points to test habitat model predictions and to improve confidence in the final habitat map.

Autumn

In May 2009, a survey was conducted for BHPBIO Rapid Growth Project 6 (RGP6) to the west of Port Hedland Harbour in the embayment and creek system between Weerdee and Downes Islands (SKM 2009k). A total of 390 transects of 50 m in length each were filmed, spaced approximately 200 m apart. The data were quantitatively analysed for habitat composition and density.

4.1.2. Diver Video Transects

From January to May 2008, 52 sites spread throughout the study area were surveyed by divers conducting video transects. At each site, three 50 m transects totalling an area of approximately 60 m^2 were filmed and quantitatively analysed. Divers also recorded observations of the benthic habitat surrounding transects at each site.

Also during this period, 13 sites paralleling the coastline were visited with the intention of conducting diver video transects. As they were found to be bare sand or mud devoid of benthic habitat, video transects were not conducted but diver observations were recorded and used as inputs for habitat modelling. These sites are labelled as ‘spot dives’ on **Figure 4-1**.

4.1.3. Opportunistic Diver Observations

From December 2007 to September 2008, a total of 213 sites spread across the study area were dived on for the purpose of collecting sediment samples. Divers recorded observations of the benthic habitat at each site. The location of all sediment sampling sites is shown in **Figure 4-1** and are separated into each sampling period:

- during the summer of 2007-08, 143 sites spread across the central third of the study area were dived on for the purpose of colleting sediment samples;
- in May 2008, sediment sample collection dives were conducted at a total of 33 sites to the east and west of the current dredge footprint; and
- in September 2008, 27 sites within the current turning basin/wharf head and ten sites to the west were dived to collect sediment samples.

4.1.4. Subtidal Habitat Mapping

The habitat map was produced using models based on methods developed by Holmes et al. (2008). Modelling from LiDAR[2], field observations and underwater video of marine benthic habitat distribution was used to predict habitat distribution within the surveyed areas.

The modelling included two substrate types, soft (sediment) and hard substrate, and the biota that may be present on the substrate types. Estimates of the accuracy of the modelled habitat distribution were made and compared against actual ground truthing sites. Final categories of hard substrate presence and sediment were predicted with high (97%) overall accuracy and the correct classification rates for each of the habitat categories were generated.

For a detailed account of the habitat mapping refer to **Section 6.6.2** of the PER/EIS.

4.2. Benthic Habitats

Benthic habitats can be described as either hard or soft substrates. Benthic primary producer habitat is benthic habitat that can or does support benthic primary producers (refer **Section 4.3**).

In the Port Hedland region, the distribution of benthic primary producers is strongly associated with areas of hard substrate and vertical relief associated with a series of limestone ridges, shoals and banks, as well as numerous islands and inshore rocky platforms that extend into the intertidal

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[2] LiDAR stands for light detection and ranging. It is a technique used to construct an image representing the terrain of an area by firing rapid pulses of light at the landscape and a sensor measures the return of light once it bounces off the landscape surface. The time taken for the light to return to the sensor allows distances and therefore topography to be measured (http://www.csiro.au/resources/LightDetectionLidar.html).

zone. Interspersed between these features are vast areas of coarse sandy sediment and mobile sand banks with extremely sparse coverage of biota, either benthic primary producers or non-benthic primary producers.

Within the total area (86,821 ha) of State waters covered by the proposed Outer Harbour Development area, and outside of the Port Hedland Harbour entrance, 92% (79,591 ha) is sediments while 4% (3,843 ha) is hard substrate (**Table 4-2**).

- **Table 4-2: Benthic Habitats of the Proposed Outer Harbour Development within State Waters**

Habitat Category	Area (in ha)	Proportion (%)
Sediment	79,591	92
Hard substrate	3,843	4
Sediment covered hard substrate	2,248	3
Undefined substrate	1,139	1
Total	**86,821**	**100**

4.3. Benthic Primary Producers

EAG No. 3 defines primary producers as: '*organisms (mainly green plants and algae) which can manufacture organic substances (food) from simple inorganic substances*.' (EPA 2009; p. 23). Primary producers occurring in the benthic environment of State waters of the proposed Outer Harbour Development area include hard corals, macroalgae and seagrasses.

4.3.1. Hard Corals

The outer limestone ridgeline systems and mid-shore ridge and shoal systems located in Commonwealth waters generally have higher coral cover than the islands, inshore shoals or banks located within State waters (**Table 4-3**). A total of 37 diver and towed video plus spot dive survey sites were located within State waters. A summary of the survey results for the percentage cover of hard corals and the percentage cover of sand, rubble and rock at these 37 sites investigated in the baseline study is provided in **Table 4-3**.

Table 4-3: Hard coral Cover at Sites Surveyed within State Waters

Area (number of sites visited)		Proximity to Port Hedland Entrance	Hard Coral Cover (%)	Abiotic substrate (sand, rubble, rock) (%)
Inshore Shoals and Banks	Proposed Port Areas (5)	4–6 km north	0–12.9	>79
	Weerdee Ridge (7)	11 km west	0.2–21.6	11–75
Islands	Weerdee Island (6)	12 km west	<5	12–66
	North Turtle Island (4)	58 km north-east	0.2–18.9	>81
	Little Turtle Island (5)	40 km north-east	8.4–17.8	>69
Non-reef Areas	Eastern Shoreline (8)	Nearshore, from Port Hedland to Spit Point	0	100
Non-reef Areas	Western Shoreline (1)	Nearshore, from Port Hedland to Cape Thouin	0	100

Source: Summarised from SKM (2009c) (surveyed December 2007 to May 2008).
^sites sampled at a proposed footprint which was subsequently realigned. Further investigations conducted within the current dredge footprint concluded the same results.

Coral monitoring sites were established in May 2008 at key representative locations on the limestone ridgelines (**Figure 4**–2) and on nearby shoals, in both Commonwealth and State waters. The results of these surveys from May 2008 to June 2009 are detailed in *Port Hedland Outer Harbour Development: Baseline Coral Health Monitoring Report* (SKM 2009g) and are summarised below.

A total of 51 species of coral from 19 genera were identified from areas offshore of Port Hedland (SKM 2009g), which is considerably lower than the 120 coral species from 43 genera recorded in the Dampier Port and inner Mermaid Sound (Blakeway & Radford 2004). The highest coral species richness occurred at the COR (42 species, 18 genera) monitoring site located in offshore Commonwealth waters. The coral species richness at the Weerdee Island inshore site located in State waters was considerably lower (26 species, 12 genera). The Cornelisse Shoal monitoring site was the only site in which stands of *Acropora* and *Pocillopora* were noted.

The ridgelines and shoals and banks in the State waters were dominated by sparse *Turbinaria* colonies and corals from the Faviidae family (*Favites*, *Favia*, *Cyphastrea* spp.) with diameters of less than or equal to 0.5 m. The small colony sizes may indicate slow growth rates as a result of sedimentation and poor light conditions, or high colony turnover rates due to seasonal cyclonic activity and coral bleaching caused by elevated water temperatures.

The species richness of coral taxa at all sites surveyed in both Commonwealth and State waters is very low in comparison to other studies carried out in the Pilbara region. Based on the low species richness and abundance of corals and dominance of *Turbinaria*, coral communities that inhabit subtidal habitats in the Port Hedland region are likely to be predominantly high turbidity, high sedimentation adapted communities. The species and habitats observed during field surveys are considered typical of the broader marine environment of the Pilbara region.

4.3.2. Macroalgae

The macroalgae of north-west WA are not well known (Huisman & Borowitzka 2003). Marine field surveys found that macroalgae at offshore sites were patchily distributed and were generally not the dominant BPP component (**Figure 4**–3). Where macroalgae were observed on offshore ridges and shoals, they were typically sparse patches of green algae (*Caulerpa* and *Halimeda* spp.). *Halimeda* is a calcified, segmented alga and where abundant, dead segments can form a large proportion of the sediment.

The percentage of substrate occupied by macroalgae varied along each of the outermost ridges that were surveyed (0 to 15%, but generally less than 5%) (SKM 2009c). Three sites in the proposed development area had no macroalgae present at the time of survey. In some areas macroalgae was locally abundant and dominant. At Weerdee Reef, 11 km west of Port Hedland Harbour, macroalgal cover varied between 0 and 71% of the substrate, with *Caulerpa* and *Halimeda* the most common algae at this site (SKM 2009c).

The shallow subtidal limestone pavement at Weerdee Island has around 30 to 40% macroalgal cover; common genera included *Caulerpa*, *Halimeda* and *Sargassum* (SKM 2009c). At Little Turtle Island, 40 km north-east of Port Hedland Harbour, macroalgal cover on subtidal pavement was lower (0 to 15%, but generally less than 5%). The intertidal pavement of the island also had sparse algal cover although species diversity was higher; 35 species comprising 17 red, 13 green and 5 brown algal species (SKM 2008g). Similar diversity and community structure was observed at North Turtle Island (58 km north-east of Port Hedland Harbour) although there were differences in the species present (Huisman 2008). Macroalgae were not observed on the subtidal pavement around North Turtle Island (SKM 2009c).

One of the most prolific of the macroalgae (in terms of biomass) in the Pilbara region is the brown alga genus *Sargassum* (Huisman 2004). Several *Sargassum* species were recorded during field surveys. These plants exhibit a pattern of annual growth and reproduction followed by senescence, with individual plants appearing during late winter and rapidly attaining lengths of up to 3 m during spring before breaking off above the holdfast in early summer (pers. com. Gus Paccani 2009, SKM). These algae are known to occur on the shoals offshore from Port Hedland and have been observed at four of the six sites chosen for ongoing coral health and water quality monitoring (SKM 2007g).

4.3.3. Seagrasses

Walker and Prince (1987) recorded four seagrass species in marine areas adjacent to Port Hedland, namely *Thalassia hemprichii*, *Halodule uninervis*, *Halophila ovalis* and *Halophila decipiens*. *Halophila decipiens* can be distinguished from other species of the genus by its leaf margin which has very fine serrations, and is generally much smaller than *Halophila ovalis*.

Halophila ovalis has a tropical distribution and often forms extensive beds which are commonly an important food source for dugongs (Edgar 1997). *Halophila ovalis* and *Halodule uninervis* are generally considered to be pioneer or opportunistic species capable of rapidly colonising new areas, particularly after disturbance, and surviving well in unstable or depositional environments (Waycott et al. 2007; Lee Long et al.1993; Bridges et al. 1981; Birch & Birch 1984). These species are also found in ephemeral and dynamic communities and therefore better adapted to recovery after disturbance than other later successional species of seagrass (Waycott et al. 2007).

Field investigations by SKM reported sporadic observations of the four seagrass species listed above (SKM 2009c) (**Figure 4**–4). A sparsely inhabited area (approximately 5 m x 5 m area of *Halophila decipiens* (**Figure 4**–4) was observed offshore of Weerdee Island. A similarly small and sparse stand of *Halophila ovalis* was observed at North Turtle Island. In addition, drop video investigations identified patches of seagrass, predominantly *Halophila ovalis*, in the shallow protected embayment between Weerdee and Downes Islands, to the west of Finucane Island (SKM 2009d). The seagrass was mapped to cover approximately 86 ha or 4.8% of the embayment in beds of sparse (5 to 25% cover) to medium (25 to 50% cover) density, and were mixed assemblages most commonly present with macroalgae and occasionally sponges.

Given the field effort undertaken (refer **Section 4.1**) and the temporal breadth of these studies, it is likely that the distribution of seagrass, specifically *Halophila* spp., throughout the Port Hedland region is spatially and temporally dynamic. In addition, it appears that seagrasses in the area are preferentially located in areas that offer shelter from prevailing metocean conditions (e.g. in the lee of islands).

4.4. Non-Benthic Primary Producers

EAG No. 3 defines primary producers as: '*organisms (mainly green plants and algae) which can manufacture organic substances (food) from simple inorganic substances*.' (EPA 2009; p. 23).

In this impact assessment, non primary producers are considered to be that component of the benthic community that is not a benthic primary producer. The primary non benthic primary producers occurring in the benthic environment of State waters of the proposed Outer Harbour Development area are soft corals and sponges.

Sponges are simple, multi-cellular animals that permanently attach themselves to substrate and can be found in a range of locations from shallow tidal waters to the deep ocean. Sponges are predominantly filter feeders that mostly consume food particles and bacteria in the water column and occasionally prey on small crustaceans when the abundance of particulate material in the water column is poor (Pile et al. 2003; Yahel et al. 2003, 2007). Some sponges have a symbiotic relationship with green algae, dinoflagellates or cyanobacteria from which they derive nutrients.

Unlike hard corals, soft corals (octocorals) do not produce a calcium carbonate skeleton and are not colony-forming, although they are typically found in reef environments. They are simple multi-cellular animals with a poly structure. Most live in nutrient rich waters with reduced light intensity. A few species of soft corals also support photosynthesising symbiotic algae.

In the Port Hedland Harbour, sponges and soft corals are found on the limestone ridgeline systems and the island shoals. They commonly co-habit the ridgelines where hard corals are also found, forming a mosaic benthic community.

Figure 4-2 Hard Substrate that Supports Hard Corals (>5% cover), Monitoring Sites and Representative Photographs

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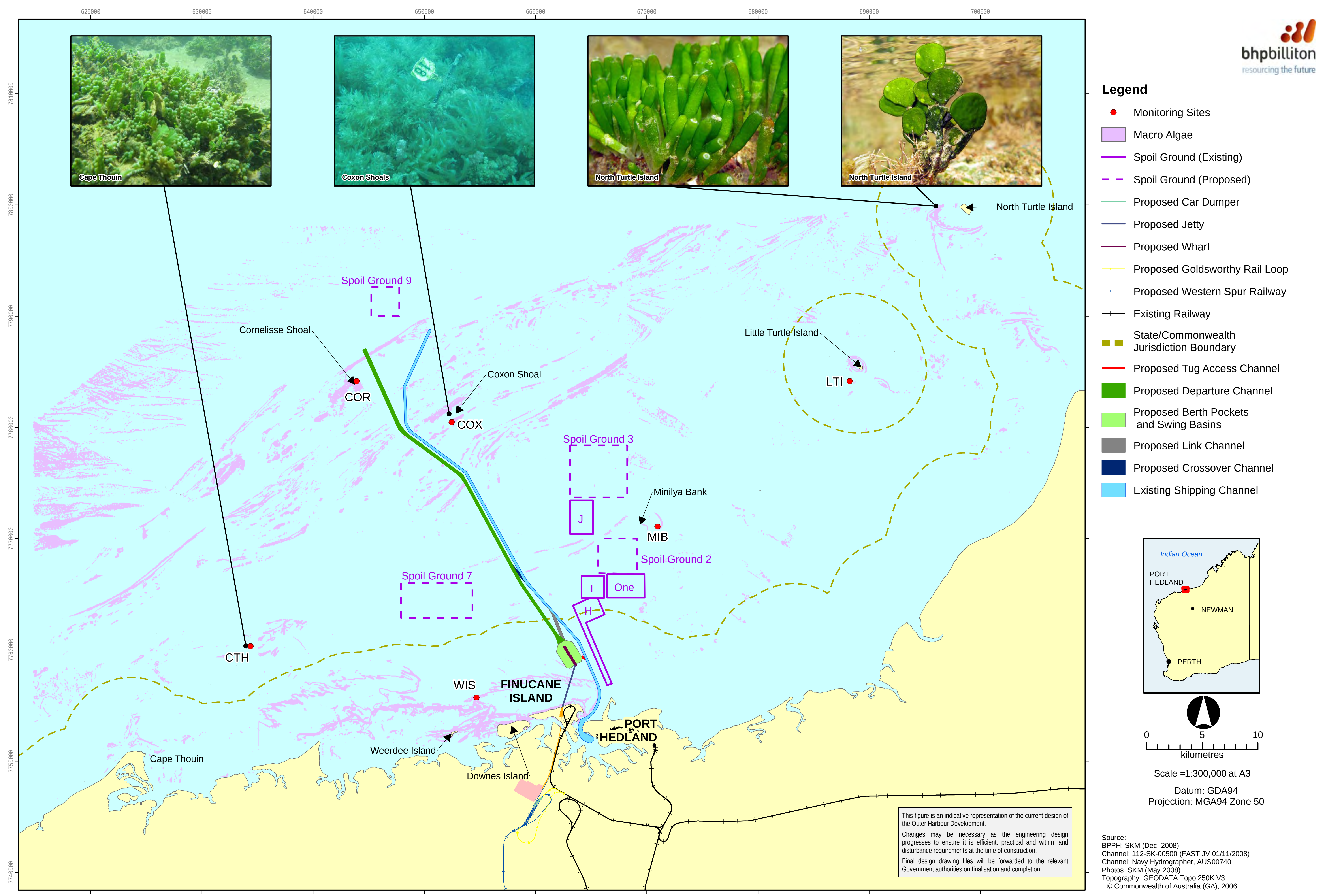

Figure 4-3 Hard Substrate that Supports Macroalgae (>5% cover) and Representative Photographs

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Figure 4-4 Seagrass Distribution and Representative Photographs

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5. Dredge Plume Modelling

Provided below is a summary of the approach to dredge plume modelling, and the modelling outputs used to predict impacts to benthic communities and habitats due to sediment plumes generated by construction dredging activities of the proposed Outer Harbour Development. For a more detailed account of this information, refer to **Appendix A15** of the PER/EIS.

Construction dredging for the proposed Outer Harbour Development includes the dredging of 54 Mm^3 of material to accommodate the construction of the channel and navigational facilities. Dredging is proposed to occur in a staged approach, resulting in 56 months of dredging over a five year period. A summary of the construction dredging activities, their timing and the associated volumes of material is provided in **Table 5–1**.

- **Table 5–1: Construction Dredging Activities, their Timing and Associated Volumes**

Stage	Year	Facilities	Duration (months)	Volume (Mm^3)
1	1–2	Berth pockets, eastern swing and departure basins, tug access channel, link channel	24	22
2	3–4	Western swing and departure basins, departure channel, crossover link channel	25	25
3	5	Extension for the wharf, additional berth pockets, swing and departure basins for four loading berths	7	7
Total			**56**	**54**

Due to the range of sediment material types present, a combination of dredging methods is required. It is proposed that a trailing suction hopper dredger (TSHD) will be used for unconsolidated materials, while harder materials will first require cutting and/or crushing using a cutter suction dredger (CSD). Once consolidated material has been crushed by the CSD, the material will be left on the seabed and subsequently removed by the TSHD.

In shallower areas to be dredged, it is proposed that the CSD will likely be required to dredge materials initially so that the water depths are deep enough for the TSHD to operate in these areas. Where this is the case, the material dredged by the CSD will be stockpiled in deeper water within the dredge footprint, from where the TSHD will subsequently remove the material once water depths sufficient for access.

The dredging program will release sediment particles into the water column – suspended solids – resulting in a sediment plume. The extent of the sediment plume will be influenced by a range of factors including the dredging method, sediment characteristics of the area, ambient current movement, depth of water column and wind direction. The net effect of sediment particles being mobilised into the water column from the dredging will be an increase in total suspended solid (TSS) concentrations in the water column, and increased sedimentation rates because the higher load of sediment particles in the water column means that a higher amount of sediment will in turn fall out of the water column. Where the particles fall out is governed by the hydrodynamics and the particle size: in areas with strong currents particles will likely remain suspended while in calmer waters particles are more likely to fall out of suspension; larger sediment particles will fall out of suspension before smaller particles because they are heavier and more energy is required to keep them in suspension.

Modelling of the impacts from the sediment plume generated by the proposed dredging and spoil disposal activities, as indicated by the measures of TSS and sedimentation, was undertaken by Asia Pacific ASA (APASA). Provided here is a summary of the modelling approach, objectives and findings. For a full account of sediment plume modelling refer to **Appendix A15** of the PER/EIS.

5.1. Modelling Approach

Modelling of the sediment plume likely to be generated by construction dredging and disposal activities of the proposed Outer Harbour Development was based on detailed hydrodynamic and wave models in combination with a sediment transport model (SSFATE).

The sediment transport model accounts for the sinking rates of particles depending on their size (i.e. how long particles remain in suspension), sedimentation of particles (i.e. when and where particles drop out of the water column) and resuspension (i.e. the re-mobilisation of deposited dredged particles). The model computes the TSS concentration above background that directly results from dredging operations given the prevailing current (hydrodynamic) and wave conditions.

The model HYDROMAP was used to describe the flow-field conditions that are locally induced in the Port Hedland coastal region where tides and winds are the most important sources of hydrodynamic forcing. Validation of the hydrodynamic model demonstrated that HYDROMAP faithfully reproduced both shorter-term tidal magnitudes and directions, and longer-term transport along the coast.

The wave model used was the Simulating Waves Nearshore (SWAN) model, a regional model developed to simulate spatially-varying wave conditions over a wide domain. The large-sized model domain enabled sediments to be tracked over the long time span of the dredging and disposal construction activities of the proposed Outer Harbour Development. Validation of the SWAN model showed faithful reproduction of observed wave parameters across the full wave spectra.

The modelling domain[3] was sufficiently large to encompass the total area that may be affected by sediment plumes generated by the dredging and disposal activities, including cumulative impacts due to resuspension of particles distant from the project activities. As such, the model domain spanned 131 km from east to west and 83 km from north to south.

Collectively, the current and wave models were demonstrated to be fit for the purpose of representing ambient current and wave fields as input to sediment fate modelling.

Data used to run the models included:

- detailed bathymetric data derived from the LiDAR survey to provide high resolution in areas proposed for dredging and disposal, and in surrounding areas a larger bathymetric grid resolution was used;
- wind and wave data for the area which was carefully selected to ensure seasonal and interannual variation in response to the Southern Oscillation Indices (i.e. La Niña and El Niño events) was represented in the sediment plume modelling;
- geotechnical information providing detail on the particle sizes of the sediments to be dredged in the proposed areas throughout the entire dredging depth profile; and
- details of the dredging method likely to be used including the types of dredges, predicted dredge logs (i.e. when, where and for how long a dredge will operate) and disposal of the dredge spoil.

5.2. Assumptions and Limitations

Assumptions and limitations of the modelling outputs included:

- the model computes the TSS concentration above background[4] that directly results from dredging operations given the prevailing current and wave conditions;
- TSS results are predicted for the near seabed level (0.5 to 1.5 m above the seabed) and are not depth averaged through the water column. This results in a worst case representation;
- the model computes the total sediment deposition above background levels; and
- resuspension of fine sediment is continuous throughout the dredging and may result in an over estimate of TSS through material being repeatedly resuspended.

[3] The modelling domain is the spatial extent represented by the predictive models.

[4] Background is a reference to natural conditions of the existing environment.

Model output parameters were chosen so that near seabed predictions (0.5 to 1.5 m above bottom) for TSS concentrations were generated. It is these concentrations that are most applicable to the impacts of the sediment plume on benthic primary producers and their habitats (refer **Section 4**). The modelling results predict that the extent and severity of the sediment plume will be greatest just above the seabed. As such, the magnitude of impact predictions made for the proposed Outer Harbour Development are considerably greater than if predictions had been made as depth-averaged water column conditions, as is often the case with sediment plume modelling outputs.

To balance suitable temporal and spatial resolution while maintaining acceptable computational times, the minimum time step in the model was set at 30 min. This required the durations provided in the dredge logs to be adjusted to multiples of 30 min, with the exception of disposal operations, where 10 min steps were required.

Background TSS is not included in the model results but is taken into account in the seasonal threshold values used to assess impacts on benthic primary producers and their habitats, which is discussed in **Section 0**. The model predicts that during the dredging program, the amount of fine sediment available as a source for resuspension will continually increase such that a sediment plume is generated well away from the immediate dredging and disposal areas.

An independent review of the sediment plume modelling undertaken by APASA was provided by RPS MetOcean. The results of this review can be found in **Appendix A15** of the PER/EIS.

5.3. Scenarios

Simulation scenarios were separated into four operations for dredging:

1) dredging by the TSHD of unconsolidated surface sediment;
2) dredging by the CSD of rock strata, with direct discharge back to the seabed;
3) dredging by the TSHD of the sediments deposited by the CSD; and
4) TSHD disposal at the disposal site from operations 1 and 3 above.

Initial modelling investigations were undertaken to test and compare the influence of disposal location on the outcome of this component of the operation. The study used two procedures to identify the optimum disposal location, in terms of the stability of deposited sediments and the potential for sediments to impinge upon adjacent sensitive habitats from either the initial release or from remobilisation of deposited sediments.

Firstly, predictions of shear-stress were calculated at seabed level throughout the domain shared by the hydrodynamic and wave models. This analysis provided an indication of the likely stability of spoil that is initially deposited within each area.

Secondly, disposal was simulated into areas that had been identified as potentially suitable for disposal of dredge spoil on the basis of logistic and environmental considerations. The results were primarily judged by examining overlap of the expected distributions of TSS and sedimentation with buffer areas that are designated around limestone ridges adjacent to the disposal areas.

Dredging and disposal activities associated with the proposed Outer Harbour Development were modelled for all of the development stages (1, 2 and 3) over the five-year duration of construction at approximately two month blocks of time for quality control and data security.

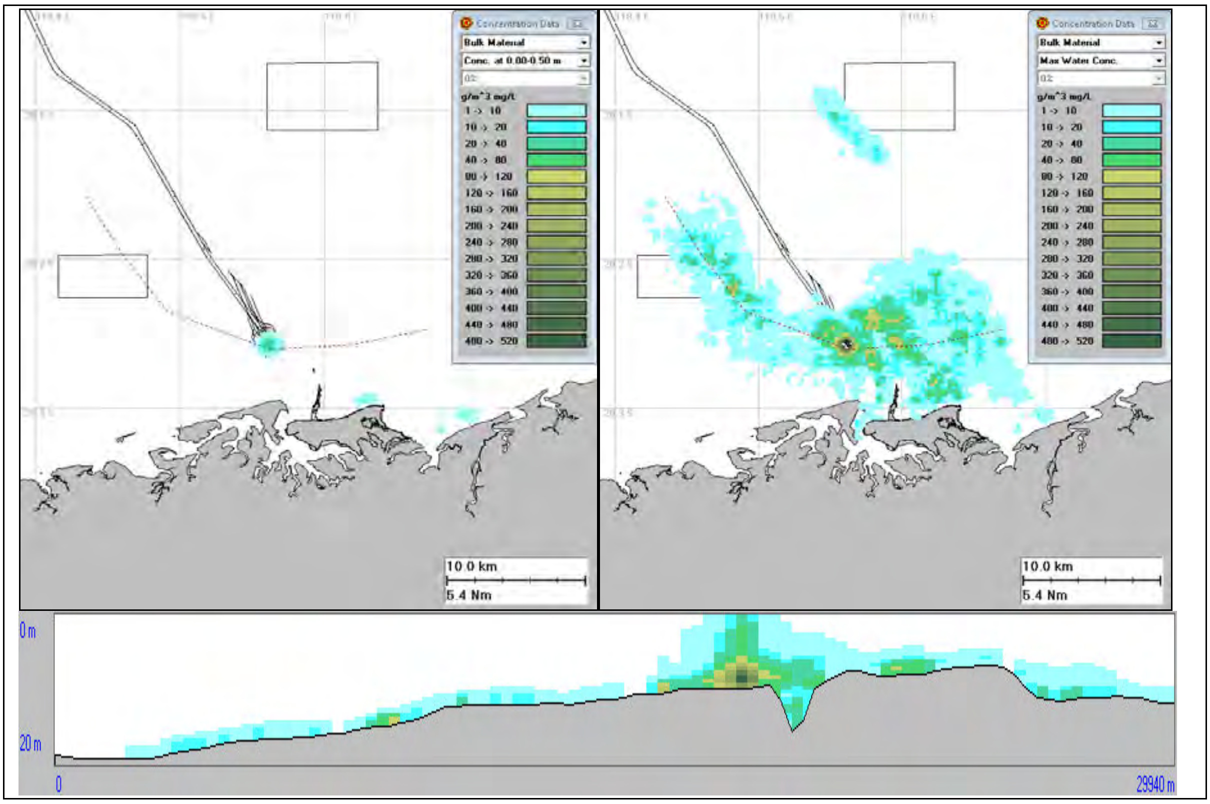
The modelled scenarios did not include proposed management actions targeted at reducing the extent of the dredging plume, therefore plume behaviour predicted by the model can be considered extremely conservative. The actual extent and severity of the altered water quality conditions resulting from the plume are likely to be less extreme than predicted by the model.

5.4. Modelling Results – Changes to TSS Concentrations

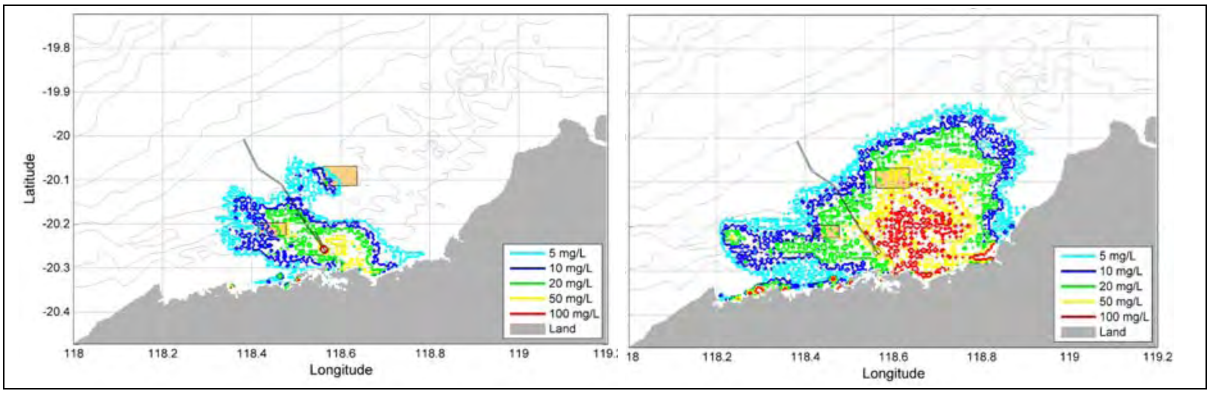
Dredging and disposal operations are likely to release a proportion of relatively fine sediments (clay, silt and fine sand) that will be subject to the current and wave climate. Heavier sediments and a proportion of the finer sediments are predicted to deposit around the dredging and disposal operations; finer sediments are predicted to deposit as thin layers for short durations over a wider area.

Sediment plumes are expected to disperse as a benthic plume (close to the seabed), undergoing cycles of settlement and resuspension due to tide and waves. In particular, the diurnal tide will induce cycles of sedimentation and resuspension for a portion of the finer sediments. While resuspended, these fine sediments will migrate with a tendency to distribute near the seabed. Sedimentation rates will also be subject to the prevailing waves, with a more irregular frequency.

The modelling demonstrated that the proposed Outer Harbour Development dredging and spoil disposal activities will create a sediment plume characterised by increased total suspended solid concentrations and sedimentation rates relative to ambient conditions. The plume will be manifested at the surface by a relatively small, visible plume mainly restricted to within a few kilometres of the activities (**Figure 5–1**). Close to the seabed, the plume will be much larger in area and will be subject to regular resuspension of sediment. The areas where the sediment plume will be present will shift seasonally primarily due to changing conditions in the wave climate (**Figure 5–2**). The presence of the plume will persist throughout construction dredging activities, gradually dissipating over several weeks following their completion.

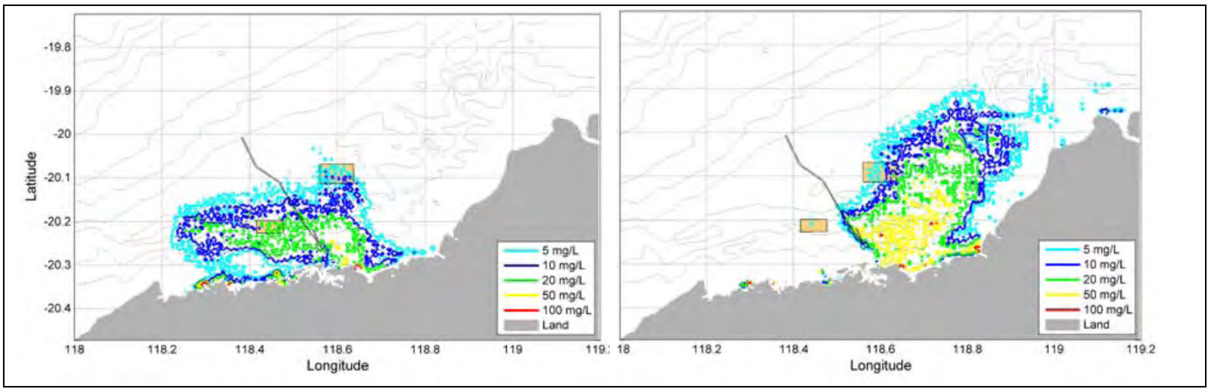


- **Figure 5–1: Sediment Plume Predictions as TSS Concentrations (in mg/L) at the Surface (top left), 0.5 m above the Seabed (top right) and a Bottom Profile (bottom)**



- **Figure 5–2: Stage 1 February to April (left) and October to December (right) of Year 1; 80th Percentile TSS Concentrations (in mg/L)**

Migration of sediment particles is predicted to vary over seasonal and shorter time scales. Flooding and ebbing tides will move sediment back and forwards over short durations and are predicted to spread sediment plumes in a generally onshore-offshore direction (south-east to north-west, respectively). In the longer term, the tropical dry (June to November) and wet (December to May) seasons create a directional change in the plume. A net migration of sediment to the west is indicated by the middle of the dry season, while during the wet season the plume is advected in an east and north-east direction (**Figure 5–3**).



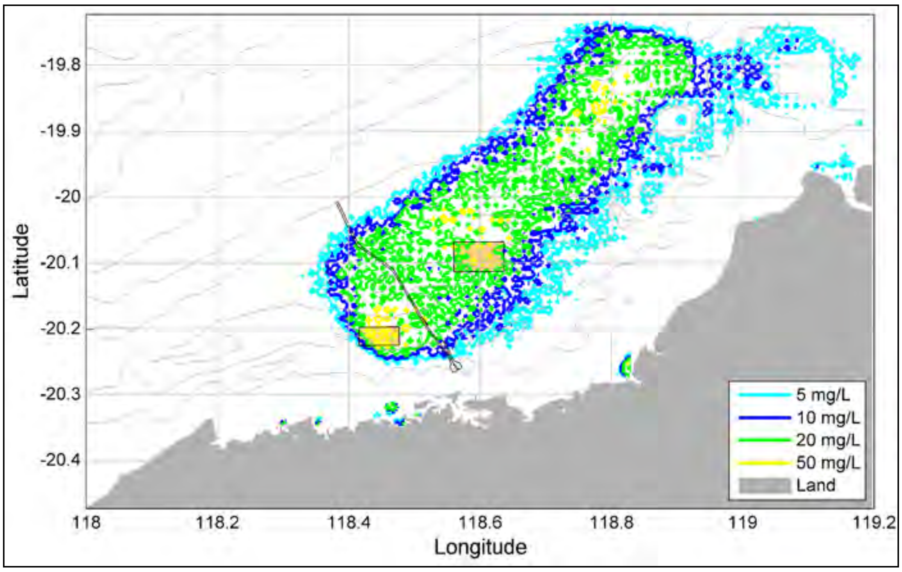
- **Figure 5–3: Stage 1 Dry Season (left) and Wet Season (right) of Year 1; 50th Percentile TSS Concentrations (in mg/L)**

The height of the wet season will bring a strong north-easterly movement to the plumes. The most extensive sediment plumes (extending over 80 km to the north-east of the source) with high TSS concentrations are predicted to occur during the wet season. The worst case wet season plume will be influenced by strong winds and large waves in combination with tidal currents, causing resuspension and dispersion of finer sediments. Late in the wet season the intensity of the plume to the north-east is expected to reduce, followed by a transitional period and reestablishment of the dry season pattern when the severity of high TSS concentrations abates.

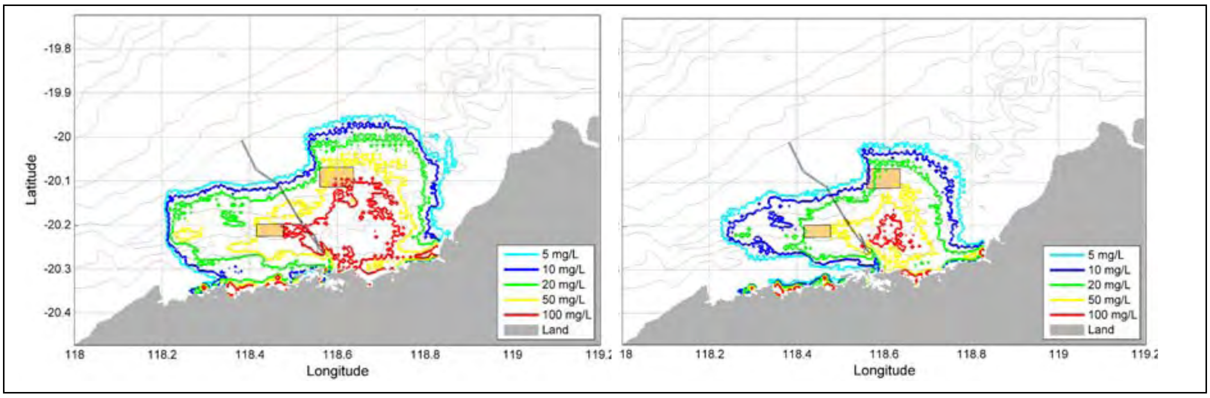
Highest TSS concentrations predicted during construction dredging and disposal activities of 160 mg/L are predicted to occur approximately 0.5 m to 1.5 m above the seabed. These high TSS concentrations are likely to be highly localised occurrences, forming in small pockets along the coast due to transport and trapping of material in these areas, and compounded by further resuspension.

Nearing the end of the main dredging component of Stage 2, the sediment plume is expected to shift further offshore due to the location of the dredging by this stage being concentrated in the outer part of the channel (**Figure 5–4**).

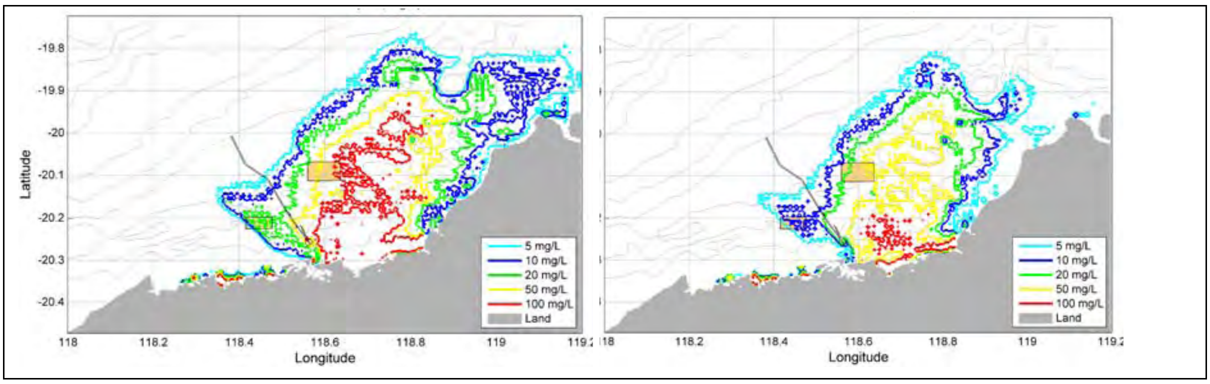
Stage 3 of construction dredging and disposal activities is proposed to commence 15 months after completion of Stage 2 dredging and disposal activities. Due to this delay, no cumulative effects from the previous dredging and disposal activities of Stages 1 and 2 are expected. The seasonal behaviour of the sediment plume within Stage 3 is predicted to be very similar to that of the previous stages, with westward migration in the dry season (**Figure 5**–5), and north-easterly migration in the wet season (**Figure 5**–6).



- **Figure 5–4: Stage 2 December to March of Year 4; 80th Percentile TSS Concentrations (in mg/L)**



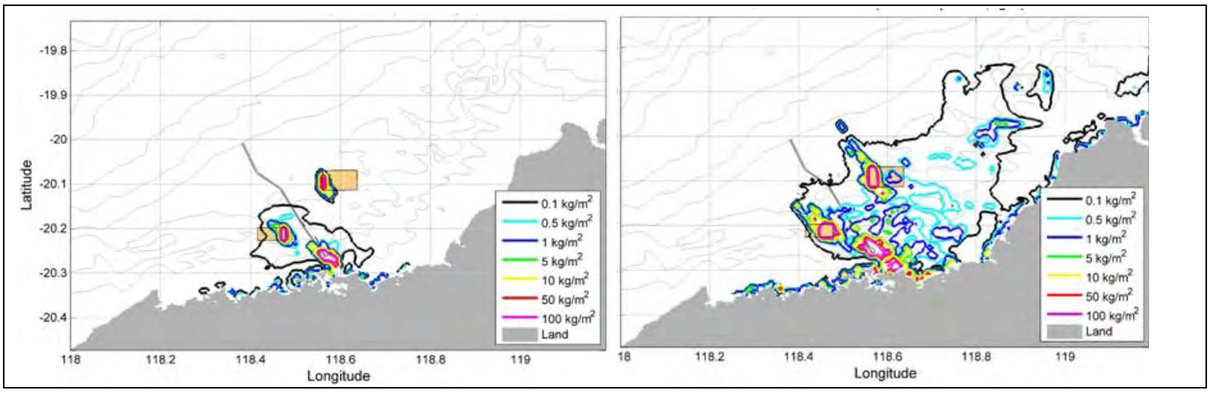
- **Figure 5–5: Dry Season – Stage 3 September to November of Year 5; 80th Percentile (left) and 50th (right) TSS Concentrations (in mg/L)**



- **Figure 5–6: Wet Season – Stage 3 November to December of Year 5; 80th Percentile (left) and 50th Percentile (right) TSS Concentrations (in mg/L)**

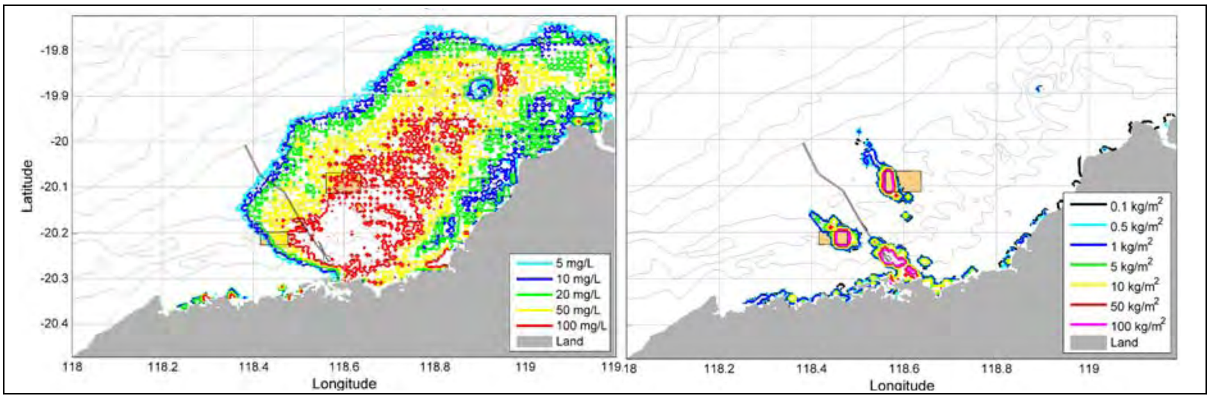
5.5. Modelling Results – Changes to Sedimentation Rates

Modelling of sediment deposition indicates that the majority of the sediment will sink from the surface within a short distance from the construction dredging and disposal activities. However, with increasing inputs and spreading of the sediment particles, predicted deposits will extend progressively further away from these areas (**Figure 5–7**).



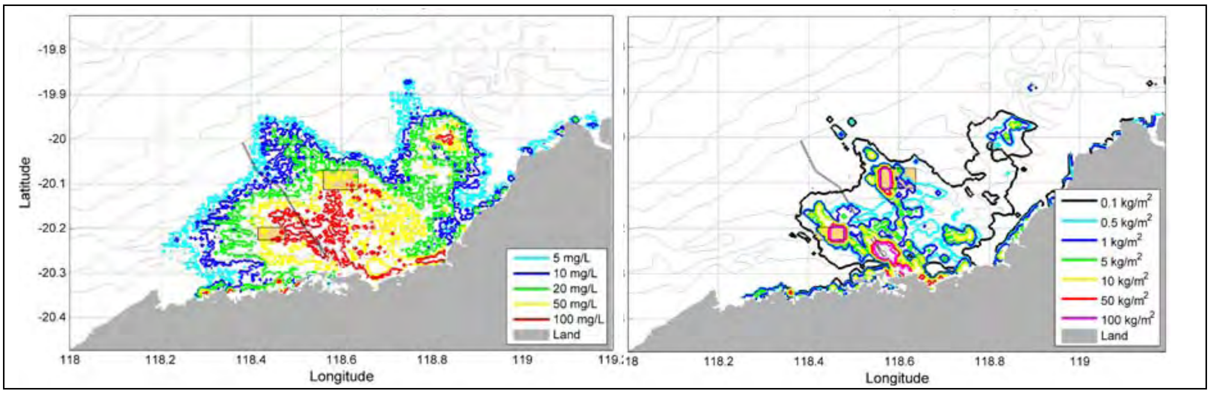
- **Figure 5–7: Stage 1 – 2 to 4 Months after Commencement (left) and 10 to 12 months later (right); 80th Percentile Sedimentation Rates (in kg/m²)**

The seasonal patterns in the sediment plume indicated by sedimentation rates show a similar directional trend to that predicted by TSS concentrations: westerly during the dry season and north-easterly during the wet (**Figure 5–8**). Although the wet season conditions are predicted to result in greatest spread of increased sedimentation rates, the spatial extent of increased sedimentation greater than 0.1 kg/m^2 is expected to be notably smaller compared to the spread of increased TSS predictions.



- **Figure 5–8: Wet Season – Stage 1 December to January 80th Percentile TSS Concentrations (mg/L; left) and Sedimentation Rates (in kg/m²; right)**

Although the predictions for sediment deposition over time indicate a progressive build-up of sediment particles, this trend is not expected to be consistent in the longer term. Periods of highly energetic hydrodynamic conditions that are predicted to create the most extensive sediment plumes as indicated by TSS concentrations show a far smaller plume distribution when modelled as sedimentation. This is because much of the fine sediments will either remain suspended during this period or will be resuspended. This will result in a time lag between the worst TSS plume conditions occurring, caused by particles resuspended into the water column, and the worst sedimentation conditions caused by less energetic conditions that allow sediment particles to settle out of the water column (**Figure 5–9**).

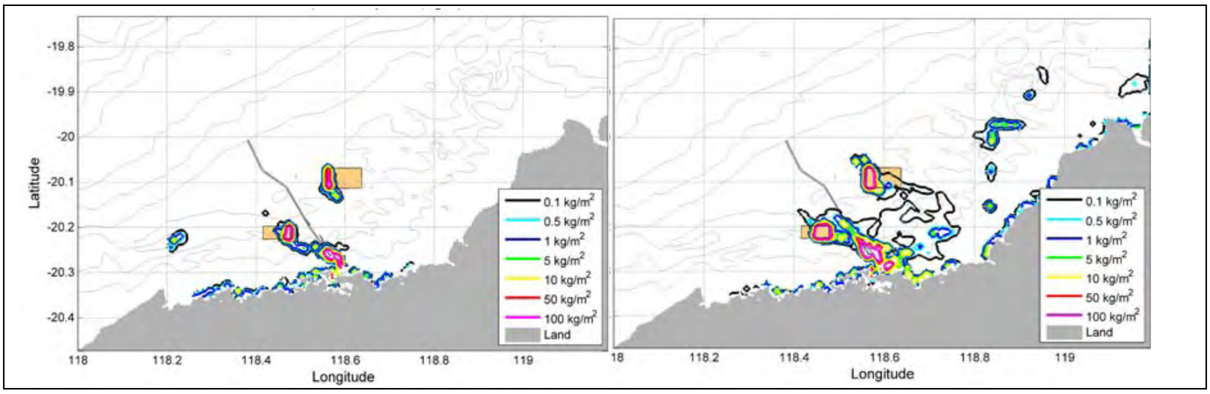


- **Figure 5–9: Wet to Dry Transition – Stage 1 April to June 80th Percentile TSS Concentrations (mg/L; left) and Sedimentation Rates (in kg/m^2; right)**

Areas of increased sedimentation are also predicted off Cape Thouin during the dry season and a shallow area near Turtle Island during the wet season (appearing as isolated patches in **Figure 5–10**, left and right respectively). Because these sites have shoaling bathymetry and therefore have naturally increased wave exposure and current speeds, they are predicted to experience repeated resuspension and settlement of sediment that accumulates in the areas.

The regular onshore-offshore pulsing of the tide is predicted to result in an onshore-offshore migration of suspended sediments released by the operations as well as resuspension of settled sediments. Because shear stresses decrease during slack tides at the end of the ebb and flood, there will be a resulting increase in the rate of settlement over the turning of the tides followed by an increased rate of resuspension as the tidal current speeds increase thereafter.

The relatively strong tidal currents in shallow areas are predicted to establish sufficient shear stress at the seabed to inhibit settlement of finer sediment particles (clays and silts) onto the seafloor and to resuspend a proportion of fine particles that had previously deposited. Resuspension of finer sediment particles is also predicted to generate secondary surface plumes and to contribute to sedimentation rates along the shallow coastal margin.



- **Figure 5–10: Stage 1 June to August (left) and Stage 2 February to April (right) 50th Percentile Sedimentation Rates (in kg/m^2)**

5.6. Modelling Results – Sediment Disposal Areas

The area of the proposed Outer Harbour Development is considered to be dispersive meaning that sediment particles naturally susceptible to resuspension will be moved away from the area over time. As such, relatively short period (30 days) model simulations of spoil disposal into alternative disposal areas indicated there will tend to be a migration of finer sediment particles (clays and silts) outside the bounds of the disposal areas. This is due initially to migration with the tide as these particles tend to be jetted into the water column after the descending plume generated by ocean disposal strikes the seabed. Habitats up to 10 to 15 km to the north-west and south-east of the disposal grounds are predicted to receive elevated TSS concentrations in the water column, and subsequently increased sedimentation. A greater net drift of spoil material is predicted for disposal into areas closer to shore than areas further offshore, indicating a response to the onshore steering of tidal currents with proximity to land.

Over the longer term, the modelling predicted that material deposited in the disposal areas, which are located in water depths sufficiently shallow enough for storm swells to penetrate the seabed, will disturb the heavier sediment particles resulting in trapped fines being resuspended. Given that this circumstance is related to storms, resuspension of fines from disposal areas is likely to occur for several years after completion of construction disposal.

5.7. Summary of Predicted Impacts

Modelling of the construction dredging and disposal activities of the proposed Outer Harbour Development predicts that heavier sediment particles and a proportion of finer sediments will deposit around the dredging and disposal operations while finer sediments will deposit as thin layers, for short durations, over a wider area.

The model predicted smaller sediment particles (silts and clays) as being susceptible to the prevailing levels of shear stress arising from tidal currents, causing sediment plumes to migrate and disperse close the seabed (half a metre to a metre and a half above the bottom). In addition, daily cycles of settlement and resuspension of sediment are likely to occur due to the strong tides and influence of waves, with flooding and ebbing tides spreading the particles and plume in an onshore-offshore direction. Over seasons, a net migration of finer particles to the east and north-east in summer months and west in winter months is predicted.

Evaluation of sediment plume behaviour associated with dredge spoil disposal predicted a greater net drift of spoil material into areas up to 10 to 15 km closer to shore from disposal area boundaries, a response to the onshore steering of tidal currents with proximity to land. In addition, heavier sediment particles will be distributed during storm events in disposal areas located in shallower waters, resulting in trapped fines being resuspended. This will likely occur for several years after completion of construction disposal, and will be a function of the frequency of local storm events.

6. Interpreting Sediment Plume Modelling Outputs

For a full account on the development of the approach used to interpret the sediment plume modelling outputs refer to **Appendix A2** of the PER/EIS.

6.1. Predicting the Impacts on Hard Corals Using Light Climate Thresholds

The threshold values set to delineate the Zone of High Impact are based on TSS concentrations that occlude all light from reaching the benthic community. The threshold values set to delineate the Zone of Moderate Impact are based on TSS concentrations that will occlude 40% of light from reaching the benthic community.

If these TSS concentrations occur frequently in a 14-day period then this period is termed a “low-light” fortnight. If the “low-light” fortnights are consecutive then impacts on the hard coral community, as a sentinel to the broader benthic primary producer community, are assumed to have occurred. The actual number of consecutive reduced light fortnights that occur and the assigned loss of hard coral were determined using:

- the literature available on the length of “low-light” periods which correspond to hard coral mortality; and
- the periods of “low-light” the coral communities at Port Hedland experience from the baseline light climate data already collected, and the measures of mortality of these communities during and after the periods of “low-light”.

The results of assessments outlined in **Section 6.1** indicate:

- hard coral communities show no signs of mortality after periods of 10 to 28 days of “low light”; and
- hard coral communities at Port Hedland frequently experience “low-light” periods for 7 to 14 days without any mortality.

Based on these investigations values for hard coral losses due to reduction in the light climate were developed:

- the Zone of High Impact is predicted to experience 100% coral loss if at any stage during the dredging program there is one period of four consecutive fortnights; and
- the Zone of Moderate Impact is predicted to experience 0% coral loss if at any stage during the dredging program there is one period of four consecutive “low light” fortnights.

These loss categories are not considered irreversible damage.

6.2. Predicting the Impacts on Hard Corals Using Sedimentation Thresholds

Sedimentation thresholds have been estimated from baseline data collected from the Weerdee monitoring site (refer **Chapter 6.4** of the PER/EIS) located in State waters on gross sedimentation rates to determine the Zones of High and Moderate Impact. Sedimentation rates in both the wet and dry seasons have been taken into account when interrogating the model outputs.

Zones of High and Moderate Impact are based on the increases in sedimentation due to project activities in the State waters as described below:

- the Zone of High Impact is predicted to encompass areas which experience twice the maximum background mean daily gross sedimentation rates in any 14 day period; and
- the Zone of Moderate Impact is predicted to encompass areas which experience 1.1 times the maximum baseline mean daily gross sedimentation rates in any 14 day period.

Provided in **Table 6-1** are the daily sedimentation rates used to delineate the zones of high and moderate impact. For future information on the development of these thresholds refer to **Appendix A2** of the PER/EIS.

- **Table 6-1: Decision Rules Based on Sedimentation for Defining the Zones of High and Moderate Impact**

Sedimentation Factor and Zone	Daily Sedimentation Rates ($kg/m^2/d$)	
	Dry Season	Wet Season
Zone of Moderate Impact	0.07	0.73
Zone of High Impact	0.13	1.32

The data in the table above is based on the particle size distribution data collected from within sediment traps, and next to the sediment traps at each site, for comparison. On the seafloor 95% of the sediment PSD was found to be greater than 150 µm compared to only approximately 3% of the sediment in the trap consisting of sediment particles greater than 150 µm. This indicates that the majority of sediment collected in the traps does not settle under normal metocean conditions (e.g. non-cyclonic conditions).

In the Zone of High Impact it is predicted that there will be a 100% loss of BPP underneath areas experiencing these sedimentation rates. BPP communities within these areas are predicted to be completely smothered by elevated sediment loads resulting in an irreversible loss.

In the Zone of Moderate Impact there is predicted to be sub-lethal impacts (e.g. reduced photosynthetic activity, increased mucous production) to BPP communities within this zone.

6.3. Seagrass Health and Water Quality

There is a general relationship between the depth at which seagrasses colonise and the light attenuation coefficient of the water. The relationship is log-based[5], and shows that the colonisation depth rapidly declines as the water becomes more turbid. The data collected and tested against this relationship indicate that seagrasses can colonise to depths where more than 11% of surface irradiance is received (Hemminga & Duarte 2000).

The limit at which the primary productivity of seagrass species is reached varies greatly between species, and within species occurring in different coastal habitats. Particularly, 11% of surface irradiance is very much an extreme critical limit for continued primary production for seagrasses broadly; much higher limits than this have been determined for other species (for example 24 to 37% for *Halodule wrightii* and *Syringodium. filiforme*) (Hemminga & Duarte 2000).

It is not only the light intensity experienced by the seagrasses that is important in maintaining primary productivity; the duration for which light-saturated photosynthesis is experienced is also important. As well, where species have become adapted to environments where ambient light conditions vary greatly due to seasonal effects (for example *Halophila ovalis*), the impacts resulting from anthropogenic perturbation to light climate may not be severe. The ability to cope with strong temporal variations in the light climate is often the result of the ability of the seagrass to store non-structural carbohydrates.

It is with this conceptual approach that potential impacts to seagrasses in the proposed Outer Harbour Development area have been assessed, particularly considering that:

- *Halophila ovalis* is adapted to environments with strong variations in the ambient light climate;
- *Halophila ovalis* has the ability to store non-structural carbohydrates over peak growing periods;
- *Halophila ovalis* has developed the ability to shed above ground biomass during low light periods and re-establish above ground biomass when improved light conditions return; and
- in the project area, *Halophila ovalis* is found in shallow (-1 to -4 m CD) nearshore waters.

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[5] $\log Z_c = 0.26 - 1.07 \log K$, where Z_c is the colonisation depth (in m); K is the light attenuation coefficient (in m^{-1}) (Hemminga and Duarte 2000).

7. Approach to Impact Assessment

Provided in this section is an outline to the approach used in assessing the probable impacts to benthic communities and benthic habitats. This assessment has been undertaken in keeping with EAGs No. 3 and No. 7 (EPA 2009, 2010; refer to **Section 2**). As such, boundaries for Local Assessment Units (LAUs) have been determined and impacts considered within each where perturbations to water quality or removal/disposal of material is proposed. In addition, specific descriptions of the benthic ecology in the LAUs of interest with respect to the proposed project infrastructure, impacts arising from the proposed construction and operational activities and identified as ecologically significant to the region offshore of Port Hedland, are provided. Finally, a summary of historical losses of benthic habitat is also provided.

7.1. Definition of Impacts

The terms used in defining the nature of impacts to benthic communities and habitats are summarised in **Table 7-1**. In addition, the list of definitions provided by EAG No. 7 (EPA 2010; refer **Table 7-2**) have been adopted in this report.

- **Table 7-1: List of terms used to define impacts to benthic communities and benthic habitats**

Term	Definition
Loss	Direct removal or destruction of BPPH. Considered to be irreversible.
Damage	Alteration to the structure or function of a community.
Serious Damage	Timeframe for full recovery is expected to be longer than five years.
Minor Damage	Timeframe for full recovery is expected to be less than five years.

- **Table 7-2: List of definitions as described in EAG No. 7**

Word or Phrase	Definition
Benthos	Benthos are the organisms which live on, in, or near the seabed
Dredge spoil	Seabed substrate material after it has been excavated from the seabed
Dredging	Activities that involve excavation of the seabed from the upper intertidal zone to the subtidal zone. Dredging in the sense of the EAG No. 7 means both dredging and dredge spoil disposal activities
Extent	The area over which an impact extends
Infrastructure	Is taken to mean the areas developed by dredging. Shipping channels, turning basins, berth pockets, pipeline trenches, spoil disposal sites, sub-sea mine areas and land reclamations are some examples of infrastructure
Irreversible	Lacking a capacity to return or recover to a state resembling that prior to being impacted within a timeframe of five years or less
Near real-time	Refers to a system for monitoring and interpreting data where the time lag between

Word or Phrase	Definition
	collecting monitoring data and responding is sufficiently short to be considered as immediate as practicable
Persistence	The period of time that an impact continues
Prediction	A forecast of future outcomes
Pressure threshold	Pressure thresholds signify a level of pressure (intensity, frequency and duration) that equates to a pre-defined level of impact in the biota of interest
Recoverable	See reversible
Reversible	A capacity to return or recover to a state resembling that prior to being impacted within a timeframe of five years or less
Severity	The degree of harm caused. For example, the degree of harm or severity of impact to biota could range from sub-lethal effects to mortality or loss
State coastal water	The State coastal waters extend three nautical miles seaward from the territorial baseline. EAG No. 7 applies to dredging or dredging-related impacts in these waters
Uncertainty	In relation to prediction is doubt or concern about the reliability of achieving predicted outcomes

Source: EPA (2010)

7.2. Dredging Induced Impacts on BPPH

EAG No. 7 (EPA 2010) focuses on the direct loss of benthic habitats and communities by removal or burial, and the indirect impacts on benthic habitats and communities from the effects of sediments introduced to the water column by the dredging. Specifically, EAG No. 7 defines direct and indirect impacts as follows (EPA 2010; p. 13):

- direct impacts are, for the most part, coincident with the footprint of infrastructure and the areas immediately around the infrastructure; and
- indirect impacts arise when the pressure imposed by dredging exceeds the biota’s natural tolerance to that type of pressure. The severity of indirect impacts will range from irreversible to readily-recoverable effects.

Section 8 presents BPPH loss assessments relating to direct loss of habitats and communities through removal due to construction of the marine infrastructure as proposed for the Outer Harbour Development, and indirect losses due to sedimentation.

Indirect effects on benthic habitats and communities due to the effects of sediments introduced to the water column by dredging are presented in **Section 9**.

7.3. Definition of Impact Zones

EAG No. 7 requests that impact zones due to marine construction activities be provided as follows (EPA 2010; p. 19):

- **Zone of High Impact (ZoHI)**: the area directly impacted (e.g. the channel and spoil disposal site) and a zone immediately about the proposed dredging and dumping areas where indirect impacts are predicted to be severe and irreversible. This zone defines the area where mortality of, and long term (i.e. months to years) serious damage to, biota and their habitats would be predicted. The impacts on the BPPHs and their habitats would be predicted. The impacts on the BPPHs within the ZoHI should be considered in the context of EAG No. 3;
- **Zone of Moderate Influence (ZoMI)**: abuts, and lies immediately outside of, the ZoHI. Within this zone sub-lethal effects on key benthic biota would be predicted, but there should be no long term damage to, or modification of, the benthic organism, the communities they form or the substrates on which they grow. Proponents should provide information about impacts in this zone both in the context of what would be impacted and what would be protected. The outer boundary of this zone is coincident with the inner boundary of the next zone, the Zone of Influence;
- **Zone of Influence (ZoI)**: the area where at some time during the proposed dredging and spoil disposal activities small changes in sediment-related environmental quality which are outside natural ranges might be expected however the intensity and duration is such that no detectable effects on benthic biota or their habitats should be experienced; and
- **Outer Boundary of the ZoI**: the point beyond which there should be no dredging (or spoil disposal) related changes from natural conditions. This is the area where it would be appropriate to establish suitable reference sites for the purpose of monitoring potential effects of dredging in the ZoHI, ZoMI and ZoI.

This approach has been applied in the assessment of impacts to BPPH as undertaken in this report. Specifically, the decision rules that have been used to determine the zones and/or their boundaries as outlined above are summarised in **Table 7-3**. **Figure 7**–1 illustrates the Zones of Impact within State waters for the proposed Outer Harbour Development.

- **Table 7-3: Decision Rules Used to Determine the Zones of Impact and their Boundaries**

Zone	Description of Decision Rule
ZoHI	Anywhere that direct removal of BPPH is proposed to occur; where the benthic environment is predicted to experience one period of four consecutive “no light” fortnights (refer **Section 6.1**); and where twice the maximum background mean daily gross sedimentation rates is predicted to occur (refer **Section 5.5**).
ZoMI	Areas predicted to experience one period of four consecutive “low light” fortnights (refer **Section 6.1**); and where 1.1 times the maximum baseline mean daily gross sedimentation rates is predicted to occur (refer **Section 5.5**).
ZoI	Water column TSS concentrations are greater than 5 mg/L above background concentrations
Outer Boundary of the ZoI	Water column TSS concentrations are 5 mg/L or less above background at any point in time

7.4. LAU Boundaries

The approach to assessing impacts to benthic communities and benthic habitats is spatially based. As defined in EAG No. 3 (EPA 2009; p. 7):

'*The EPA has termed the areas within which to calculate cumulative losses*[6] *Local Assessment Units (LAUs). The EPA is of a view that LAUs should normally be approximately 50 km^2*.'

In accordance with this approach, LAU boundaries have been proposed to enable the assessment of cumulative impacts to subtidal marine benthic habitats due to the proposed Outer Harbour Development construction activities. The LAUs and their boundaries have incorporated the following considerations:

- LAUs will be approximately 50 km^2 in area;
- as the LAUs are intended to assess impacts to subtidal benthic habitats, the lowest astronomical tide mark forms the shoreward boundary; and
- the State waters boundary forms the seaward boundary of the LAU.

The Office of the EPA Marine Ecology Branch was consulted on the 13th of January 2011 and is in agreement to the boundary setting approach described.

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[6] Cumulative impact is defined as the sum of all irreversible loss of, and serious damage to, benthic primary producer habitat caused by human activities since European habitation of Western Australia. In this context, cumulative impacts do not include changes to benthic primary producer habitat caused by natural disturbances.

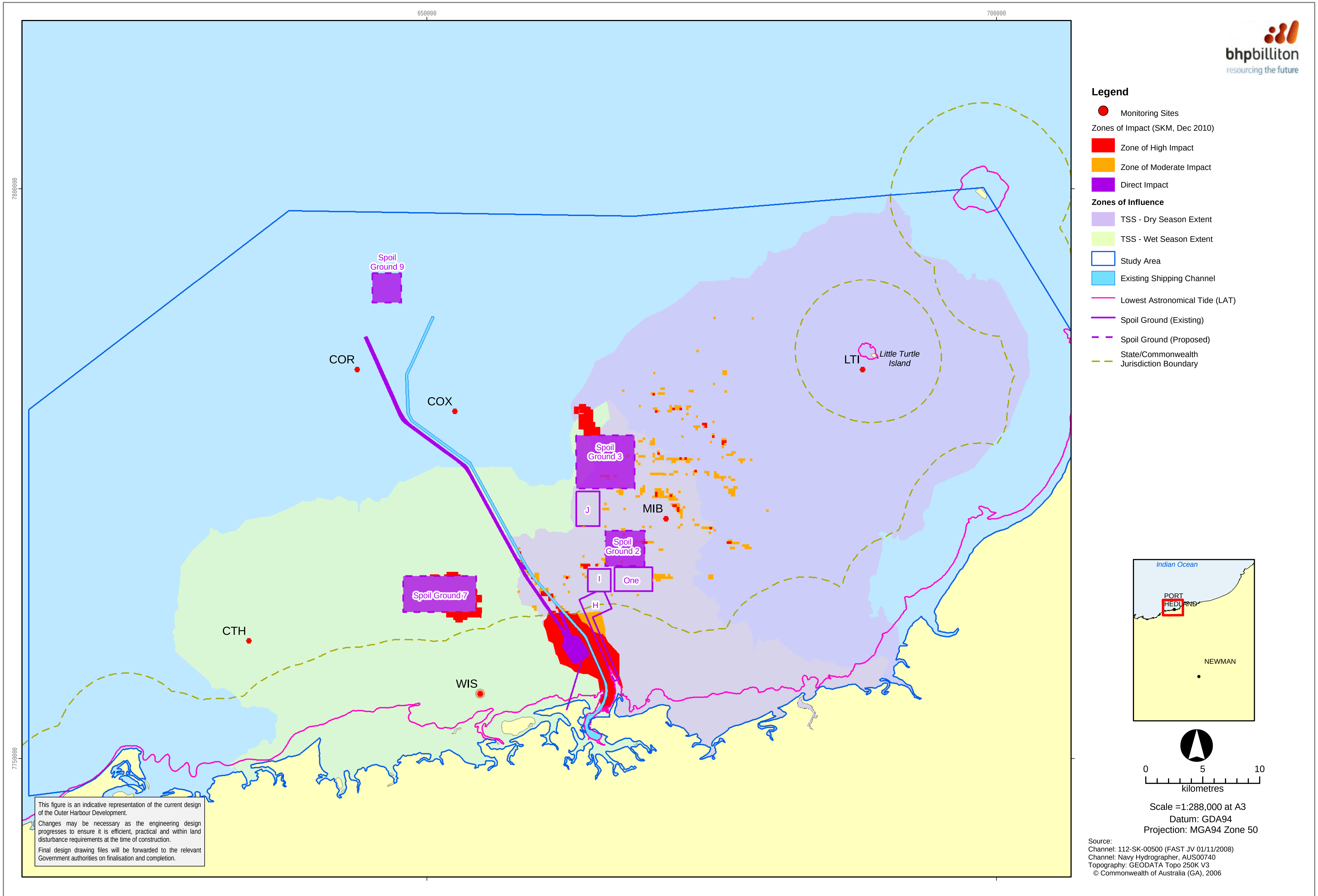

Figure 7-1 Zones of Impact and Influence for the Proposed Outer Harbour Development

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The proposed LAUs and their boundaries are presented in **Figure 7**–2 and the total areas covered by each unit are provided in **Table 7-4**. The Port Hedland Industrial LAU[7] is an existing LAU within the region and as such has been incorporated into the assessment framework as is.

- **Table 7-4: Proposed LAUs and their Boundaries for the Impact Assessment of Subtidal Benthic Habitats**

LAU	Area	
	in ha	in km^2
1	4,289	42.89
2	4,941	49.41
3	3,580	35.80
4	3,653	36.53
5	4,411	44.11
6	4,767	47.67
7	4,651	46.51
8	5,680	56.80
Port Hedland Industrial LAU	898	8.98
9	4,642	46.42
10	4,438	44.38
11	4,793	47.93
12	4,821	48.21
13	4,429	44.29
14	4,264	42.64
15	4,149	41.49
16	4,109	41.09
17	2,372	23.72
18	6,800	68.00

[7] Previously known as the Port Hedland Industrial Area Management Unit, as identified in EPA (2001).

Figure 7-2 Boundaries of the Local Assessment Units (LAUs) for Assessment of Impacts to Subtidal Benthic Communities and Benthic Habitats for the Proposed Outer Harbour Development

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7.5. Benthic Ecology in LAUs of Interest

Provided in the sub-sections below is a brief description of the benthic habitat and communities that have been observed or predicted to occur in each of the LAUs of interest. An LAU is of interest if:

- it is predicted to be impacted by the proposed activities at some time over the construction timeframe;
- if it is nearby to the LAU predicted to contain substantial impacts; or
- if it is an area that supports benthic habitats considered to be ecologically significant.

7.5.1. LAU 6 – Weerdee Island

LAU 6 is 4,767 ha in area, of which 282 ha (5.9%) is hard substrate and 4,322 ha (90.7%) is sediments (**Table 7-5**).

Areas of hard substrate were predicted to support a mosaic benthic community. Less than 5% of the benthic community at Weerdee Island was recorded as being hard corals, while on the Weerdee Ridgeline system the proportion of benthic community represented by hard corals was between 0.2 and 21.6% (**Table 4-3**).

- **Table 7-5: Breakdown of BPPH and BPP Areas within LAU 6**

Component	Area (in ha)	Proportion of Area (%)
Substrate		
Sediment	4,322	90.7
Hard substrate	282	5.9
Sediment covered hard substrate	114	2.4
Undefined substrate	47	1.0
Total	**4,767**	**100**
BPPs		
Hard coral	284	6.0
Macroalgae	487	10.2
Total	**771**	**16.2**
Non-BPPs		
Sponges	264	5.5
Soft coral	27	0.6
Sessile invertebrates	178	3.7
Total	**468**	**9.8**

A sparsely inhabited area (approximately 5 m x 5 m) of *Halophila decipiens* was observed offshore of Weerdee Island. Drop video investigations also identified patches of seagrass, predominantly *Halophila ovalis*, in the shallow protected embayment between Weerdee and Downes Islands. The seagrass was mapped to cover approximately 86 ha in beds of sparse (5 to 25% cover) to medium (25 to 50% cover) density, and were mixed assemblages most commonly present with macroalgae and occasionally sponges (refer **Section 4.3.3**).

7.5.2. LAU 7 – West of Project Footprint

LAU 7 is 4,651 ha in area, of which 231 ha (5.0%) is hard substrate and 4,229 ha (90.9%) is sediments (**Table 7-6**). The Weerdee Ridgeline traverses LAU 7, a system that is approximately 11 km west of the entrance to Port Hedland Harbour and 3 km north-east of Weerdee Island (**Figure 7**–3). The ridgeline is a broken string of ridges, approximately 12 km in length, and runs in a south-west to north-east direction (**Figure 7**–4). This shallow system has a low profile with ridge peaks ranging from -3.0 to -6.0 m CD.

The seabed at the time of survey was predominantly sand and rubble covering a hard rocky pavement. The percentage cover of biota was highly variable although predominantly comprising BPP including macroalgae and hard corals, and non-BPP including sponges and soft corals. The macroalgae present were predominantly species from the phylum Chlorophyta and included the genera *Caulerpa* and *Halimeda*. The hard corals were dominated by foliose (*Turbinaria*) and massive (*Porites*) varieties.

- **Table 7-6: Breakdown of BPPH and BPP Areas within LAU 7**

Component	Area (in ha)	Proportion of Area (%)
Substrate		
Sediment	4,229	90.9
Hard substrate	231	5.0
Sediment covered hard substrate	161	3.5
Undefined substrate	28	0.6
Total	**4,651**	**100**
BPPs		
Hard coral	185	4.0
Macroalgae	411	8.8
Total	**569**	**12.8**
Non-BPPs		
Sponges	269	5.8
Soft coral	79	1.7
Sessile invertebrates	242	5.2
Total	**589**	**12.7**

Figure 7-3 BPPH and BPP areas present within LAU 6

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Figure 7-4 BPPH and BPP areas present within LAU 7

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7.5.3. LAU 8 – Project Footprint

LAU 8 is 5,680 ha in area, of which 152 ha (2.7%) is hard substrate and 5,366 ha (94.5%) is sediments (**Table 7-7**).

Three sites were surveyed within LAU 8 (**Figure 7**–5). Site BH1 is in the region of the proposed berth pockets and swing basin, and was characterised by low-relief hard pavement substrate covered by a thin layer of sand. It was classified as BPPH due to the presence of BPP comprising hard corals. The dominant benthic cover was sponge and BPP hard corals (encrusting and foliose forms). Site FR1 was another low-relief site, which was dominated by sandy substrate. This site had a low percentage of sponge and soft corals (less than 4%) and a low percentage cover of BPP hard coral (1.3%) and hydroids (1.1%). Site FR2 was found to have a substrate of silty sand mounds devoid of any epibenthic cover.

▪ **Table 7-7: Breakdown of BPPH and BPP Areas within LAU 8**

Component	Area (in ha)	Proportion of Area (%)
Substrate		
Sediment	5,366	94.5
Hard substrate	152	2.7
Sediment covered hard substrate	141	2.5
Undefined substrate	19	0.3
Total	**5,677**	**100**
BPPs		
Hard coral	93	1.6
Macroalgae	165	2.9
Total	**258**	**4.5**
Non-BPPs		
Sponges	148	2.6
Soft coral	56	1.0
Sessile invertebrates	107	1.9
Total	**312**	**4.5**

Figure 7-5 BPPH and BPP areas present within LAU 8

7.5.4. LAU 9 – East of Project Footprint

LAU 9 is 4,642 ha in area, of which 55 ha (1.2%) is hard substrate and 4,549 ha (98.0%) is sediments (**Table 7-8**).

Although the benthic habitat within the area represented by LAU 9 has not been comprehensively investigated, the predicted benthic habitats have been generated (refer **Section 4.1.4** for detail; **Table 7-8**). Of the hard substrate present in the area, the greatest area of BPP predicted is for hard corals with a much smaller representation of macroalgae. Although non-BPPs of sponges, soft corals and sessile invertebrates are predicted to be present, these represent a very small proportion of the total area of the LAU (0.8%).

- **Table 7-8: Breakdown of BPPH and BPP Areas within LAU 9**

Component	Area (in ha)	Proportion of Area (%)
Substrate		
Sediment	4,549	98.0
Hard substrate	55	1.2
Sediment covered hard substrate	25	0.5
Undefined substrate	14	0.3
Total	**4,642**	**100**
BPPs		
Hard coral	76	1.6
Macroalgae	17	0.4
Total	**93**	**2.0**
Non-BPPs		
Sponges	2	0.1
Soft coral	6	0.1
Sessile invertebrates	27	0.6
Total	**35**	**0.8**

Figure 7-6 BPPH and BPP areas present within LAU 9

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7.5.5. Port Hedland Industrial LAU

The Port Hedland Industrial LAU is 898 ha in area, of which 162.73 ha (18.12%) was recorded as having biotic cover (**Table 7-9**).

The subtidal marine environments of the Inner Harbour within the Port Hedland Industrial LAU are subject to harsh environmental conditions. Physical processes such as tidal flow, storm events and temperature influence the distribution of subtidal BPPH more so than the subtidal habitats of the open waters outside the Harbour entrance. In the Inner Harbour, both reef and sediment substrates support BPP communities.

▪ **Table 7-9: Breakdown of BPPH and BPP Areas within the Port Hedland Industrial LAU**

<table>
<tr><th>Component</th><th>Area (in ha)</th><th>Proportion of Area (%)</th></tr>
<tr><td colspan="3">Substrate</td></tr>
<tr><td>Sediment</td><td rowspan="4">707.49</td><td rowspan="4">78.79</td></tr>
<tr><td>Hard substrate</td></tr>
<tr><td>Sediment covered hard substrate</td></tr>
<tr><td>Undefined substrate</td></tr>
<tr><td>Total</td><td>898</td><td></td></tr>
<tr><td colspan="3">BPPs</td></tr>
<tr><td>Hard coral</td><td>0.48</td><td>0.05</td></tr>
<tr><td>Macroalgae</td><td>150.82</td><td>15.08</td></tr>
<tr><td>Total</td><td>151.3</td><td></td></tr>
<tr><td colspan="3">Non-BPPs</td></tr>
<tr><td>Filter feeders</td><td>11.10</td><td>1.24</td></tr>
<tr><td>Soft coral</td><td>0.33</td><td>0.04</td></tr>
<tr><td>Sessile invertebrates</td><td>–</td><td>–</td></tr>
<tr><td>Total</td><td>11.43</td><td>1.28</td></tr>
</table>

7.5.6. LAU 14 – De Grey Point

LAU 14 is 4,264 ha in area, of which 145 ha (3.4%) is hard substrate and 3,946 ha (92.5%) is sediments (**Figure 7**–10).

Although no field observations have been undertaken within LAU 14, the predicted benthic habitats have been generated (refer **Section 4.1.4** for detail; **Table 7-10**). Of the hard substrate predicted to support BPPs, most is largely attributable to hard corals. Non-BPPs are largely represented by sessile invertebrates, although macroalgae, sponges and soft corals are also predicted to be present in combination forming a mosaic benthic community.

Figure 7-7 BPPH and BPP areas present within the Port Hedland Industrial Local Assessment Unit

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Table 7-10: Breakdown of BPPH and BPP Areas within LAU 14

Component	Area (in ha)	Proportion of Area (%)
Substrate		
Sediment	3,946	92.5
Hard substrate	145	3.4
Sediment covered hard substrate	94	2.2
Undefined substrate	77	1.8
Total	**4,264**	**100**
BPPs		
Hard coral	206	4.8
Macroalgae	143	3.3
Total	**349**	**8.2**
Non-BPPs		
Sponges	88	2.1
Soft coral	41	1.0
Sessile invertebrates	150	3.5
Total	**279**	**6.6**

7.5.7. LAU 17 – North Turtle Island

LAU 17 is 2,372 ha in area, of which 447 ha (18.8%) is hard substrate and 1,606 ha (67.7%) is sediments (**Table 7-11**).

North Turtle Island is approximately 58 km north-east of the entrance to Port Hedland Harbour. The island was surveyed once during January 2008. The island is comprised of vegetated sand and is 1.1 km long by 0.5 km wide. The island is in the centre of a large fringing subtidal platform area that extends in all directions to a distance of up to 3.0 km. The intertidal platform is completely exposed at any low tide below 4.9 m CD and is rocky with numerous shallow (<1 m) pools of varying sizes.

The subtidal sites surveyed indicated a seabed that was comprised of sand and rubble covering a hard rocky pavement. The BPP cover was predominantly hard corals, with macroalgae and non-BPP sponges, soft corals and hydroids forming a benthic mosaic community. The hard corals were dominated by encrusting and massive varieties.

Figure 7-8 BPPH and BPP areas present within LAU 14

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- **Table 7-11: Breakdown of BPPH and BPP Areas within LAU 17**

Component	Area (in ha)	Proportion of Area (%)
Substrate		
Sediment	1,606	67.7
Hard substrate	447	18.8
Sediment covered hard substrate	144	6.1
Undefined substrate	175	7.4
Total	**2,372**	**100**
BPPs		
Hard coral	532	22.4
Macroalgae	303	12.8
Total	**835**	**35.2**
Non-BPPs		
Sponges	57	2.4
Soft coral	22	0.9
Sessile invertebrates	231	9.7
Total	**310**	**13.1**

7.5.8. LAU 18 – Little Turtle Island

LAU 18 is 12,415 ha in area, of which 531 ha (4.3%) is hard substrate and 11,236 ha (90.5%) is sediments (**Table 7-12**).

Little Turtle Island is approximately 40 km north-east of the entrance to Port Hedland Harbour. The island is approximately 0.5 km long and is almost awash at high tide. It has a fringing subtidal area that extends over 1.1 km to the north-west and marginally around the rest of the island.

The subtidal area in the vicinity of Little Turtle Island when surveyed comprised a combination of sand, rubble and rock. The percentage cover of BPP was predominantly macroalgae and hard corals dominated by encrusting and massive varieties.

The area surveyed also had non-BPP sponges and a small amount of soft corals and hydroids.

Figure 7-9 BPPH and BPP areas present within LAU 17

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- **Table 7-12: Breakdown of BPPH and BPP Areas within LAU 18**

Component	Area (in ha)	Proportion of Area (%)
Substrate		
Sediment	11,236	90.5
Hard substrate	531	4.3
Sediment covered hard substrate	341	2.7
Undefined substrate	306	2.5
Total	**12,415**	**100**
BPPs		
Hard coral	958	7.7
Macroalgae	160	1.3
Total	**1,118**	**9**
Non-BPPs		
Sponges	160	1.3
Soft coral	110	0.9
Sessile invertebrates	471	3.8
Total	**741**	**6**

Figure 7-10 BPPH and BPP areas present within LAU 18

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8. Direct Impacts due to Marine Infrastructure

The impacts to BPPH described in this section are predicted to occur within the Zone of High Impact. As such, they are all considered irreversible.

The impacts detailed include historical impacts to BPPH (either estimated or recorded), the proposed BPPH losses due to removal during construction of the proposed marine infrastructure, and irreversible indirect impacts due to changes in water quality caused by the dredging activities. Finally, measures proposed to manage impacts predicted during marine construction activities are summarised.

8.1. Historical Loss of BPPH

In estimating historical loss of BPPH, it has been assumed that permanent loss has occurred only where substrate has been physically removed during the dredging of channels or where hard substrate has been smothered by spoil disposal grounds.

Port Hedland has been an operating port since the late 1800's, when a jetty was created to service the pastoral industry of the eastern Pilbara. Prior to 1965, the harbour was crescent-shaped and had a maximum depth of 9 m at its widest point near the southern end (Hope Downs Management Services 2002). In 1965, with the development of the iron ore industry in the region, dredging began to alter the natural bathymetry of the harbour. Since that time, modifications have included:

- dredging of an approach channel to the harbour;
- reclamation of East Creek to accommodate developments at Nelson Point;
- construction of iron ore, salt and general cargo wharves; and
- dredging of a turning basin and berthing pockets.

Much of the development to date at Port Hedland has taken place inside the harbour, within the area of the tidal creek system, and impacts outside the mouth of the creek system have been confined to the shipping channel, spoil grounds and anchorages. Outside the harbour, dredge spoil has either been used for land reclamation or disposed of at the large spoil bank immediately to the east, north of the township. More recently, dredge spoil has been disposed of at offshore spoil grounds H, I and J (**Table 8-1**). The build up of sediment in the harbour channel requires maintenance dredging to be conducted every three to four years. Capital dredging for new projects has also occurred.

The exact extent of historical BPPH loss due to previous dredging and spoil disposal activities is difficult to determine because there is no baseline habitat data or mapping available prior to the first dredging and disposal activities. The detailed habitat mapping carried out for the proposed

Outer Harbour Development is the first time the subtidal marine habitat offshore from Port Hedland has been quantified. This detailed habitat map aids in assessing the estimates for historical loss of BPPH.

By interpreting where the existing channel has cut through hard substrate or ridgelines, approximately 15 ha of BPPH from the LAU 8 were removed.

Spoil dredged from the entrance to the inner harbour was disposed to the east of the existing channel forming a large bank and an artificial sand spit to the north of the township, now known as 'spoil bank'. The spoil bank extends from the shore covering areas that would have been intertidal rocky platform and near shore bare sandy habitat. Again it is difficult to determine the exact extent of historical BPPH loss resulting from this spoil disposal. Assuming that the rocky intertidal area may have supported similar habitat to the area east of spoil bank, and the base of the spoil bank is approximately 1 km wide where it adjoins the beach to the north of the town, an area of approximately 5 to 10 ha may have been lost depending on the width of the platform.

Historical spoil ground H was located on areas of bare sediment and generally avoided areas of limestone reef or substrate that would have supported BPPH.

Due to the naturally harsh environment and a long history of anthropogenic impacts, the Inner Harbour was not considered to have substantial benthic communities. Consequently, direct and indirect impacts to BPPH for projects undertaken in the Inner Harbour had not been evaluated prior to Rapid Growth Project 6 (BHP Billiton Iron Ore 2009).

The predicted impacts to subtidal BPPH in the Inner Harbour due to Rapid Growth Project 6 were due to the dredge footprint, where sparse macroalgal and filter feeding invertebrate communities had been identified. A total area of 4.17 ha or 2.19% of the total area of BPPH mapped (190.07 ha) was predicted and approved to be lost due to this project.

Subsequent to the approval of Rapid Growth Project 6, the South West Creek Dredging and Reclamation Proposal has been released (EPA 2011). The proposal notes that indirect impacts to a small coral community in the western arm of South West Creek are predicted, due to the proximity to the dredging footprint and increases in water column turbidity and sedimentation rates. A loss for this BPPH however was not predicted.

A summary of the discussion on likely or known historical losses that have occurred within the Port Hedland Industrial Management Unit are provided in **Table 8-1**.

Table 8-1: Historical losses of BPPH (in ha and proportion (%) of the total area)

LAU	Estimated Original Area (ha)	Historical Loss (ha)	Historical Loss (%)	EPA Category and Loss Threshold
LAU 8	308	Access channel: 15	4.87	E – 10%
Port Hedland Industrial LAU	190.07	RGP6: 4.17 South West Creek: 0	2.19 0	E – 10%
Totals	**498.07**	**19.17**	–	–

8.2. Direct Loss due to Marine Infrastructure Footprint

Direct loss of BPPH will occur in the proposed Outer Harbour Development footprint from construction of the jetty and wharf, from removal of seabed during dredging of the berth area, turning basin and channel. The estimated areas of BPPH directly impacted by these activities are summarised in **Table 8-2.**

Table 8-2: Proposed Direct losses of BPPH (in ha and proportion (%) of the total area) due to the Marine Infrastructure Footprint

LAU	Total Area of BPPH (ha)	Proposed Loss due to Infrastructure (ha)	Total Loss (ha)	Total Loss (%)	EPA Category and Loss Threshold
LAU 8	308	Departure Channel: 0.0 Link Channel: 0.0 Jetty: 1.9 Berth Pockets & Turning Basin: 4.3 Tug Channel: 1.4	7.6	2.5	E – 10%

The majority of the proposed channel appears to have been aligned to follow the deepest areas between the limestone ridgelines and thereby it has largely avoided hard substrate BPPH. The channel alignment can be clearly seen in the habitat mapping as being located over areas mainly comprising bare sandy habitat (**Figure 8**–2). The channel does however intersect limestone substrate near the harbour entrance.

There are no proposed spoil grounds within State waters for the proposed Outer Harbour Development. The estimated impacts to BPPH arising from dredge spoil disposal are discussed in **Section 10.3** of the PER/EIS.

LAU	Historical Loss (ha)
8	14.53
Port Hedland	2.17

Figure 8-1 Historical BPPH Loss for the Proposed Outer Harbour Development

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Figure 8-2 Direct Losses of BPPH due to the Proposed Marine Infrastructure Footprint

8.3. Indirect Loss due to Sedimentation

8.3.1. Water Quality Conditions in the Zone of High Impact

Water quality conditions in the ZoHI will include very high TSS concentrations (up to 150 mg/L at times in some areas), and extremely elevated sedimentation rates (up to 100 kg/m^2 adjacent to the dredging activities) of very coarse sediment particles (**Section 5.5**). The fact that a large proportion of the material to be dredged is very coarse-grained, heavy particles that cannot be transported far is the main reason behind the high predicted sedimentation rates and the small areas over which this impact will occur.

The nature of the predicted water quality perturbations will be such that low and no light conditions will be experienced at the benthos, and because very coarse sediment particles will be falling out of suspension in these areas, it is likely that they will remain where they fall until very strong metocean conditions are experienced (e.g. cyclone). As a result, indirect losses of BPPH are predicted to occur in the ZoHI due to both low light conditions and elevated sedimentation rates (refer **Section 5**). Largely, these environmental conditions will be spatially coincident (i.e. losses due to low light and high sedimentation will both lead to BPPH losses rather than one or the other being the main impact driver). The environmental benefit arising from these unique conditions is that the indirect losses arising from sedimentation and turbidity are relatively small spatially and therefore the total benthic area predicted to be affected is also relatively small in context of the size of the proposed Outer Harbour Development.

8.3.2. Indirect Losses of BPPH

Indirect and irreversible loss of BPPH is predicted to occur in LAU 8 due to elevated sedimentation rates associated with the proposed Outer Harbour Development construction dredging activities. The areas of BPPH predicted to be lost due to the indirect impact of sedimentation are summarised in **Table 8-3.**

- **Table 8-3: Predicted Indirect Losses of BPPH (in ha and proportion (%) of the total area) due to the Dredge-Related Sedimentation**

LAU	Total Area of BPPH (ha)	Proposed Loss due to Smothering (ha)	Total Loss (ha)	Total Loss (%)	EPA Category and Loss Threshold
LAU 8	308	140.3	140.3	45.6	10%

Figure 8-3 illustrates the predicted irreversible losses of BPPH in LAU 8 due to elevated sedimentation rates.

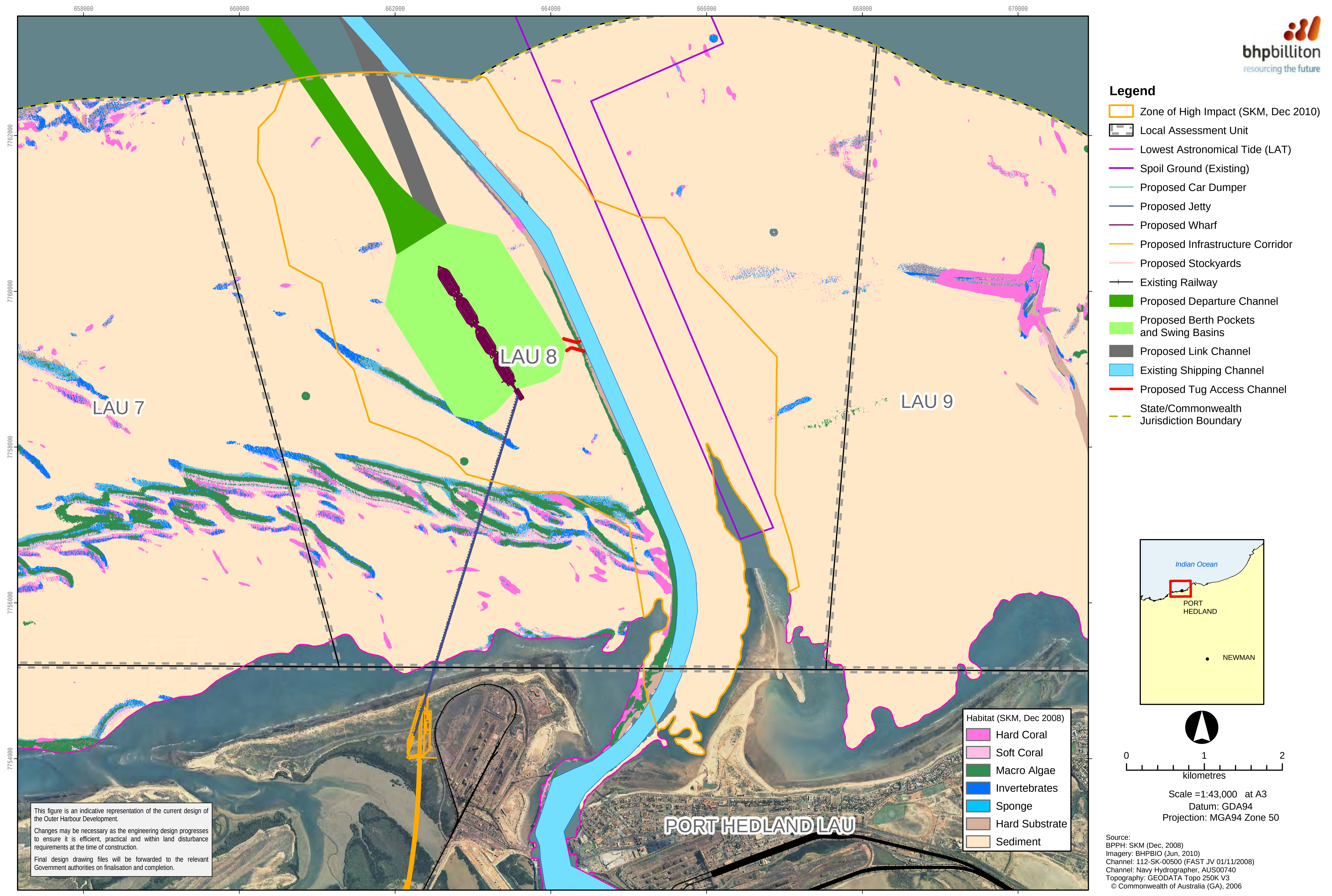

Figure 8-3 Predicted Irreversible Losses of BPPH due to Elevated Sedimentation Rates

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8.4. Summary of BPPH Losses

A summary of the historical losses estimated for the region, direct losses proposed for removal during construction of the marine infrastructure, and irreversible indirect losses predicted to occur due to elevated sedimentation rates, is provided in **Table 8-4**.

However, due to the approach used in preparing the habitat distribution maps (refer **Section 4**) the loss areas of BPPH provided in **Table 8-4** are unnecessarily conservative and overestimate what is probable loss.

Habitat investigations, including towed video and diver video transects, were undertaken at sites selected based on bathymetric features and existing knowledge of the area. Additional benthic habitat information was gathered opportunistically during other marine investigations.

LiDAR datasets and habitat data collected in the field were then input into a model to generate maps predicting the presence of biota, substrate and combined habitat classes across the entire study area. Prediction of the presence of a biota or substrate class in a given location was reliant on a benthic percentage cover of less than or equal to 5%.

The dimensions of the given locations or ‘cells’ used in the habitat modelling interrogation represented a 5 x 5 m area. If this cell was deemed to have less than or equal to 5% cover of a particular BPP then the percentage cover within this cell is assumed at 100% cover. As a result, the habitat model tends to over-predict the amount (in hectares) of each individual mosaic BPP likely to be present on the suitable substrate in a given area. As set out in EAG No. 3 (EPA 2009), when comparing the cumulative loss to the cumulative loss guidelines the EIA documentation should provide the most ‘realistic’ benthic primary producer habitat loss scenario. In this case, the use of data from *in situ* surveys of the habitats in each LAU provides the most realistic loss estimates.

To do this, each area of mosaic BPP where impacts leading to irreversible losses are predicted require a re-examination using the information from baseline studies on the actual percentage covers of each mosaic BPP, to more accurately determine the actual amount of each mosaic BPP present.

The available information on percent cover of mosaic BPP within the State waters is presented in **Table 8-5.** There is little information on the percentage cover of mosaic BPP in the project footprint and surrounding areas (LAU 8) as this area was devoid of any major features that were deemed suitable to survey during the baseline surveys. There is, however, a wealth of information baseline surveys from the 16 diver video transect undertaken in close proximity at Weerdee Island and Weerdee Ridgeline. These data, along with any data collected from the project footprint and surrounds, are used (refer **Appendix A14** of the PER/EIS). This information is assumed to be indicative of the cover of mosaic BPP on any small ridgelines within the LAU 8 that are located within the Zone of High Impact including the project footprint.

- **Table 8-4: Total Cumulative Losses of BPPH (in ha and proportion (%) of the total area) due to the Proposed Outer Harbour Development**

LAU	Total Area of BPPH (ha)	Historical Loss (ha)	Direct Loss (ha)	Indirect Loss (ha)	Total Loss (ha)	Total Loss (%)	EPA Category and Loss Threshold
LAU 8	308.0	15.0	7.6	140.3	162.9	52.9	E – 10%
Port Hedland Industrial LAU	190.07	4.17	–	–	4.17	2.2	E – 10%
Total	**498.07**	**19.17**	**7.6**	**140.3**	**167.07**	**–**	–

- **Table 8-5: Predicted Actual Irreversible Losses of BPPH due to and Direct Removal and Indirect Loss**

Mosaic Benthic Group	Average percentage cover (n =16)	Total irreversible losses predicted by the model (ha)	Actual irreversible losses predicted by baseline surveys (ha)
Macroalgae	41.1	60.8	19
Sponges	19.5	28.8	1.3
Soft corals	3.5	5.2	0.2
Hard corals	15.1	22.3	1.3
Other (includes sessile invertebrates)	17.4	25.7	1.5

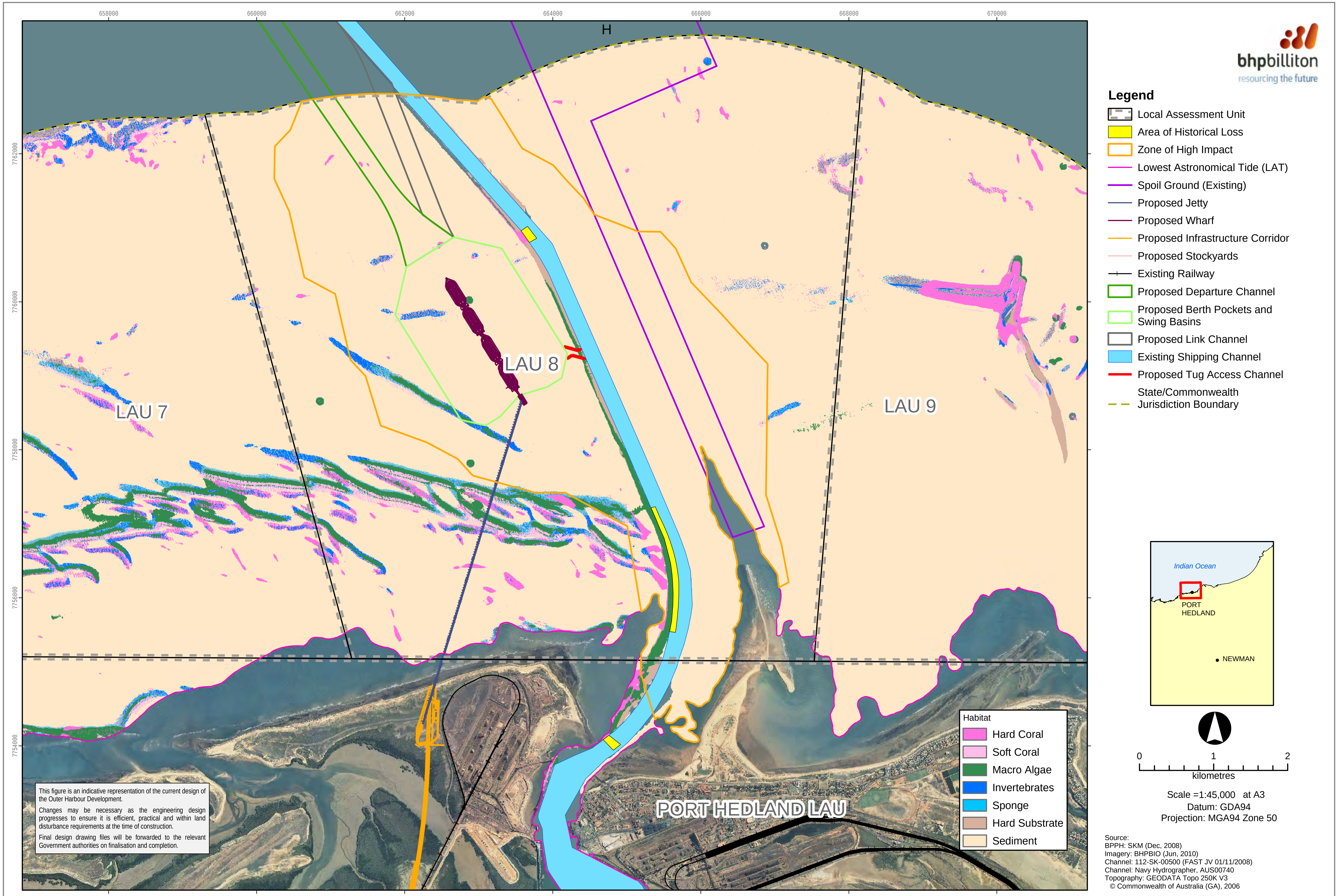

Figure 8-4 Estimated BPPH Losses for the Proposed Outer Harbour Development

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8.5. Management of Impacts during Construction Dredging Activities

The management measures to be used for the minimisation of impacts to marine BPPH during the proposed Outer Harbour Development have been drawn from management plans for the project.

The management measures recommended fall into five categories:

- controls around dredging and disposal equipment and methods to minimise impacts to marine water quality;
- monitoring programs to assess the ongoing health of hard corals during the program;
- thresholds around water quality and coral health that will serve as triggers for management action if exceeded; and
- location of spoil grounds to minimise impacts to BPPH supporting BPP communities.

These are detailed in the DSDMP management strategies relevant to management of marine BPPH:

- **Section 7.1** Benthic Habitat Management;
- **Section 7.4** Spoil Ground Management; and
- **Section 7.5** Waste Management.

9. Indirect Impacts to BPPH

Indirect impacts on benthic habitats and communities from the effects of sediments introduced to the water column by dredging are discussed in this section. These impacts are predicted to occur within the ZoMI and as such all impacts discussed here are considered to be either sub-lethal or recoverable within a five-year timeframe.

The results of the interrogation of the sediment plume model for impacts from elevated TSS concentrations indicated that the vast majority of these impacts will occur in Commonwealth waters. The indirect impacts presented in this section are constrained to those predicted to occur in State waters; indirect impacts to benthic communities and habitats in Commonwealth waters are presented in **Section 10.3** of the PER/EIS.

9.1. Water Quality Conditions in the Zone of Moderate Impact

Water quality conditions in the ZoMI will include elevated concentrations of sediment particles in suspension (i.e. increased TSS concentrations) and, where calmer water conditions are experienced, the coarser particles in suspension will fall out resulting in elevated sedimentation rates (**Figure 9–1**).

As detailed in **Section 5**, modelling of the sediment plume predicted that heavier sediment particles and a proportion of finer sediments will deposit around the dredging and disposal operations while finer sediments will deposit as thin layers, for short durations, over a wider area. In particular, daily cycles of settlement and resuspension of sediment in the broader area are likely to occur due to the strong tides and influence of waves. It is this thinner layer of sediments, deposited, resuspended and dispersed on a daily basis that is the driver of indirect impacts in the ZoMI.

Indirect impacts to the benthic ecology due to this thin layer of sediments redistributed on a daily basis will affect both benthic primary producers (BPPs) and non benthic primary producers (non-BPPs).

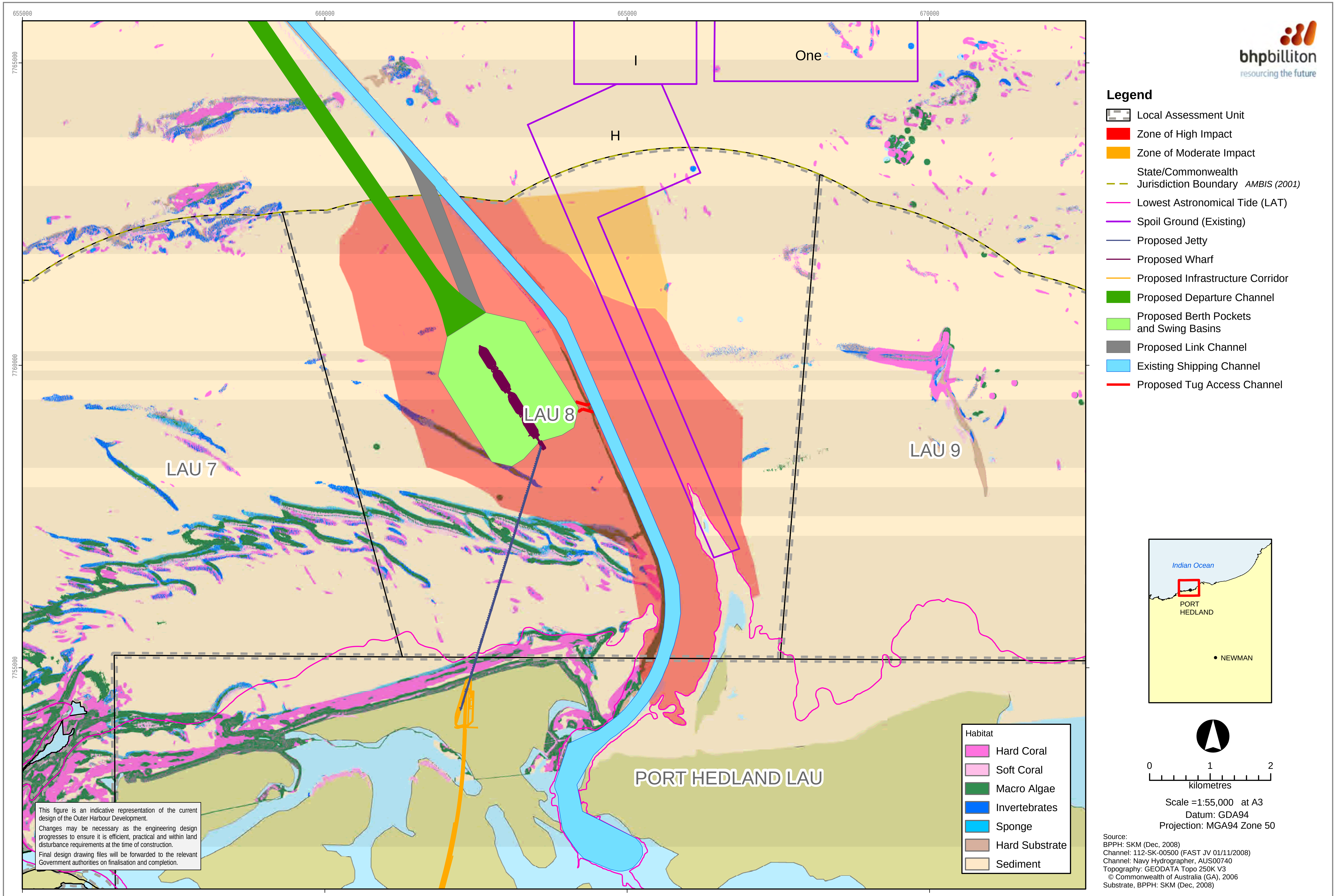

Figure 9-1 Zone of Moderate Impact Predicted for the Proposed Outer Harbour Development

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9.2. Indirect Impacts to BPPs

BPPs observed to be present at some time during the year within the ZoMI are hard corals and macroalgae. The nearest seagrasses are some 10 km to the south west of the boundary of the ZoMI and lie within the ZoI (**Figure 9–2**).

The majority of sedimentary material that will be suspended in the water column within the ZoMI will be fine (less than 64 µm) sediment particles that are easily resuspended through tide and wave action. As such, there will be times during the day when suspended materials will fall from the water column and deposit on the benthos (e.g. during slack tide) and there will be times of the day when the deposited material will be resuspended into the water column making the waters more turbid (e.g. during ebb tides). Given that tidal action is diurnal, this pattern will occur twice a day and possibly more if coincident wave conditions are energetic.

As a result of the predicted dynamic movement of fine sediment particles within the ZoMI, BPPs will experience windows of clearer water conditions, and removal of deposited sediment materials, on at least a daily basis.

Although the water column will be more turbid than background, and although a fine layer of silt will be depositing on BPPs within this zone, the suspended and deposited material will be very mobile. This will create an environment that allows BPPs within the ZoMI to photosynthesise. It is due to this regular opportunity to photosynthesise that no irreversible losses due to turbidity and sedimentation are predicted for BPPs in the areas demarcated by the ZoMI.

9.3. Indirect Impacts to Non-BPPs

As for BPPs, non-BPPs will experience increased sedimentation rates. The non-BPP assemblage in State waters of the proposed Outer Harbour Development comprises sessile invertebrates including sponges and soft corals. The non-BPP community are predominantly filter feeders.

Elevated suspended solids in the water column and increased sedimentation rates have the potential to impede filter feeding activity with an overload of suspended material. For example, mussels under such may close up and avoid feeding until improved conditions return. When the water quality perturbation occurs over extended durations (e.g. days) this can reduce the feeding opportunities that mussels would otherwise undertake. For sponges that do not have the opportunity to shut down under such conditions, an overload of filtered material results.

As described in **Section 9.2**, the nature of the increase in suspended material and sedimentation rates is such that the material will be primarily fine particles and will be resuspended and redistributed on at least a twice daily basis. As such, sessile invertebrates comprising the majority of the non-BPP community will have a period of respite during the change of tide when material will be lifted and moved relieving any sedimentary cover they are experiencing, and during slack tides the concentration of suspended material will temporarily reduce. It is this daily dynamicity in suspended solid concentrations and sedimentation conditions that will allow non-BPPs to survive within the ZoMI.

9.4. Summary of BPPH Impacts

The benthic communities within the Zone of Moderate Impact will experience increased suspended solids concentrations and sedimentation rates, however it is due to the frequent (twice-daily) resuspension and redistribution of sedimentary material that will provide temporary relief from deposited and suspended materials.

It is due to this frequent relief of fine sedimentary material within the ZoMI that results in the prediction that BPPs and non-BPPs will not suffer indirect losses in this zone, and at most, sub-lethal impacts such as reduced photosynthetic activity, increased mucus production and decreased filtration rates may occur.

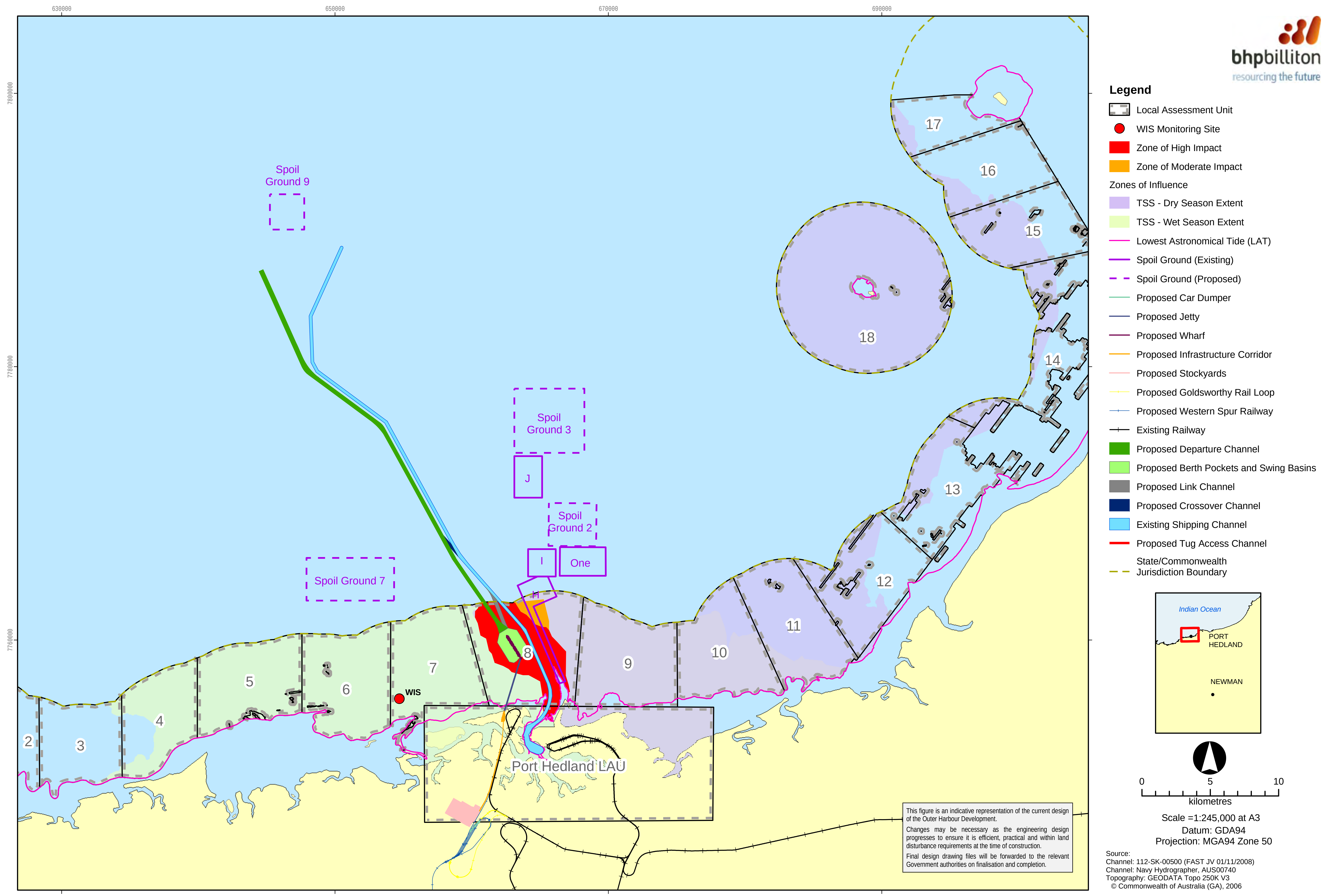

Figure 9-2 Zone of Influence Predicted for the Proposed Outer Harbour Development within State Waters

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10. Benthic Habitat Loss Assessment Summary

Outcomes of the assessment of impacts to marine BPPH due to the proposed Outer Harbour Development, and a summary of the information underpinning the assessment, are provided below.

10.1. Irreversible BPPH Losses

The areas of estimated loss occur within and in close proximity to the dredging activities.

Physical seabed disturbance from dredging will result in the removal and direct loss of 7.6 ha of BPPH within State waters. In addition, elevated sedimentation rates are predicted to result in the loss of 140.3 ha of BPPH.

Changes in water quality due to increased suspended solid concentrations and sedimentation rates are predicted to incur serious damage, including mortality of hard corals that grow there, and resultant irreversible indirect impacts. These increases in sedimentation rates will not cause the loss of the underlying hard substrate on which the BPPs grow.

The cumulative irreversible loss of BPPH from both historical and proposed losses is predicted to be:

- 2.5% (7.6 ha) in LAU 8 due to removal within the infrastructure footprint;
- 45.6% (140.3 ha) in LAU 8 due to sedimentation; and
- 2.2% (4.17 ha) in the Port Hedland Industrial LAU due to historical losses.

This level of cumulative irreversible loss is unavoidable if the Outer Harbour Development is to proceed as proposed, as the design and placement of the infrastructure footprint has minimised the potential BPPH losses.

10.2. Ecological Significance of Losses

LiDAR mapping offshore from Port Hedland indicates low relief ridgelines extending along the entire extent of the coastline from North Turtle Island in the north-east to beyond Cape Thouin in the south-west. The ridgelines extend well beyond the extent of the mapping, which implies a uniform ecosystem composed of parallel ridge lines extending for hundreds of kilometres.

The ecological significance of estimated hard coral losses is minimal, based on the observations that:

- the direct losses of BPPH associated with the marine infrastructure represent a very small fraction of the total BPPH of this type in the Port Hedland region;

- any areas in which indirect losses occur are expected to be rapidly recolonised because the supply of coral recruits through the extensive representation of this benthic community and habitat will be available;
- from a regional perspective, the species richness of coral taxa in the area affected is very low in comparison to elsewhere in the Pilbara region. In addition, these coral communities do not appear to contain endemic species and are not considered to be regionally significant coral communities with high preservation values; and
- there is little evidence of carbonate accretion onto the tops of the limestone ridges on which the coral communities are found, suggesting that the extreme metocean conditions the coral communities experience during the seasonal storms and frequent cyclones that occur in this area are likely responsible for the observed low diversity, relatively small colonies and low percent cover of coral.

10.2.1. Seagrasses

The impact assessment concluded that no losses of seagrasses would result from the proposed Outer Harbour Development, and no impacts to the ecological significance and function of the seagrass beds would occur.

The nearest seagrasses are some 10 km to the south west of the boundary of the ZoMI and lie within the ZoI. As such, they may experience slightly reduced light conditions due to slightly elevated TSS concentrations (up to 5 mg/L higher than background) although this will be a seasonal influence and will vary on a daily basis, making adequate opportunities to maintain photosynthetic activity.

10.3. Recoverable Impacts to BPPH

The benthic communities within the ZoMI will experience increased suspended solids concentrations and sedimentation rates, however it is due to the frequent (twice-daily) resuspension and redistribution of sedimentary material that will provide temporary relief from deposited and suspended materials.

It is due to this frequent relief of fine sedimentary material within the ZoMI that results in the prediction that BPPs and non-BPPs will not suffer indirect losses in this zone, and at most, sub-lethal impacts such as reduced photosynthetic activity, increased mucus production and decreased filtration rates may occur.

10.4. Predicted Environmental Outcomes

Direct loss of BPPH (6.7 ha; 2.5% of LAU 8) will be removed during construction of the marine infrastructure, and indirect loss of BPPH due to elevated sedimentation rates is predicted to also occur close to the dredging activities (140.3 ha; 45.6% of LAU 8). When accounting for historical losses in the Port Hedland Industrial LAU (4.17 ha) and in LAU 8 (15 ha) this amounts to a cumulative loss of BPPH within State waters for the proposed Outer Harbour Development of 167.1 ha of BPPH, primarily due to indirect losses arising from sedimentation in the ZoHI. The predicted indirect losses due to increases in sedimentation rates will not cause the loss of the underlying hard substrate on which BPPs grow. When taking into account the *actual* the percentage hard coral cover from baseline surveys of sites within State waters and comparing the predicted area of hard coral impacted (by the habitat model), the actual indirect losses due to increased sedimentation of hard corals is 1.3 ha (see **Section 8.3.2**).

The ecological significance of the losses of BPPH arising from the proposed Outer Harbour Development is considered to be minimal. Hard corals were the most dominant BPP growing along the ridgelines that will be affected by dredging activities, and the dominant corals present are from the genus *Turbinaria* and from the families Faviidae and Poritidae. Based on the low species richness and abundance of corals and dominance of *Turbinaria*, coral communities that inhabit subtidal habitats in the Port Hedland region are high turbidity, high sedimentation adapted communities. In addition, the species and habitats affected are considered typical of the broader marine environment of the Pilbara region, and no new species have been recorded.

The nearest seagrasses are some 10 km to the south west of the boundary of the ZoMI and lie within the ZoI. No losses or impacts to seagrasses recorded within the proposed Outer Harbour Development area are predicted.

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