BLNG Precinct

Section 43A Application

Change in Dredging Volumes
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BLNG Precinct - Section 43A Application

Change in Dredging Volumes

1. PURPOSE OF DOCUMENT

Under Section 43A of the Environmental Protection Act 1986 (EP Act), the Department of State Development (DSD) (on behalf of the Proponent) is requesting a change to the dredging and spoil disposal element of the Key Characteristics of the BLNG Precinct proposal currently under assessment by the Environmental Protection Authority (EPA) (Assessment Number 1730). Section 43A allows the EPA to consent to the proponent changing a proposal while it is being assessed (without a revised proposal being formally referred) if the Authority considers that the change is unlikely to significantly increase any impact that the proposal may have on the environment. As shown in Table 1.1, DSD is seeking that the approved dredging and spoil disposal volume be increased from 21 Mm$^3$ to 34 Mm$^3$ and that the duration of foundation dredging activities be increased from 12 months within 18 to 21 months.

Table 1.1 Summary of Key proposal Characteristics

<table>
<thead>
<tr>
<th>Element</th>
<th>Current Description (pre Section 43A)</th>
<th>Proposed Description (post Section 43A)</th>
</tr>
</thead>
</table>
| Dredging and Spoil Disposal | • Up to 21 million cubic metres of capital dredge material and periodical maintenance dredging as required.  
• Foundation development requiring approximately 18 months of dredging.  
• Spoil to be placed over an area outside State waters of up to 600 ha with location to be determined through Commonwealth Sea Dumping permit process. | • Up to 34 million cubic metres of capital dredge material plus periodical maintenance dredging as required.  
• Foundation development requiring approximately 21 months of dredging.  
• Spoil to be placed over an area outside State waters of up to 600 ha with location to be determined through Commonwealth Sea Dumping permit process. |

The proponent is of the opinion that based on the following supporting documentation, the proposed increase in dredging volumes and associated dredging duration will not lead to a significant change in environmental impact and therefore is eligible to be considered under Section 43A of the EP Act.

2. OVERVIEW

A numerical sediment plume dispersion model has been used to support the proposed Browse LNG Precinct, Strategic Assessment Report (SAR). The numerical modelling incorporated a range of broad assumptions and representative input which was appropriate for a strategic-level environmental assessment of a multi-user marine facility in the early planning stages of development. The SAR modelling included a high-level assessment of potential impacts from the dredging and dredge spoil disposal activities during the construction phase of the proposed Browse LNG marine facilities, assuming indicative dredging volumes for the capital deepening of an access channel and turning basin.

An expanded and more detailed, numerical modelling study of potential impacts due to dredging activities in connection with the proposed Browse LNG Precinct have since been undertaken. This new modelling benefits from a Browse LNG design which has been refined by ongoing Front End Engineering Design (FEED) activities, reliable seabed geotechnical, metocean and bathymetric data and from a more detailed description of the dredging operations anticipated for the construction of the
marine facility. The numerical models and impact thresholds have also been significantly refined and now incorporate a wealth of measured baseline data which was unavailable at the time of the preparation of the SAR.

As a result of the above refinements, the approach to predicting and assessing direct and indirect impacts resulting from dredging related activities has also been refined. This document which has been prepared to support a request for the EPA to change the proposed dredging volume and duration of the proposed Browse LNG Precinct proposal under Section 43A of the EP Act, discusses these refinements. As such this document:

- Describes the changes to the dispersion model which have occurred post submission of the SAR
- Outlines the changes related to dredging aspects of the proposal which have occurred post submission of the SAR
- Presents the revised impact thresholds
- Presents findings of revised plume dispersion modelling which has been conducted based on proposal changes, the additional knowledge of the dredging campaign and physical characteristics of the environment
- Presents the predicted impacts using the revised threshold
- Compares dredging impacts predicted, as presented in the SAR, with the latest predictions (for all phases of the 50 Million tonnes per annum (Mtpa) proposed Browse LNG Precinct)
- Presents conclusions of the revised assessment.

3. ASSESSMENT PRESENTED IN THE SAR

3.1 Introduction

An appropriate, but necessarily simplistic, plume dispersion modelling exercise was conducted for the SAR. The modelling was constrained by:

- early port layout, not informed by geotechnical, metocean, bathymetric and model test inputs, resulting in greater potential variations in the volume and location of dredged material
- limited data on the geology and material type to be dredged leading to greater uncertainty on the volume of fines (<63 µm diameter) that need to be dredged
- lack of definition of the dredging program and in particular the type of dredge that could be used (which will be influenced by the amount and type of material to be dredged, metocean conditions or constraints and the market availability of dredges).

3.2 Design Inputs

The SAR considered that the construction of infrastructure required to support a total proposed Browse LNG Precinct production capacity of 50 Mtpa would be staggered/phased and likely to be provided by two or more proponents. The foundation proponent proposes to construct facilities to support an initial LNG production rate of 12 Mtpa and would expand the facilities to an ultimate capacity of 25 Mtpa at a later time, in response to customer demand. Although it is likely that a
second proponent would also phase their production capacity, until a second proponent is identified and their plans made known, it is assumed that the ultimate capacity of the second proponent would be achieved through one phase. Therefore, the ultimate 50 Mtpa proposed Browse LNG Precinct production capacity of the Precinct, is indicatively shown to be achieved through three key construction phases namely:

**Phase 1** – foundation proponent to 12 Mtpa production capacity (Foundation Project)

**Phase 2** – foundation proponent to 25 Mtpa production capacity

**Phase 3** – second proponent providing a further 25 Mtpa capacity.

The capital dredging and offshore spoil disposal will be staged in accordance with the above distinct phases. Phase 1 dredging would support the installation of the major multi-user infrastructure (e.g. shipping channel, berth pockets) and export pipelines for the foundation proponent. It is unlikely that the dredging for the export pipelines will occur at the same time as that for the multi-user infrastructure. Timing of pipe laying activities will be governed by the upstream construction schedule and is likely to be subsequent to port construction activities. Further dredging would be required by the foundation proponent for additional breakwaters and export pipelines to support a subsequent expansion to 25 Mtpa (Phase 2). The additional dredging required for Phase 2 is minimal and is estimated to be approximately 2 Mm$^3$. Table 4-2 provides a comparison of dredging volumes by construction phase. Future proponent(s) in Phase 3 would require dredging to construct turning basins, berth pockets and breakwaters, to expand the integrated marine facility and for pipe-lay trenching of pipelines (in the northern corridor).

At the time of submission of the SAR, preliminary estimates of the total dredged volume for the nearshore infrastructure, based on conceptual site layout options shown in Part 2, Section 5 (Description of Activities and Facilities under the Plan), were of the order of 21 Mm$^3$ (DSD 2010). Table 3.1 provides a summary of the estimated dredging volumes presented in the SAR.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SAR (Mm$^3$) (Preliminary) 25 Mtpa (Foundation Project)</th>
<th>SAR (Mm$^3$)(Preliminary) 50 Mtpa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipping Channel</td>
<td>Included in the calculations below</td>
<td>Included in the calculations below</td>
</tr>
<tr>
<td>Turning Basin &amp; Berth Pockets</td>
<td>12</td>
<td>17.5</td>
</tr>
<tr>
<td>Integrated Marine Facility (IMF)</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Breakwaters</td>
<td>Not included in calculation</td>
<td>Not included in calculation</td>
</tr>
<tr>
<td>Pipeline trenching</td>
<td>Not included in calculation (3)</td>
<td>Not included in calculation (6)</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>15.5</td>
<td>21</td>
</tr>
</tbody>
</table>

During the development of the SAR, the port layout was at a very early stage of concept design. Preliminary estimates indicated that the total dredging volume for the installation of the major multi-user infrastructure by the foundation proponent (for a 25 Mtpa facility) was likely to be of the order of 15.5 Mm$^3$ over approximately 18 months, equating to approximately 10 Mm$^3$ per annum. Given the strategic nature of the assessment, the sediment plume modelling presented in the SAR was based
on 12 months of dredging within an 18 month period, at a rate of 10 Mm$^3$ per annum from a point source within the Precinct Port area. Pipeline trenching for the southern and northern export pipelines were not included in the modelling. As such, the impact assessment presented in the SAR, is based on dredging and spoil disposal activities associated with the production of a 25 Mtpa facility, without the necessary export pipelines. A suite of conservative assumptions were used in the preparation of the modelling presented in the SAR and it was considered that this approach resulted in an assessment of impacts that would encompass impacts from future activities which would be of a comparatively minor scale and so represented a sound assessment of a potential 50 Mtpa development.

The base case scenario was run for a full 12 month simulation (May 2008 – April 2009) using actual metocean and meteorological data collected for that period (DSD 2010). The period was selected to coincide with the available field program data that was used to calibrate the model.

The exact timing of construction of the three Precinct phases is currently unknown. It is unlikely that the foundation proponent would commence construction of Phase 2 (to 25 Mtpa capacity) within five years of commissioning Phase 1. Similarly, given the lead time required to turn a gas find into a fully designed and approved LNG project, it is also unlikely that a second proponent would commence construction activities within the five year window following commissioning of Phase 1. It is possible that construction activities associated with the second and third phases coincide. However, it is important to recognise that the majority of dredging is associated with the establishment of multi-user port facility which is undertaken during Phase 1 (see Table 4.3).

There was limited potential for ‘relief’ periods for environmental receptors that would typically be associated with bunkering, maintenance, phasing of works etc. to be simulated using the modelling approach adopted for the SAR. The SAR assumed a continuous point source discharge located within the turning basin.

The modelling focused on the dispersion of fine sediments (<63 μm) as the primary influence on water quality, because coarse, non-cohesive sediments are likely to settle out of the water column in close proximity to the dredging or disposal activities.

3.3 SAR Thresholds

The Benthic Primary Producer Habitat (BPPH) impact assessment presented in the SAR was undertaken in accordance with the Environment Assessment Guideline No. 3 (EAG3) (Protection of Benthic Primary Producer Habitats in Western Australia’s Marine Environment) (EPA 2009). As such, the following definitions were employed:

- **Zone of High Impact (ZoHI).** This zone corresponds to the area of BPPH that will be permanently lost within and immediately adjacent to the project footprint. This zone is primarily related to direct removal or smothering of habitat;

- **Zone of Moderate Impact (ZoMI).** This zone corresponds to the area where BPPH will be subject to a range of physiological effects ranging from sub-lethal stress to mortality, yet recovery in less than five years is likely as per EAG 3 (EPA, 2009). This boundary is determined primarily by Minimum Light Requirements (MLR) for seagrass, macroalgae, and coral and sponges; and

- **Zone of Influence (ZoI).** This zone corresponds to the area in which changes in water quality are likely to be detectable (perhaps visually) but no environmental impact is anticipated. It is considered that the main concerns/receptors for this zone are visual amenity and public perceptions.
The thresholds applied for the impact assessment presented in the SAR are shown in Table 3.2.

Table 3.2 Impact thresholds applied for the impact assessment presented in the SAR.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Receptor</th>
<th>Threshold Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZoHI</td>
<td>For seagrass, but based on corals</td>
<td>Any 84 day rolling period when the sum of gross sedimentation &gt; 7056 mg/m²</td>
</tr>
<tr>
<td>ZoMI</td>
<td>Seagrass - acute</td>
<td>Mean daily SI² &lt;1% for 3 days</td>
</tr>
<tr>
<td></td>
<td>Seagrass - Chronic</td>
<td>Mean daily SI &lt;12% for 15 days</td>
</tr>
<tr>
<td></td>
<td>Coral</td>
<td>Median sedimentation over 4 weeks &gt;30 mg/cm²/d above background daily</td>
</tr>
<tr>
<td></td>
<td>Coral - Chronic</td>
<td>Any 56 days in a 64 day period where mean daily PAR ≤ 25% relative to natural levels</td>
</tr>
<tr>
<td>Zol</td>
<td>Water Quality</td>
<td>TSS from dredging alone &gt; 5 mg/l for 5% of the modelled period</td>
</tr>
</tbody>
</table>

Notes:
1. Corals are recognised as one of the most sensitive marine receptors for anomalous increases in sedimentation and turbidity (Brown et al. 1990), therefore, in lieu of a categorical level of sedimentation at which seagrass mortality is known to occur, the coral ZOHI sedimentation threshold has been adopted for seagrass to account for potential impact from chronic fines sedimentation.
2. SI sub-surface irradiance

3.4 Outcome of SAR Modelling

Figures 3-1 to 3-4 show representative “snapshots” from the model run for both a spring and neap tide in both summer and winter (reproduced from Part 3, Browse LNG Precinct SAR). Results of annual simulations suggested that the plumes were generally likely to extend equally north and south of dredging activities (except during summer/neap conditions where the plume often extends further northward than southward; Figure 3.2).

The greatest spatial extent of plumes were predicted to occur during summer/spring conditions, where the concentrations of TSS due to dredging and spoil disposal activities were predicted to reach 10 mg/l above background in an area extending from Quondong Point to just south of Coulomb Point and approximately 14 km seaward (Figure 3.1). Baseline monitoring conducted to support the SAR, demonstrated that a TSS concentration of 10 mg/L is exceeded frequently in the James Price Point nearshore marine environment. In summer/spring conditions, the predicted TSS concentrations reached up to 50 mg/L above background in an area extending approximately 3-5 km north, west and south of the point source discharge. During winter/neap conditions when dispersing forces are lowest (Figure 3.4), high levels of TSS >750 mg/l were predicted in the immediate area around dredging activities.
Figure 3.1 Water Quality Model ‘Snapshot’ (i.e. a particular point in time) Showing the Contribution of Suspended Solids (i.e. above background) during Summer Spring Tide Conditions (Figure 2.3-2 from Browse LNG Precinct SAR - DSD 2010).
Figure 3.2 Water Quality Model ‘Snapshot’ (i.e. a particular point in time) Showing the Contribution of Suspended Solids (i.e. above background) during Summer Neap Tide Conditions (Figure 2.3-3 from Browse LNG Precinct SAR - DSD 2010)
Figure 3.3 Water Quality Model ‘Snapshot’ (i.e. a particular point in time) showing the Contribution of Suspended Solids (i.e. above background) during Winter Spring Tide Conditions (Figure 2.3-4 from Browse LNG Precinct SAR - DSD 2010)
Figure 3.4 Water Quality Model ‘Snapshot’ (i.e. a particular point in time) Showing the Contribution of Suspended Solids (i.e. above background) during Winter Neap Tide Conditions (Figure 2.3-5 from Browse LNG Precinct SAR - DSD 2010)
3.5 SAR Impact Assessment

Section 2.4.2.2, Part 3 of the SAR identified the following aspects associated with the dredging required to establish the proposed Browse LNG Precinct, as having the potential to impact benthos:

- Marine site disturbance and excavation
- Sediment deposition and turbidity

**Potential Impact to Benthos due to Marine Site Disturbance and Excavation**

Direct impacts of dredging are those within the immediate footprint of dredging and spoil disposal, where biota or habitat is either physically removed or totally smothered with sediment. These impacts are generally spatially restricted to very close to the dredging operation and disposal grounds. The SAR determined that nearshore construction, infrastructure, pipelines, dredging and spoil disposal are likely to result in physical disturbance to the seabed and therefore will have an impact through the direct removal and disturbance of substrates.

The final configuration and exact location of the marine facilities were unknown at the submission of the SAR, therefore the impact assessment assumed a “worst case” scenario. This scenario assumed that the excavation and removal of substrate would directly impact the entire proposed Browse LNG Precinct Port area. This area is approximately 1000 ha within Port Area A. As a consequence, all BPPH within the Port area was assumed to be permanently lost.

**Potential Impacts to benthos due to Sediment Deposition and Turbidity**

The SAR identified the potential impacts associated with the deposition of sediment and increased turbidity in the water column from dredging and spoil disposal activities, to be the permanent and temporary loss of benthic habitat (benthos and BPPs) from increased sedimentation and light deprivation.

Dredging will result in both fine and coarse sediments being suspended within the water column. Disturbance of existing marine sediments will lead to increased concentrations of suspended sediment in the water column, and a subsequent reduction in benthic light availability. Light reduction will cause an indirect effect of reduced productivity from photosynthetic BPPs in areas where levels of dredging induced suspended sediment attenuate light to below critical levels. While the effect may cause loss of some BPPH and BPPs, the SAR assumed that this will be a temporary loss (for seagrass and macroalgae) or partial loss (for coral and sponges), as the underlying conditions supporting re-colonisation and/or recovery will be present after the activity has been completed.

Sedimentation occurs as particles suspended in the water column settle out away from the source, either partially or completely burying BPPs and BPPHs. Duration and intensity of sedimentation play a key role in determining resulting impact potential on coral. Extended periods of sedimentation are likely to have a greater effect on BPPs’ capacity to recover than short periods. Sediment particle size also influences removal and recovery processes.

A sedimentation threshold was applied to the plume modelling results to determine the area in which sedimentation is likely to result in significant BPPH loss and the substrate is likely to be altered to an extent where recolonisation/recovery within a period of approximately 5 years is unlikely. The high sedimentation impact area was estimated to extend 1 km from the dredging activities.

Therefore the SAR assumed that the level of sediment deposition occurring within 1 km of the infrastructure footprint would result in significant BPPH loss, and the substrate altered to an extent where recolonisation/recovery within a period of approximately 5 years would be unlikely. Based on
the “worst case” scenario, the high impact sedimentation area extends from the edge of the port boundary. In addition, the SAR also considered that high impact sedimentation would extend 0.5 km out from the centre line of the export pipelines routes within 3 nm of the coast.

Zone of High Impact: The SAR defined the zone of high impact as the region where a lethal affect on benthos is expected, and recovery within five years is unlikely. This zone is primarily related to direct removal or smothering of habitat and corresponds to the area of BPPH that will be permanently lost within and immediately adjacent to the project footprint. The BPPH loss calculations presented in the SAR were not based on the plume dispersion modelling, but rather were estimated assuming:

- the area beneath the dredge footprint, where mortality of benthos is predicted to occur as a direct result of removal/disturbance due to development activities encompassed the entire Port area.

- an area extending 1 km from the entire Port area, where smothering by fine sediment would result in permanent alteration of substrate preventing recovery/recolonisation within 5 years.

- the entire area contained within the northern and southern pipeline corridors

- an area extending 0.5 km from the centre-line of each of the northern and southern pipeline corridors.

The extent of BPPH and the percentage loss in each category is presented in Table 3.3. BPPH types that were defined and mapped within the SAR, from which loss calculations were determined, include algae, hard coral, and photosynthetic soft coral and seagrass. The intertidal BPPH extent and subsequent loss calculations were based on a combined BPPH class as insufficient detail was available in the survey data to allow partition into individual categories.

**Table 3.3 Estimated loss calculations of BPPH from relevant Local Area Unit as predicted in the SAR**

<table>
<thead>
<tr>
<th>BPPH Category</th>
<th>Local Area Unit (ha)</th>
<th>Loss of BPPH (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total BPPH</td>
<td>3314</td>
<td>1138</td>
</tr>
<tr>
<td>Intertidal mosaic of coral, algae and filter feeders</td>
<td>372</td>
<td>91</td>
</tr>
<tr>
<td>Macroalgae only</td>
<td>1707</td>
<td>600</td>
</tr>
<tr>
<td>Hard coral only</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Soft coral only</td>
<td>115</td>
<td>34</td>
</tr>
<tr>
<td>Seagrass only</td>
<td>514</td>
<td>251</td>
</tr>
<tr>
<td>Mixed mosaic of hard coral and algae</td>
<td>270</td>
<td>72</td>
</tr>
<tr>
<td>Mixed mosaic of hard coral and soft coral</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mixed mosaic of soft coral and algae</td>
<td>127</td>
<td>32</td>
</tr>
<tr>
<td>Mixed mosaic of seagrass and algae</td>
<td>143</td>
<td>17</td>
</tr>
<tr>
<td>Mixed mosaic of seagrass and hard coral</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>Mixed mosaic of seagrass and soft coral</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>Mixed mosaic of hard coral, soft coral and algae</td>
<td>3</td>
<td>0.5</td>
</tr>
<tr>
<td>Mixed mosaic of seagrass, hard coral and algae</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Mixed mosaic of seagrass, soft coral and algae</td>
<td>35</td>
<td>28</td>
</tr>
</tbody>
</table>
**Zone of Moderate Impact:** Figure 3.5 presents the cumulative predicted ZoMI in the SAR (i.e. sub-lethal stress or partial mortality with recovery expected within 5 Years) to BPP and Non-BPP. The ZoMI was determined primarily by Minimum Light Requirements (MLR) for seagrass, macroalgae, and coral and sponges. As such, Figure 3.5 presents three ZoMI: worst case (based on threshold for chronic impacts on coral), moderate case (based on chronic impact to seagrasses) and best case (based on acute impacts to seagrasses). The worst case ZoMI is predicted to extend approximately 50 km to the north and 30 km to the south of James Price Point. The southern extent of the worst case ZoMI lies to the north of Willie Creek.

**Zone of Influence:** Figures 3.1 to 3.4 also present (as a dashed black line) the ZoI in the SAR. This boundary is used to indicate the maximum range that the point source discharge modelled may influence water quality. This region is defined as any area where dredging TSS contribution exceeds 5 mg/l for more than 5% of the modelled period. The ZoI extends northward beyond Cape Baskerville, southward to North Cable Beach and approximately 20 km westward from the coast. There are no environmental impacts associated with this zone.
Figure 3.5  Cumulative Predicted Impacts - Zone of High Impact (i.e. Permanent Loss) and Zone of Moderate Impact (i.e. Sub-lethal Stress to Partial Mortality with Recovery Expected within 5 Years) to BPP and Non-BPP (Figure 2.4-5 from Browse LNG Precinct SAR - DSD 2010).
4. DREDGING ASSESSMENT POST SUBMISSION OF SAR

4.1 Introduction

The approach followed to assess the potential direct and indirect impacts generated by dredging and spoil disposal activities due to construction of the proposed Browse LNG Precinct has been revised. A non-exhaustive list of key differences in assumptions, inputs and methodology is provided in Table 4.1.

Table 4.1 Key updates in assumptions, inputs and methodology of revised assessment approach relative to SAR.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Revised Assessment Approach compared to SAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGINEERING INPUTS</td>
<td>(SAR made no inherent assumptions regarding design of facility)</td>
</tr>
<tr>
<td>Design</td>
<td>More matured design for marine facilities and channel alignment</td>
</tr>
<tr>
<td>Dredging Volumes</td>
<td>Revisited from 21 to 34 Mm$^3$ based on more mature design for marine facilities and inclusion of pipelines to establish the 50 Mtpa Browse LNG Precinct</td>
</tr>
<tr>
<td>Duration of Construction of Phase 1 of Foundation Project</td>
<td>Revisited from 12 within 18 to 21 months for Phase 1 based on more mature design of marine facilities</td>
</tr>
<tr>
<td>Geotechnical Data</td>
<td>Greatly increased body of knowledge regarding material to be dredged</td>
</tr>
<tr>
<td>DREDGING BEHAVIOUR</td>
<td>(SAR made no inherent assumptions regarding equipment or methodology.)</td>
</tr>
<tr>
<td>Equipment</td>
<td>Continuous spillage at static locations.</td>
</tr>
<tr>
<td>Methodology</td>
<td>Defined and applied in modelling. SAR made no explicit assumption of equipment</td>
</tr>
<tr>
<td>Equipment Cycling (time)</td>
<td>High level dredging sequence has been defined and applied in modelling</td>
</tr>
<tr>
<td>Equipment Cycling (space)</td>
<td>Work area has been partitioned, with representative dredger movements within each area</td>
</tr>
<tr>
<td>Spill Rates</td>
<td>Defined as a function of equipment, activity, production rate, geotechnical conditions, and previous handling of material</td>
</tr>
<tr>
<td>Weather Downtime</td>
<td>Wave-induced downtime defined by vessel type and applied in modelling</td>
</tr>
<tr>
<td>Cyclone Season Stoppage</td>
<td>Dredge programs tested with and without full stoppage over cyclone season</td>
</tr>
<tr>
<td>MODEL UPDATES</td>
<td></td>
</tr>
<tr>
<td>Simulation Period</td>
<td>The production simulation period has been extended to 21 months, as per the dredging volumes and durations for Phase 1 based on more mature design of marine facilities</td>
</tr>
</tbody>
</table>
Further information concerning the comparison of the assumptions applied in the SAR (as presented in Table 3.1 of Appendix C-13 of the Browse Liquefied Natural Gas Precinct Strategic Assessment Report (DSD 2010)) and those of the revised assessment approach is provided in Table 4.2.

Table 4.2 Comparison of the Inputs applied for the SAR and the Revised Dredging Assessment Approach

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Description – SAR</th>
<th>Description – Revised Assessment Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fines Content</td>
<td>The highest fines content (29%) from the particle size distribution (PSD) samples taken during the preliminary geotechnical program has been used as the basis for modelling. It has been assumed that all material dredged will have a PSD where 29% of sediment has a particle size &lt;63μm. It is likely that a range of sediment types will be encountered throughout the dredging program. This can only be confirmed through an expanded geotechnical program which is currently underway.</td>
<td>Recent PSDs show that the mean fines percentage is approximately 22% which is somewhat lower than the 29% assumed in the SAR. Further, the in situ density of dredged material for the SAR was very conservatively assigned as a uniform dry density of 2650 kg/m³, whereas the measured density has been confirmed to be typically below 2000 kg/m³. As a result, total spillage in terms of mass released into the water column per m³ of excavated material reduces significantly for the revised assessment approach relative to the SAR.</td>
</tr>
<tr>
<td>Modelled Fines Loss</td>
<td>The water quality and sediment transport modelling base case assumed uniform losses equating to 70% of in situ fines, which is the sum of 50% of in situ fines lost to the water column upon initial dredging plus a further 20% of in situ fines lost upon dumping. This equates to a total of 1.45 million cubic metres of fines being lost over a 12 month period. The assumed 50% loss of fines in initial dredging as cited above is considered very conservative; based on previous project experience which suggests losses in the range of 10% to 35% are more likely, depending on the dredge and sediment types involved.</td>
<td>Under the revised assessment approach, spill rates are assigned as a percentage of the given dredger’s production rate, largely based on DHI’s extensive spill monitoring database. However, the effective spill rate by mass into the water column is also a function of the fines content, the density of the material being moved, and the history of that material (specifically, whether a portion of the fines have already washed out in previous steps of the handling process). Once the progressive reduction of fines content is incorporated into this bookkeeping, the net spillage tends to be about 55% of the total volume of the fines present in virgin seabed material excavated, which is somewhat lower than the net 70% of fines assumed in the SAR. This is also a contributing factor to the lower total mass of spilled fines for the revised assessment approach.</td>
</tr>
<tr>
<td>Metocean Conditions</td>
<td>Metocean data selected to drive the hydrodynamic model (May 2008 to April 2009) is considered to represent an abnormally windy year, with three Tropical Cyclones (Billy, Dominic, and Freddy) and one significant tropical low affecting the region between December 2008 and February 2009. Cyclones are common in the region; however, the pattern experienced in 2008/2009 resulted in persistent abnormally high wind speeds along the Dampier Peninsula. For example, the wind speed exceeded 50% of the time between 2004 and 2008 was 3-4m/s and in 2008/2009 it was 12.5m/s. This is likely to have significantly enhanced the spreading characteristics of the plume.</td>
<td>For the revised assessment approach, candidate simulation periods were screened based upon hindcast wave statistics, wind statistics from Broome Airport, and in terms of the number and intensity of tropical cyclones passing within 500 km of the site, in order to confirm that the chosen simulation period is not an outlier. Based upon this analysis, the period of May 2007 – Jan 2009 was chosen as being adequately representative for the simulation of 21-month long revised dredging program. Further comparison (post submission of the SAR) of modelled and measured currents demonstrated that the hydrodynamic model captures the character and directionality of northward-directed tidal residual currents north of James Price Point. However, it matches somewhat less well, the weaker southward residual flow. Tests showed that the introduction of a forcing function from the north, equivalent to an artificial wind component of 5 m/s, onto the existing MesoLAPS wind fields does a reasonably good job of compensating for the apparent model bias in residual flows, showing a near-universal improvement against the available current meter locations once this adjustment is implemented. This wind adjustment has been applied for the Revised</td>
</tr>
</tbody>
</table>
### Discharge Frequency and Rate

The water quality and sediment transport modelling uses a fixed continuous point source discharge over a 12 month period. Sediment losses associated with dredging programs are typically pulsed as a result of regular pauses between loading and dumping. In addition, delays associated with weather, breakdowns, maintenance, and sourcing dredging equipment frequently result in a staggered dredging program.

Pulsing of sediment losses allows periodic dissipation of the plume, which therefore provides periods of relief/recovery for biota.

The SAR did not incorporate weather downtime.

### Zone of Moderate Impact Thresholds

The Zones of Moderate Impact (temporary loss) depicted in Section 6 are considered conservative as they represent a range of conditions under which biota are likely to experience a range of physiological effects, ranging from no effect, through sub-lethal stress, to mortality. The thresholds used to define the outer boundary of these zones have been set at conservative levels based on available literature and previous project experience. The severity of the effect can generally be expected to increase with proximity/exposure to the sediment source. Therefore the likely effect in the area between the point source discharge and the boundary of the zones of moderate impact should not be considered uniform. It should instead be considered as a gradient ranging from no effect at the periphery, through sub lethal stress, to potential mortality closest to the source. For example, the coral zone of moderate impact threshold is set at a level which literature suggests is a likely transition point between no effect and sub-lethal effect. At this stage of assessment, with the data available, it is not possible to subdivide the zones of moderate impact.

Revised impact thresholds by (MScience 2012), for zone of moderate impact were developed for:

- **mixed benthos**: a patchwork of various benthos including sponges, hard corals, soft corals, a variety of other sessile fauna, macroalgae and occasional sparse seagrass, generally with an average cover of 1-10% biota, or 40-70% cover if turf algae are included;
- **seagrass beds**: areas of sandy bottom with 2% to 20% cover of Halophila sp. with few other biota;

The revised thresholds for the zone of moderate impact were revised based on:

- A review of recent literature on the effects of turbidity and sedimentation on hard corals, soft corals, sponges and seagrasses, and thresholds used in recent dredging projects;
- Experiences drawn from monitoring around dredging programs off Western Australia’s Pilbara Region;
- Surveys of the hard coral, soft coral, sponge and seagrass fauna of James Price Point;
- Laboratory-based experiments on the effects of sedimentation on corals and sponges, and light reduction for seagrasses, using species relevant to those identified to occur at James Price Point;
- Analysis of the baseline water quality recorded off James Price Point from November 2010 to June 2011;
- Integration of the above to develop thresholds at intensities and durations relevant to the physiological mechanisms of mortality and stress affected by the impacting processes.

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Note: 1. Extracted from Table 3-1 of Appendix C-13 of the Browse Liquefied Natural Gas Precinct Strategic Assessment Report
4.2 Change in Dredging Volumes

The ongoing FEED for the design of the proposed Browse LNG Precinct Port area marine facilities has resulted in significant advances, which provide a more detailed and relevant range of potential construction sequences for evaluation in the dredging model. As a result of the refinement of the concept design, the total estimated dredging required to establish a 50 Mtpa proposed Browse LNG Precinct, has been revised upwards from 21 to 34 Mm³.

Estimates of the dredging volumes required to establish the various marine infrastructure for the Precinct have increased due to:

- Pre-lay trenching required for the southern and northern export pipelines not quantified in the original estimates
- The width of the access channel has been increased to reduce wave penetration into the port
- Recent geotechnical data has identified that deeper excavations are required for the foundation of main breakwater in order to remove weak underlying materials
- Increased provision for inaccuracy of bathymetry
- Final designs under consideration include shifting the port infrastructure (including the integrated marine facility) further onshore from initial concepts.

4.3 Dredging Behaviour

4.3.1 Infrastructure

The plume modelling presented in the SAR made no inherent assumptions regarding the design of the facility, rather dredging was simulated to occur at a single location within the Port area. Increasing clarity around the design of the Port area marine facility has resulted in a more detailed and relevant range of potential construction sequences for simulation in the dredging model. The following infrastructure/activities are simulated by the model:

- Dredging of outer, mid and inner shipping channel
- Dredging western turning basin and berth pockets
- Dredging eastern turning basin and berth pockets
- Dredging of main breakwater foundation
- Dredging of foundation proponent's integrated marine facility
- Dredging of foundation proponent's tug harbour
- Disposal of dredged material to inner spoil ground.
Figure 4.1 Bathymetry and location of wind, wave and current data used to validate the model.
Table 4.3 provides a comparison of the dredging volumes (by construction phase) for the original 21 Mm$^3$ and proposed 34 Mm$^3$ scenarios.

### Table 4.3 Comparison of dredging volumes (by construction phase) considered for the SAR and the revised assessment approach.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SAR (Mm$^3$) Preliminary 25 Mtpa</th>
<th>SAR (Mm$^3$) Preliminary 50 Mtpa</th>
<th>Revised Phase 1 (to 12 Mtpa) (Foundation Project)</th>
<th>Revised Phase 2 (to 25 Mtpa)</th>
<th>Revised Phase 3 (to 50 Mtpa)</th>
<th>Revised Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipping Channel</td>
<td>Included below</td>
<td>Included below</td>
<td>3.5</td>
<td>0</td>
<td>0</td>
<td>3.5</td>
</tr>
<tr>
<td>Turning Basin &amp; Berth Pockets</td>
<td>12</td>
<td>17.5</td>
<td>9.2</td>
<td>0</td>
<td>4.1</td>
<td>13.3</td>
</tr>
<tr>
<td>IMF</td>
<td>3.5</td>
<td>3.5</td>
<td>7.2</td>
<td>0</td>
<td>1</td>
<td>8.2</td>
</tr>
<tr>
<td>Breakwaters</td>
<td>Not included in calculation</td>
<td>Not included in calculation</td>
<td>1</td>
<td>0.5</td>
<td>1.5</td>
<td>3</td>
</tr>
<tr>
<td>Pipeline trenching</td>
<td>Not included in calculation (3)</td>
<td>Not included in calculation (6)</td>
<td>1.5</td>
<td>1.5</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>TOTAL</td>
<td>15.5</td>
<td>21</td>
<td>22.4</td>
<td>2</td>
<td>9.6</td>
<td>34</td>
</tr>
</tbody>
</table>

The actual dredging volumes that were modelled for the SAR and the revised assessment approach are compared in Table 4.4. The SAR considered an indicative dredging program, consisting of 10 Mm$^3$ of continuous dredging from a point source within the turning basin of the Port area for a 12 month period. The revised assessment approach, which represents an upper bound on likely dredging volume and construction time for the Phase 1 simulated the continuous dredging and disposal of 21 Mm$^3$. As discussed further below, dredging of the southern corridor was not included in the modelling.

### Table 4.4 Comparison of dredging volumes and spillage for the SAR and Revised Assessment Approach.

<table>
<thead>
<tr>
<th>Browse LNG Project</th>
<th>Dredge Volume (Mm$^3$) considered in modelling assessment</th>
<th>Duration (months)</th>
<th>Total Spillage of Fines by in situ volume (Mm$^3$)</th>
<th>by mass (Mton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAR</td>
<td>10</td>
<td>12</td>
<td>2.0</td>
<td>5.4</td>
</tr>
<tr>
<td>Revised Assessment Approach</td>
<td>21</td>
<td>21</td>
<td>2.8</td>
<td>5.1</td>
</tr>
</tbody>
</table>

The pipeline dredging for the southern (Phase 1 and 2) and northern (Phase 3) export pipelines has not been included in the modelling. The increased clarity around the Port area layout and dredging methodology has not extended to the trenching required to lay the northern or southern export pipelines. The maximum total dredging required to establish the northern and southern export pipelines is estimated to be 6 Mm$^3$ of the 34 Mm$^3$ necessary to establish the 50 Mtpa proposed Browse LNG Precinct. It is noted that the anticipated temporal separation for the three phases will mean that it is unlikely that any Phase 2 or Phase 3 dredging works will occur during Phase 1. It is also unlikely that the dredging for the export pipelines in Phase 1 will occur at the same time as that for the multi-user infrastructure. If it were to occur concurrently, it is anticipated that the spillage from
the pipeline trenching will make a minor contribution to the sediment plume and its sedimentation, and that the mean daily TSS signals would be lost within the plume generated by dredging associated with the establishing the multi-user port facility. However, as discussed below (Section 4.6.1), the northern and southern corridors have been included in the calculation of direct losses which constitute the ZoHI.

The vast majority of spillage will be associated with the construction of the multi-user facilities by the foundation project during Phase 1. This dredging is estimated to be of the order of 21 Mm³ over a 21 month continuous duration. Only incremental dredging (excluding pipeline trenching) will be required subsequent to the establishment of the multi-user infrastructure, including 0.5 Mm³ for an additional breakwater during Phase 2 and another 6.6 Mm³ by the second proponent during Phase 3. These dredging activities will be contained within the Phase 1 dredging footprint and therefore the areal extent of the ZoHI will not be impacted by this additional dredging. Furthermore, it is not unreasonable to expect that given the relative dredging volumes, the ZoMI and ZoI associated with the Phase 2 and Phase 3 dredging campaigns will also be contained with the corresponding Phase 1 zones. The anticipated temporal separation of the three Phases will mean that it is unlikely that any Phase 2 or Phase 3 dredging activities will occur during Phase 1. It is therefore considered that the zones of high impact, moderate impact and influence generated by Phase 1 dredging activities encompass any subsequent zones due to the minimum dredging requirement for Phase 2 or Phase 3 activities. The only exception to this is the dredging associated with laying the export pipelines the northern and southern corridors. These activities have been included in the ZoHI.

It is assumed that the overburden will be primarily removed with a trailer suction hopper dredge (TSHD) and that hard material (limestone) will be cut with a cutter suction dredge (CSD), deposited to seabed and rehandled with a TSHD. A back hoe dredge (BHD) (with attendant barges) is assumed to be used for difficult to reach areas. The full 21 month long detailed representative dredging programme is simulated. Given the inherent variability in the ultimate dredging programme (based on equipment availability, phasing of various work packages, weather, etc), pre-dredging bathymetry is considered throughout the 21 months. It is recognised that the dredging will alter the bathymetry, however, modelling the spillage using the pre-construction bathymetry is the most universally conservative option. The presence of breakwaters and deeper dredged areas will tend to enhance deposition within the port footprint (as opposed to spreading beyond precinct boundaries) and reduce re-suspension, and will in general reduce dredging impacts.

4.3.2 Equipment

No intrinsic assumptions regarding dredging equipment or methodology were made for the SAR dredging assessment. In contrast, the equipment assumed to be brought to bear in the revised approach has now been defined. It is anticipated that the following equipment will move the vast majority of marine material:

- 1 medium to large cutter suction dredger (CSD)
- 1 medium trailer suction hopper dredger (TSHD)
- 1 medium to large backhoe dredger (BHD)

A net production rate has been assigned to each of the above vessels based upon their production rate when actively dredging, and accounting for typical downtime intervals for scheduled maintenance, changing of CSD teeth, bunkering, etc.
4.3.3 Methodology

The CSD will be used primarily for crushing coastal limestone, and for cutting into shallow areas inaccessible to the TSHD. Material crushed by the CSD will be either barge loaded or deposited to the seabed and rehandled by the TSHD. The BHD will work side slopes and small inshore features difficult to access for the other vessels, and will load to attending barges. One or both of two candidate spoil grounds in Commonwealth waters, namely the Inner (roughly 8 km from shore) and Outer (roughly 30 km from shore) will be utilised.

Other details of the construction methodology under consideration (and assumed in the modelling) are Commercial-in-Confidence under the ongoing dual FEED activities.

4.3.4 Equipment Cycling (time)

The primary simulations executed under the SAR considered static, continuous sources intended to be representative of spilled material.

Under the revised assessment approach, each vessel and if relevant its attending barge, are assigned a cycling time based on its respective activities. For the TSHD and barges this accounts for loading time, as well as sailing time to/from the relevant spoil ground and dumping time. For a CSD pumping to the seabed, the source is largely continuous with the exception of scheduled downtime.

4.3.5 Equipment Cycling (space)

Under the revised assessment approach, a linear path representative of each vessel’s spillage is assigned within each subarea of the worksite where that vessel is anticipated to work. These movements are intended to be representative, as very detailed movements (“mowing the lawn”) are not justifiable given that the achieved movements of vessels in the actual construction will inevitably differ. However, the level of detail in terms of dredging movements is a notable increase in realism relative to the assumptions of the SAR.

4.3.6 Spill Rates

For the modelling presented in the SAR, spill rates were calculated assuming uniform losses equating to 50% of in situ fines upon initial dredging, which would also incorporate rehandling if any, and a further 20% of in situ fines upon dumping.

Under the revised assessment approach, spill rates are assigned as a percentage of the given dredger’s production rate, largely based on the modeller’s interrogation of an extensive spill monitoring database. However, the effective spill rate by mass into the water column is also a function of the fines content, the density of the material being moved, and the history of that material (specifically, whether a portion of the fines have already washed out in previous steps of the handling process). Once the progressive reduction of fines content is incorporated into this bookkeeping, the net spillage tends to be somewhat lower than the net 70% of fines assumed in the SAR. This is also a contributing factor to the lower total mass of spilled fines for the revised approach seen in Table 4.4.

4.3.7 Geotechnical

Very little information was available to support the SAR in terms of characterization of the material to be dredged, as well as the extent of dredging required for the shipping channel and major structures. The SAR assumed a constant fines content of 29%, based upon sampled particle size distributions (PSDs) from a terrestrial borehole at the site.
Now, marine geotechnical boreholes are now well distributed within the proposed dredging area and a clearer understanding of geotechnical conditions exists. For the revised assessment approach, geotechnical baseline data is sufficient to support estimates of the relative content of pindan sand, marine sand, and coastal limestone units within partitioned areas of the worksite. Further, an indicative PSD curve has been identified for each of the geological units. As a result, a weighted PSD of spillage material is assigned for dredging tasks operating within each partitioned area of the worksite. The largest uncertainty in this regard relates to the cutting of the coastal limestone unit, the character of which is known to be highly variable at the site. In advance of construction, a conservative approach to its character in terms of fines percentage and PSD after being cut has been employed.

It is interesting, and relevant, to note that the total amount of spilled mass in Table 4.4 is less for the revised approach than for the SAR. While this appears counterintuitive given the larger dredging volumes being assessed, this is in large part due to conservative geotechnical assumptions in the SAR which have since been revised in the light of more data. Recent PSDs show that the mean fines percentage is somewhat lower than the 29% assumed in the SAR. Further, the in situ density of dredged material for the SAR was conservatively assigned as a uniform dry density of 2650 kg/m³, whereas the measured density has been confirmed to be typically below 2000 kg/m³. As a result, total spillage in terms of mass released into the water column per m³ of excavated material reduces significantly for the revised assessment approach relative to the SAR.

4.3.8 Weather Downtime

The modelling conducted for the SAR did not incorporate weather downtime. This assumption can be overly conservative during energetic events which resuspend previously deposited material and/or inhibit deposition of new material. If a given sea state exceeds that at which a given vessel will typically operate, it is unrealistic to add new spillage to the water column during the passage of such events. It is also critical to incorporate weather downtime, as this can result in a significant reduction in the total number of viable operating days per year on site for some equipment.

Weather induced downtime has been applied in the revised assessment approach in terms of a simple on/off threshold for each vessel, triggered by a hindcast significant wave height just offshore of the work area.

4.3.9 Cyclone Season Stoppage

The SAR simulated 12 months of dredging within an 18 month period. The increase in total dredged volume for the 50 Mtpa proposed Browse LNG Precinct to 34 Mm³ will result in a subsequent increase in duration of the dredging of the revised Phase 1 Foundation Project to 21 months. Currently, dredging operations are assumed to occur throughout the year, however, dredging activities will cease prior to the passage of cyclones, with the dredgers and various support vessels sailing to safer waters. Operations during the summer are complicated not only due to cyclone passages, which carry risks of attendant downtime as well as limited evacuation options for equipment from a remote worksite, but also due to seasonally elevated wave-induced downtime under non-cyclonic conditions.

4.4 Model Updates

4.4.1 General

Extensive updates have been made to the plume dispersion models subsequent to the submission of the SAR. A summary of key improvements is provided in the following sections.
4.4.2 Simulation Period

The SAR dredging assessment featured a 12 month production simulation covering the period of May 2008 – April 2009, inclusive, which was chosen in large part based upon overlap with DSD’s Acoustic Wave and Current (AWAC) measurement campaign ongoing during this period.

For the revised assessment approach, candidate simulation periods were screened based upon hindcast wave statistics, wind statistics from Broome Airport, and in terms of the number and intensity of tropical cyclones passing within 500 km of the site, in order to confirm that the chosen simulation period is not an outlier. Based upon this analysis, the period of May 2007 – Jan 2009 was chosen as being representative for the simulation of 21-month long dredging program.

4.4.3 Computational Mesh

The revised assessment approach utilizes the same model extent as the SAR, however, the mesh resolution has been significantly enhanced around James Price Point. Identical meshes are applied for all of the wave, flow and dredging models.

The baseline bathymetric data for the area is sparse and at times conflicting. A high resolution Laser Airborne Depth Survey was undertaken in the nearshore area around James Price Point. This data was supplemented with Geoscience Australia bathymetry data (with 250 m grid point centres) and that from the CMAP global digital charting database to create a regional bathymetry dataset.

There are significant differences between the Geosciences Australia data and that in published charting, with the former showing a circular shaped deep region near the opening of Roebuck Bay. In contrast, AUS50 shows a narrower, and deeper (maximum depth of 100 m CD on the detailed AUS51), scoured channel oriented roughly perpendicular to the alignment of Cable Beach. Sensitivity tests conducted in the context of modelled residual flows, demonstrated that the two geometries showed a comparable response in terms of residual flow behaviour on the open coast between Broome and James Price Point.

4.4.4 Wave Model

Numerous improvements have been made to the MIKE21 SW wave model subsequent to the submission of the SAR, and the degree of model validation against measured field data has also increased dramatically.

The model is executed in a fully spectral, quasi-stationary formulation with 27 frequencies and 32 directions. Notable updates post assessment of the SAR, include:

- The SAR wave model applied only bulk spectral parameters from RPS hindcast, and as a result was challenged by bi-model sea conditions. The revised model applies fully spectral, spatially varying boundary data from RPS hindcast.

- The SAR model did not incorporate wind forcing. The revised model applies time and spatially varying SatOcean wind fields.

- The SAR wave model was validated against a single measured record over a period of several weeks. The revised wave model was subsequently successfully validated against:
  - Hs and Tp (total, sea, swell) from AWACs pressure series, utilizing all measurements available
  - Hs and Tp (total, sea, swell) from AWACs AST series, utilizing all data available
Wave conditions off of James Price Point are frequently bi-modal, under which conditions the AWAC instruments can produce biased measured directions (visible in Figure 4.1). As such, the validation also incorporated a statistical comparison of the modelled directions vs. a directional waverider buoy from the 2010 Fugro metocean campaign.

4.4.5 Hydrodynamic Model

Numerous improvements have also been made to the MIKE21 FMHD hydrodynamic model subsequent to the submission of the SAR, as well as expanding the datasets against which the model has been validated. Notable updates post assessment of the SAR, include:

- The SAR model was forced directly by boundary levels extracted from the KMS global tidal model. The local hydrodynamic model is now forced by a regional MIKE21 FMHD model, rather than directly from the coarse global tidal model. This results in improved boundary behaviour with minimal artificial circulation.

- Extensive calibration against on-site current and water level measurements. Locations of measurements are shown in Figure 4.1.

- Extensive comparisons against on-site measurements to assess the model’s ability to simulate nearshore residual currents.

The model calibrates well for tidal levels and flows. As per the SAR, the model is also forced by time- and spatially-varying MesoLAPS wind fields. There is no other non-tidal forcing in the model.

Complex shore-parallel residual flows have been identified in recent current meter measurements within the study area. An extensive effort has been made to interrogate existing measurements to identify residual currents in the study area. A summary of the measurements used is provided in Table 4.5, along with the northward component of the residual current (in m/s with positives denoting flow toward north). Several issues are noted:

- The start/end dates for the instrument deployments are provided, which are not uniform. The values within Table 4.5 thus represent differences in both time and space.

- Persistent northward-directed residuals are seen to be present between James Price Point and the Lacepede Islands. The model consistently shows this feature, which is a tidally forced residual.

- The two stations most representative of the project site (JPP Inshore and JPP3-1) are the only records which capture a full year. Both indicate a southward-directed residual flow on the order of 1-2 cm/s. The JPP Offshore location also shows a southward residual.

- As per most of the stations shown in Table 4.5, JPP Inshore is a current profiling instrument. However, the adjacent JPP3-1 is a single point current meter. Both show similar behaviour, reducing the possibility that the residual current results from instrument bias.

- The groups of stations to the far north and far south of the study area show conflicting trends in residual current direction.

Table 4.5 also shows comparisons of simulated residual currents as extracted from the model. The rightmost columns of Table 4.5 consist of model output which was interrogated from the physical location and time coverage identical to the associated instrument deployment. Results in the ‘unadjusted’ model column are extracted directly from the model as validated, which includes met
forcing by MesoLAPS fields. The grey shaded cells in the table denote the mean bias of the model vs. all measurements. It is seen that the ‘unadjusted’ model shows a mean bias of 2 cm/s northward relative to the respective instruments. This is also borne out at James Price Point itself, where the model predicts a small net northward drift while the instruments suggest a small southward drift.

The rightmost column indicates results from the model following the superposition of an additional forcing function onto the MesoLAPS wind fields, comparable to an additional 5 m/s wind component from the north, which effectively induces a southward drift to the validated model. The table shows that this results in a reversal of the net residual direction at James Price Point, which is an improved alignment with that observed in measurements. Further, the mean bias of the model across all stations is reduced from 2 cm/s to effectively zero.

The behaviour of the abovementioned wind adjustment has been subsequently supported by the observed movements of a drogue released in mid-February 2012 offshore from James Price Point, which eventually beached south of Roebuck Bay following a prevailing southward drift over the course of several weeks. The path of the drogue is shown in Figure 4.2.

In summary, the hydrodynamic model is seen to capture the character and directionality of northward-directed tidal residual currents north of James Price Point as confirmed by measurements. However, it matches somewhat less well for the weaker residual flows measured in close proximity to James Price Point which measurements suggest to be directed southwards. Overall, the model tends to show a small northward bias compared to the measured residuals. Tests have shown that the introduction of a forcing function from the north, equivalent to an artificial wind component of 5 m/s, onto the existing MesoLAPS wind fields does a reasonably good job of compensating for the apparent model bias in residual flows, showing a near-universal improvement against the available current meter locations once this adjustment is implemented. This wind adjustment has been retained as an interim tool for inducing residual flows in the model for assessing dredging plume behaviour. However, it should be emphasized that the handling of residual currents is an ongoing activity and the information presented here does not necessarily represent a final view on the topic.

These flows have been confirmed to have significant effects on the fate of dredging plumes and the resulting impact footprint.

Table 4.5 Summary of measured data interrogated in the assessment of residual currents at the site, as well as comparisons of measured residuals against those generated by the model. Stations are sorted from north to south. (See Figure 4.1 for instrument locations.)

<table>
<thead>
<tr>
<th>Measurement Station</th>
<th>Start of Measured Data</th>
<th>End of Measured Data</th>
<th>MEASURED</th>
<th>DERIVED LOCAL MODEL, unadjusted</th>
<th>DERIVED LOCAL MODEL 5m/s wind from N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fugro Station B05-3A</td>
<td>13/Dec/2009</td>
<td>27/Mar/2010</td>
<td>0.003</td>
<td>0.025</td>
<td>0.013</td>
</tr>
<tr>
<td>Pender Bay Offshore</td>
<td>29/Jul/2009</td>
<td>12/Nov/2008</td>
<td>-0.008</td>
<td>0.006</td>
<td>-0.003</td>
</tr>
<tr>
<td>Pender Bay Inshore</td>
<td>29/Jul/2009</td>
<td>12/Nov/2008</td>
<td>-0.010</td>
<td>0.010</td>
<td>-0.002</td>
</tr>
<tr>
<td>Perpendicular Head Inshore</td>
<td>29/Jul/2008</td>
<td>11/Nov/2008</td>
<td>0.003</td>
<td>0.003</td>
<td>-0.005</td>
</tr>
<tr>
<td>S. Laccopede Inshore</td>
<td>06/Feb/2009</td>
<td>10/May/2009</td>
<td>0.032</td>
<td>0.050</td>
<td>0.033</td>
</tr>
<tr>
<td>Cape Berthollet</td>
<td>06/Feb/2009</td>
<td>16/Aug/2009</td>
<td>0.015</td>
<td>0.051</td>
<td>0.026</td>
</tr>
<tr>
<td>JPP Inshore</td>
<td>28/Jul/2008</td>
<td>07/Aug/2009</td>
<td>-0.033</td>
<td>0.016</td>
<td>-0.011</td>
</tr>
<tr>
<td>Fugro Station JPP3-1</td>
<td>17/Dec/2009</td>
<td>06/Dec/2010</td>
<td>-0.013</td>
<td>0.019</td>
<td>-0.010</td>
</tr>
<tr>
<td>JPP Offshore</td>
<td>06/Feb/2009</td>
<td>10/May/2009</td>
<td>-0.033</td>
<td>0.023</td>
<td>-0.051</td>
</tr>
<tr>
<td>Cape Lietrelle</td>
<td>12/Jan/2009</td>
<td>07/Aug/2009</td>
<td>0.004</td>
<td>0.012</td>
<td>-0.005</td>
</tr>
<tr>
<td>Sordon Bay Offshore</td>
<td>28/Jul/2008</td>
<td>10/Nov/2008</td>
<td>-0.018</td>
<td>0.005</td>
<td>-0.025</td>
</tr>
<tr>
<td>Sordon Bay Inshore</td>
<td>28/Jul/2008</td>
<td>10/Nov/2008</td>
<td>0.009</td>
<td>0.040</td>
<td>0.007</td>
</tr>
</tbody>
</table>
Figure 4.2 Trajectory of drogue released offshore of James Price Point in February to March 2012, showing prevailing southward drift.
4.4.6 Dredging Model

The post assessment of the SAR updates to the proposed Browse LNG Precinct engineering, dredging behaviour, and updates to the forcing models described above all influence the output of the revised assessment dredging model. Several key refinements have also been made to the dredging model itself:

- The SAR model incorporated a reasonably high dispersion value, given that one stationary dredge and one stationary spill source is used to represent spillage which will in practice occur over a wide area by moving sources. A less dispersive, higher order formulation has been applied in the revised model, which is appropriate in combination with detailed descriptions of dredger movements and task-specific spillage.

- A series of indicative re-suspension tests were performed in the revised dredging model versus the array of turbidity meters deployed around James Price Point by MScience. This comparison led to the changes in the applied wave/current shear stress formulation applied in the model in order to improve the model response to energetic wave events.

Other key assumptions applied in the SAR model have been maintained (DHI, 2012). Both models describe spilled sediment only, in the absence of ambient processes. Both conservatively neglect flocculation, due to the high content of calcareous material which is generally not conducive to flocculation. Given the highly variable character of the spillage, the long term simulations, and the omission of ambient material, and lack of data to describe the long-term behaviour of spillage, the bed description is described simply as a single layer without consolidation.

4.5 Thresholds

Dredging impact thresholds have been studied in detail by MScience (2012), and have been updated subsequent to the SAR reporting and are aligned with Environment Assessment Guideline No. 7 (EAG7) (Environment Assessment Guideline for Marine Dredging Proposals) (EPA 2011). The revised thresholds are shown in Table 4.6.

Table 4.6 Relevant impact thresholds for the Revised Assessment Approach, as described by MScience (2012).

<table>
<thead>
<tr>
<th>Category</th>
<th>Threshold</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone of Influence (ZoI)</td>
<td>TSS &gt; 5 mg/L for 5% of dredging campaign</td>
<td>All areas, entire year</td>
</tr>
<tr>
<td>Zone of Moderate Impact (ZoMI)*</td>
<td>Mean sedimentation &gt; 84 mg/cm2/d over a rolling 84 day period</td>
<td>Mixed benthos: Areas &lt; 14 m, entire year</td>
</tr>
<tr>
<td></td>
<td>Median daily TSS &gt; ([(234/z)^f-3.4]) for 30 days in any 36 day period</td>
<td>Seagrass: Areas &lt; 25 m, Apr-Nov</td>
</tr>
<tr>
<td>Zone of High Impact (ZoHI)</td>
<td>Direct dredging footprint plus 1000 m buffer or Direct dredging footprint plus 500 m buffer</td>
<td>All areas, entire year</td>
</tr>
</tbody>
</table>

Notes:
- z = depth in metres, for depths
- “<” means “shallower than”
- f = seasonal correction factor of Table 25
- * occurs where either threshold is exceeded
4.6 Impact Assessment

4.6.1 Zone of High Impact

Figure 4.3 shows the ZoHI map due to dredging of up to 34 Mm$^3$ of material required to establish the ultimate 50 Mtpa proposed Browse LNG Precinct. The ZoHI presented in Figure 4.3 has not been estimated from the modelling results, rather it has been calculated from the summation of:

- The area beneath the dredge footprint, and
- The area adjacent to dredging activities where smothering by fine sediment would result in permanent alteration of substrate preventing recovery/recolonisation.

Increased clarity concerning the final configuration and location of the Port area marine facilities, combined with improved knowledge of the bathymetry has lead to a more accurate estimate of the dredging footprint and the dredging volume. This in turn has enabled the loss of BPPH to be estimated from the actual dredging footprint, generating a more accurate estimate. As such, the ZoHI has been estimated from the following infrastructure/activities:

- Actual footprint associated with the Port area marine facilities for proposed 50 Mtpa Browse LNG Precinct
- Actual footprint of dredging activities to establish shipping channel, turning basins etc for a 50 Mtpa proposed Browse LNG Precinct
- Pipeline trenching associated with the southern pipeline
- Pipeline trenching associated with the northern pipeline corridor
- Separate allowances of 1000 m and 500 m from each dredging activity (other than pipeline trenching) to accommodate for smothering losses due to high sedimentation. The 1000 m permanent loss allowance provides consistency with the SAR, while the 500 m allowance represents the more realistic case based on improved geotech data and engineering design.
- An allowance of 500 m from the centreline of any pipeline in each of the northern and southern corridors.

As part of the refinement of the Port area design, and based on additional metocean data, the shipping channel has been shifted from the south-east/north-west alignment considered in the SAR, to an east-west alignment. The ZoHI presented in Figure 4.3 considers this revised alignment and includes both the 500 m and 1000 m buffers described above.

As discussed in Section 2, an expanded and more detailed numerical modelling study of potential impacts due to dredging activities in connection with the proposed Browse LNG Precinct have since been undertaken. The design which has been refined by ongoing Front End Engineering Design (FEED) activities, reliable seabed geotechnical, metocean and bathymetric data and from a more detailed description of the dredging operations anticipated for the construction of the marine facility have provided confidence that the ZoHI will not extend more than 500 m from any marine infrastructure.
Figure 4.3   Zone of High Impact (ZoHI) for the Port area marine facilities including the northern and southern export pipelines for the 50 Mtpa Browse LNG Precinct.
The extent of BPPH and the percentage loss of the various types for the relevant Local Area Unit (LAU) are presented in Table 4.7 for the revised channel alignment and an increase in dredging volumes from 21 Mm$^3$ to 34 Mm$^3$ for the 50 Mtpa proposed Browse LNG Precinct.

**Table 4.7 Estimated revised loss calculation of BPPH in the relevant Local Area Unit for revised channel alignment and increase in dredging volumes (including 1000 m and 500 m buffer) from 21 Mm$^3$ to 34 Mm$^3$ for the 50 Mtpa Browse LNG Precinct.**

<table>
<thead>
<tr>
<th>BPPH Category</th>
<th>LAU (ha)</th>
<th>Loss of BPPH (ha)</th>
<th>Revised Channel Alignment and Increased Dredging Volumes</th>
<th>Revised Channel Alignment and Increased Dredging Volumes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1000 m buffer</td>
<td>500 m buffer</td>
</tr>
<tr>
<td>Total BPPH</td>
<td>3314</td>
<td>1026</td>
<td>891</td>
<td></td>
</tr>
<tr>
<td>Intertidal mosaic of coral, algae and filter feeders</td>
<td>372</td>
<td>95</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>Macroalgae only</td>
<td>1707</td>
<td>528</td>
<td>484</td>
<td></td>
</tr>
<tr>
<td>Hard coral only</td>
<td>7</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Soft coral only</td>
<td>115</td>
<td>33</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Seagrass only</td>
<td>514</td>
<td>210</td>
<td>171</td>
<td></td>
</tr>
<tr>
<td>Mixed mosaic of hard coral and algae</td>
<td>270</td>
<td>72</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>Mixed mosaic of hard coral and soft coral</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Mixed mosaic of soft coral and algae</td>
<td>127</td>
<td>31</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>Mixed mosaic of seagrass and algae</td>
<td>143</td>
<td>16</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Mixed mosaic of seagrass and hard coral</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Mixed mosaic of seagrass and soft coral</td>
<td>14</td>
<td>11</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Mixed mosaic of hard coral, soft coral and algae</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Mixed mosaic of seagrass, hard coral and algae</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Mixed mosaic of seagrass, soft coral and algae</td>
<td>35</td>
<td>28</td>
<td>28</td>
<td></td>
</tr>
</tbody>
</table>
4.6.2 Zone of Moderate Impact

Preliminary results from the revised assessment approach for an ultimate dredging volume of 34 Mm$^3$ in terms of impact maps of the ZoMI based on the thresholds presented in Table 4.6 are presented in Figure 4.4. Two permutations are presented for the ZoMI based on the residual currents in the project area: one "unadjusted" (orange shaded area) which trends slightly northward and one "southward residual" (purple shaded area) which features an imposed wind from the north to generate a slight southward drift.

The ZoMI presented in Figure 4.4 has been estimated from modelling the following infrastructure/activities for the Foundation Project (Phase 1):

- Dredging of shipping channel by foundation proponent
- Dredging turning basins and berth pockets by foundation proponent
- Dredging of main breakwater foundation by foundation proponent
- Dredging of foundation proponent’s integrated marine facility
- Dredging of foundation proponent’s tug harbour
- Disposal of dredged material to inner spoil ground.

Also shown in Figure 4.4 are the overlays of the three zones of moderate impact as presented in Figure 2.4-5, Browse Liquefied Natural Gas Precinct – Strategic Assessment Report Part 3: Environmental Assessment – Marine Impacts (DSD 2010).

The modelled scenario without a regional flow indicates that the ZoMI is centred on areas of significant dredging activity associated with the turning basin, berth pockets and integrated marine facility as well as at the spoil grounds. Figure 4.5 presents the combined two ZoMI scenarios (with and without the regional flow). Spillage from dredging of the outer shipping channel and disposal at the inner spoil grounds does not trigger either the sedimentation or TSS threshold value. It is anticipated that this is largely due to the material being dredged changing over the channel length and width, changing from high fines mid channel to low fines material in the outer channel (drilling of additional geotechnical boreholes may provide greater certainty on this). Depth is also a key consideration for not triggering the thresholds for the inner spoil ground, hence the predicted impacts do not contribute to the ZoMI. Given that the dredging methodology will continue to be refined, professional judgement has been applied to the unadjusted ZoMI which has been expanded to encompass, as a minimum, the zone of high impact. This is not an unrealistic approach, given the natural variation in metocean conditions and the intuitive logic that the zone of moderate impact should include the high impact areas.

The predicted southern extent of the ZoMI (with regional flow) approaches the entrance of Barred Creek but is not predicted to enter the creek system (Figure 4.6). The deep channel at the mouth of Barred Creek, together with the visible plume to the south, suggests that under natural conditions this creek system experiences large tidal movements with resultant mobilisation of sediment from the creek.

The modelled scenario with regional flow indicates that spillage from dredging the channel and disposal at the spoil ground do not contribute to the ZoMI, with only the areas of high dredging activity in the turning basin and the IMF contributing. It is anticipated that this is due to the southerly current advecting the dredge plume out of the spill area before either the sedimentation or mean daily TSS threshold is triggered (2 cm/s equals 1.7 km net drift per day so after 30 days the components of dredge material may have moved approximately 51 km).
Figure 4.4 Zone of Moderate Impact (ZoMI) for Phase 1 unadjusted model (left) and imposed southward residual current (right). Overlay shows three predicted ZoMI areas as presented in the SAR (Figure 2.4-5) (DSD 2010).
Figure 4.5 Combined of Zone of Moderate Impact (ZoMI) for Phase 1 unadjusted model and imposed southward residual current. Predicted infill of ZoMI with overlay of the three predicted ZoMI areas as presented in the SAR (Figure 2.4-5) (DSD 2010).
Figure 4.6  Barred Creek entrance, showing the extent of the Zone of Moderate Impact (ZoMI) with addition of imposed southward residual current.
4.6.3 Zone of Influence

Preliminary results for an ultimate dredging volume of 34 Mm$^3$ in terms of impact maps of the ZoI as per Table 4.6 are presented in Figure 4.7. Two permutations are presented for the ZoI maps based on the residual currents in the project area: one “unadjusted” which trends slightly northward, and one “southward residual” which features an imposed wind from the north to generate a slight southward drift. The figure includes an overlay indicating the ZoI as presented in the SAR. The ZoI is calculated using the 21 continuous months of operations.

The ZoI presented in Figure 4.7 has been estimated from modelling of the following infrastructure/activities for the Foundation Project (Phase 1):

- Dredging of shipping channel by foundation proponent
- Dredging turning basins and berth pockets by foundation proponent
- Dredging of main breakwater foundation
- Dredging of foundation proponent’s integrated marine facility
- Dredging of foundation proponent’s tug harbour
- Disposal of dredged material to inner spoil ground.

As depicted in Figure 4.7, the imposition of a residual southward flowing current causes the predicted ZoI for the increased dredging volume to avoid Roebuck Bay, rather travelling past Gantheaume Pt and terminating just south of Broome.

As discussed above (Section 4.4.3) the high resolution bathymetric data used in the transport models maps a “hole” offshore from Gantheaume Pt and lower resolution maps (AUS50/AUS51) show the feature as being narrower and deeper. It is possible that the model does not predict a visible plume entering Roebuck Bay due to a mathematical artefact generated by this bathymetric “hole”. As the plume is transported into the deeper water of the “hole” it is mathematically diluted and the TSS concentration falls below the ZoI threshold of 5 mg/l. The modelled depth-averaged spring tidal currents in the deep region predicted by the present model are on the order of 0.4 m/s. In contrast, indicative speeds within the deeper and more confined channel are shown as 3-4 knots (1.5-2 m/s) on Chart AUS51 in the vicinity of Riddell Point. It is likely that the exchange of water in/out of Roebuck Bay generates a shear flow which will act on a sediment plume. The mixing from this mechanism provides significant dispersive capacity which will act to dilute the plume, and so the dispersive capacity of the deeper, higher energy channel shown on AUS50/AUS51 is expected to increase the effectiveness of dilution from the shear flow mechanism. As such we would not expect significant changes to the reported ZoI if the charted bathymetry were introduced into the model. The significance of this issue will be addressed in full as part of the Derived Referral.

If the plume is transported into Roebuck Bay, TSS concentrations will be below that required to generate environmental impacts. However, the plume may affect the visual amenity of the Bay. The exceedance contours presented in Figure 4.8 suggest that the plume will be offshore of Gantheaume Pt for approximately 10 to 20% of the dredging period. Therefore, if the plume were to be transported into Roebuck Bay, it will occur at a frequency (ie) consistent with that received at Gantheaume Pt (i.e. 10 to 20% of the time).

The ZoI predicted for the plume generated by 21 Mm$^3$ of dredging for the SAR includes Barred Creek, Willie Creek to the south and Cape Baskerville to the north. The revised assessment with the unadjusted dredge model for the 34 Mm$^3$ of dredging shows the ZoI reaching further north to Beagle Bay. The exceedance contours presented in Figure 4.8 indicate that a ZoI plume will be visible
offshore of Willie Creek for up to 90% of the dredging duration. However, the predicted TSS concentrations do not exceed the mean sedimentation or median daily TSS thresholds and therefore it is not anticipated that there will be an environmental impact at these locations (i.e. both Willie Creek and Barred Creek are predicted to fall outside of the Zone of Moderate Impact; Figure 4.6).

The model has not been defined specifically to represent the behaviour or exchange at what effectively are the boundaries of the modelling domain, although it is useful for determining the plume movement past these areas. The modelling for Willie Creek will have overestimated its surface area, volume and inlet mouth (which is approximately 400 m), while Barred Creek is too small to appear on the model and its southward facing inlet is approximately 120 m wide. However it is still possible to deduce the likelihood of impacts of a dredge plume on these creek systems and the biota contained within them.

Time series plots (utilising an induced southern drift) indicate that TSS concentrations are predicted to be generally higher at Barred Creek than Willie Creek (Figure 4.13; note there are two TSS scales shown for each location). This is to be expected, given the closer proximity of Barred Creek to the dredging activities. Non-cyclonic peak concentrations at Barred Creek are of the order of 100 mg/l, while at the mouth of Willie Creek, TSS concentrations peak at about 80 mg/l (Figure 4.13). Average predicted values of TSS at the mouth of both creeks during the dredging campaign (May 2007 – January 2009) were 34.4 mg/l at Barred Creek and 19.3 mg/l at Willie Creek. Being tidally dominated tropical creek systems, these areas are subjected to complex relationships between hydrodynamic conditions, geomorphology and local sediment transport (Bryce et al. 2003). Such dynamics are likely to result in regular sediment resuspension and deposition within the creek system.

It is acknowledged that there is a paucity of information on benthic habitats within both creek systems, although isolated *Halophila ovalis* patches have been reported by Walker and Prince (1987) in Barred Creek – note that Prince (1986) regarded the species as *H. uninervis* - in some rocky terraces with pools but not in great quantities. No mention of seagrasses in relation to Willie Creek is made by Prince (1986), Walker and Prince (1987) or McKenzie and Yoshida (2011).

There is no long-term in situ water quality data available for Barred Creek or Willie Creek; however studies of similar tropical mangrove creek systems within Northern Queensland demonstrate significant tidally driven variation in TSS levels (<5mg/l to >600 mg/l; Bryce et al. 2003). Whilst it is acknowledged that the physical characteristics of the creek systems in Northern Queensland may differ from Barred Creek and Willie Creek, the reported data provides an indication of mangrove tolerance to high and variable levels of TSS in the water column.

It is not known if Barred Creek or Willie Creek are net depositional environments; however, it is known that mangroves are particularly adapted to gradual changes in sediment deposition (Young and Harvey 1996). Given the distance from the proposed dredging activities (> 10 km to Barred Creek from the southern pipeline corridor), it is highly unlikely that there will be significant net sediment deposition within either creek system, that will adversely affect the mangrove communities.

It is acknowledged that there are bivalves present in Willie Creek, Barred Creek and Beagle Bay. A tourist operation also exists in Willie Creek and it is also important to consider the possible impacts of any additional TSS on oysters used for tourism purposes. It should be noted that the tourist operation in Willie Creek suspends oysters in cages above the sediment whereas naturally occurring bivalves will predominantly be buried within the sediment (i.e. infauna) or will be attached to any hard substrate available (mangroves or rock outcrops). Sediment-based infauna in these environments are naturally

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1. To minimise potential confusion by introducing subsets of plume modelling data, estimations of seasonal averages are not presented in the body text. For comparative purposes, a winter average (April to November) and a summer average (December to March) were calculated. For Barred Creek, the entire dredge average was 34.4 mg/l vs a summer average of 65.8 mg/l and winter average of 21.8 mg/l; for Willie Creek it was 19.3 mg/l vs 41.2 mg/l and 10.4 mg/l, respectively (DHI, pers. com.)
adapted to high turbidity and sediment movement and it is at the sediment interface that the highest sediment movement occurs. It is unlikely that the addition of plume-derived TSS or deposition will be measurable against the background of natural variability. It is therefore improbable that any impacts will either occur or be able to be detected on sediment-based bivalves.

In regard to pearl oysters suspended in the water column for commercial purposes, although optimum turbidity thresholds (in terms of suspended sediment) have not been widely investigated for *Pinctada maxima* (or any other pearl species), the only available research suggests that they have a wide tolerance range to suspended material. As turbid water contains substantial fractions of inorganic material, it has usually been considered a disadvantage to filter feeding organisms occurring in these waters. However adaptive strategies such as preferential ingestion of organically-rich particles and effective digestive mechanisms allow maximum energy gains under turbid conditions. *P. maxima*, in particular, is considered well-adapted to environments with high suspended particulate matter (SPM) due to its high ingestion rate and digestive ability. Optimum SPM for *P. maxima* was recorded by Yukihira *et al.* (1999, 2006), in Queensland at between 3 to 15 mg/l, although the environments in which they occurred varied naturally from 2 to 60 mg/l. Anecdotal evidence may exist regarding *P. maxima* and turbidity in the Kimberly but there has been no research worldwide properly addressing the aspect of pearl quality and SPM. The SAR did not predict an impact of TSS on oysters and no further information has come to light suggesting that oysters will be adversely impacted in the ZoI.

The refined modelling also predicts Beagle Bay to be at the edge of the ZoI should the plume travel 60 km to the north of James Price Point. The significant populations of mangroves, seagrass and dugongs are unlikely to be affected by either plume-derived TSS or sediment deposition, as this environment is at the extreme edge of the modelled plume before it meets background concentrations. As noted above and specifically because of the distance from dredging, it is unlikely that the plume will able to be statistically detected against the high background levels of TSS.

**Figure 4.9** shows the locations of three recreational receptors that may be of concern from an aesthetic perspective (Cable Beach North, Gantheaume Point and a location in Roebuck Bay close to Broome). Illustrated in **Figure 4.10** are the predicted TSS values at the three locations identified in **Figure 4.9** over the proposed 21 month period for the Phase 1 dredging. This has been imposed over 2007 and 2008 data as utilised in the SAR. The time histories of TSS are re-plotted in **Figure 4.11** with an expanded y-axis. The high spikes in TSS levels which occur during the summer months have been generated by the passage of several cyclones. The metocean conditions generated by cyclones both resuspend large quantities of deposited material and also tend to generate strong southerly transport.

The modelled time histories of the predicted TSS values at the three recreational receptor locations shown in **Figure 4.9** over a winter (clean water) period for the Phase 1 dredging are shown in **Figure 4.12**. The time histories correlate with the period where natural levels of TSS are at their lowest. Analysis has indicated that the apparent time shift between the behaviour of TSS at the three sites is the result of numerous mechanisms acting in concert. The reasons for the time shift behaviour of TSS include:

- A combination of the various metocean conditions has resulted in a residual dredging plume occurring in a narrow nearshore band. This plume is being influenced by tidally-induced oscillations while being slowly and irregularly advected by a prevailing southward-directed residual current.

- During neap tidal conditions this TSS plume tends to extend contiguously across the mouth of Willie Creek. During spring tide the cross-shore exchange of water in/out of Willie Creek is sufficient to “sever” the plume, leaving a semi-isolated mass of TSS to the south of Willie Creek which continues southward.
• The southward movement of this isolated plume generates long-period oscillations in modelled TSS at North Cable Beach and Gantheaume Pt. Although the periodicity of these oscillations is of the order of two weeks, this periodicity results from the size/shape of the isolated TSS mass and its rate of transport southward.

• At the North Cable Beach and Gantheaume Pt. Locations, the semidiurnal tide superimposes short-term oscillations on these longer period oscillations. These short-term oscillations are not generated by the tide alone, but by a combination of the local tidal excursion and the local gradient in TSS. If a large local gradient in TSS is present, then there will be noticeable semidiurnal TSS oscillations regardless of the tidal phase (but more pronounced if at spring tide). If there is no local gradient in TSS then there will be no noticeable semidiurnal variation in the TSS signal at these two locations, regardless of tidal phase.

• The TSS values at the Broome location respond more directly and more simply to the local tidal range. Although Dampier Creek (adjacent to Broome) is present in the model, it is a regional model and as such the creek is not rigorously described. In its current formulation, the model predicts net deposition within the creek. As a result, low water spring conditions at the Broome time history location is influenced by ebbing water which was slightly clarified while in Dampier Creek, resulting in a temporary reduction in TSS.

• At the locations and times in question, the material in suspension consists almost entirely of the finest sediment fraction with extremely small settling velocities. Within Roebuck Bay, this contributes to what appears in the time series plots to be a “background” concentration on the order of 2 mg/l.
Figure 4-7 Zone of Influence (ZoI) for Phase 1 unadjusted model (left) and imposed southward residual (right). Overlay (black line) shows the predicted ZoI area as presented in the SAR (DSD 2010)
Figure 4.8 Zone of Influence (ZoI) shown as percentage exceedance of threshold, with imposed southward residual current. Overlay (black line) shows ZoI area as delineated in SAR (DHI 2012).
Figure 4.9 The locations of three recreational receptors that may be of concern from an aesthetic perspective (Cable Beach, Gantheaume Point and a location in Roebuck Bay close to Broome) and the receptors adjacent Barred and Willie Creeks.
Figure 4.10  The expected TSS at the three locations identified in Figure 4.9 over the proposed period for the Phase 1 dredging (DHI 2012).
Figure 4.11 The expected TSS at the three locations identified in Figure 4.9 over the proposed period for the Phase 1 dredging re-plotted with expanded y-axis (DHI 2012).
Figure 4.12  A snapshot of the expected TSS at the three locations identified in Figure 4.9 over a winter (clean water) period for the Phase 1 dredging (DHI 2012).
Figure 4.13  A snapshot of the expected TSS at the Willie Creek and Barred Creek over a full dredging simulation year.
5. COMPARISON OF IMPACTS PREDICTED IN THE AGAINST THE REVISED ASSESSMENT

5.1 Overview

Zone of High Impact: This zone corresponds to the area of BPPH that will be permanently lost within and immediately adjacent to the project footprint which is primarily related to direct removal or smothering of habitat and corresponds to the area of BPPH.

The direct removal of substrate (and consequently BPPH) due to dredging and construction activities simulated by the revised assessment approach (including an increase in dredging volume to 34 Mm$^3$) is less than (and confined within) the Port area. The SAR determined the maximum permanent loss of BPPH to be 1138 ha, corresponding to the permanent loss of all BPPH within the Port area. The direct loss associated with the refined layout is less than the maximum loss predicted in the SAR. Therefore, the contribution to the zone of high impact from the dredge footprint (for the revised dredge volume) will not vary significantly from that considered as the worst case in the SAR using both the 500 m and 1000 m buffer.

There are minor differences in the loss for the individual BPPH categories, however, the total loss of BPPH for the revised channel alignment is less than that for the alignment presented in the SAR.

Zone of Moderate Impact: This zone corresponds to the area where BPPH will be subject to a range of physiological effects ranging from sub-lethal stress to mortality, yet recovery in less than five years is likely. In comparison to the results presented in the SAR, the aerial extent of the ZoMI predicted using the revised assessment approach, is much reduced, having a linear extent of approximately 25 km. Without the imposition of a residual southern current, the ZoMI is predicted to extend south to Cape Boileau and north to Coulomb Point. The imposition of the southerly current is expected to confine the ZoMI to the 3 nm coastal zone from James Price Point to just south of Cape Boileau.

Zone of Influence: This zone corresponds to the area in which changes in water quality are likely to be detectable (perhaps visually) but no environmental impact is anticipated. It is considered that the main concerns/receptors for this zone are visual amenity and public perceptions.

The ZoI presented in the SAR was based on a threshold of TSS > 5 mg/l for 5% of the dredging campaign applied to all areas throughout the year. This threshold continues to be applied in the revised assessment approach.

The areal extent of the ZoI presented in the SAR and that predicted using the revised assessment approach for the increased dredging volume of 34 Mm$^3$ (without the imposition of a residual southern current) are similar, however, as a result of the additional dredging volume, the zone extends further north to Beagle Bay. The imposition of the southern residual current results in a more compact ZoI which extends further southward (beyond Cable Beach) than was predicted by the SAR based on the <5 mg/L threshold. The plume is predicted to be offshore of the beach. Based on the revised assessment, it is possible that at some times throughout the dredging campaign, a sediment plume will be visible offshore from Cable Beach, however, this would be driven by the same meteorological conditions that also result in high background TSS values (e.g. storms or cyclonic events). Similarly, it is also possible that a plume may be visible off Beagle Bay at sometimes.

The exceedance plot for TSS > 5 mg/L for southward residual flow, with contouring of all values between 5% and 100%, is presented in Figure 4.7. The plot indicates that between 5 and 30% of the time during the 21 month dredging campaign, a sediment plume may be visible offshore from Cable Beach. Although, this plume may affect the visual amenity of users of the beach, no environmental impact is anticipated as the TSS concentrations are predicted to be below those likely to cause an
impact. Furthermore, the TSS values within the plume are likely to be similar (or less than) those which occur during the highly turbid wet season conditions.

Part 3 of the SAR (DSD 2010) identified the potential for the following aspects associated with the dredging required to establish the BLNG Precinct to have both direct and indirect impacts on marine fauna:

- Marine Site Disturbance and Excavation
- Sediment deposition and turbidity
- Marine noise and vibration
- Marine discharges (routine and non-routine events)
- Invasive marine species
- Light emissions
- Vessel movements

An increase in dredging volume and subsequent increase in dredging duration will increase the exposure of marine fauna to the above aspects. However, given that the SAR determined that the above impacts were either minor or could be successfully mitigated through application of appropriate management and mitigation measures, it is anticipated that the requested change in dredging volume will not have a significant impact on marine fauna.

5.2 Estimation of cumulative impacts from all Phases to develop the 50 Mtpa Proposed Browse LNG Precinct

As the shipping channel, turning basin, navigation aids and offshore anchorage area would be shared by all proponents, the majority of dredging required to establish the Precinct Port area marine facilities would be undertaken during Phase 1 of the Foundation Project. Approximately 70% of the dredging required to fully establish the 50 Mtpa LNG Precinct would occur within the first 21 months of the Project. It is during this phase of the dredging that the majority of direct and indirect impacts to the environment will occur. This percentage is reflected in scale of predicted direct and indirect impacts. Dredging and spoil disposal activities required during Phase 2 (of the Foundation Project – 12 Mtpa to 25 Mtpa) will be wholly confined within the Phase 1 footprint. Impacts arising from Phase 3 activities will be mostly within the phase 1 footprint (e.g. breakwater, export trunkline) with the exception of the northern pipeline corridor. However, given the lack of knowledge on geotech and/or construction conditions and the construction schedule, a definitive assessment of the likely extent of the ZoHI, ZoMI and ZoI resulting from Phase 3 dredging activities is not possible. However, it is anticipated at the northern pipeline that:

Zone of High Impact: already calculated, will be similar to that for the southern pipeline corridor, i.e. direct footprint and sedimentation buffer, however, the total loss calculation of BPPH for the 34 Mm$^3$ dredging volume (considering the revised channel alignment) is predicted to be less than that presented in the SAR.

Zone of Moderate Impact: it is anticipated that this zone (based on the unadjusted dredge model) will extend northward beyond the boundary of ZoHI by approximately 12 km or based on imposed southward residual drift by approximately 2 km. The southward extent of the zone will be fully confined within the ZoMI of Phase 1 activities based on both scenarios.
**Zone of Influence**: it is anticipated that this zone (based on the unadjusted dredge model) will extend northward beyond the boundary of the ZoI identified for Phase 1 by approximately 5 km. The southward extent of this zone will be fully confined within the ZoI of Phase 1 activities based on both scenarios.

It is likely that the three phases will be temporally discrete, as the delay between Phase 2 and Phase 3 activities and the completion of Phase 1 may be as long as 10-15 years. During this period, benthos impacted by Phase 1 activities will have recovered and recolonised in the ZoMI. Therefore, maximum impacts to the BPPH will occur from the construction works undertaken in Phase 1 of the Foundation Project. Any future impacts arising from subsequent phases will effectively be confined within the Phase 1 footprint for ZoMI and ZoI, with the exception of the northern pipeline as discussed above.

### 5.3 Conclusions

The permanent BPPH loss within the ZoHI is contained within the maximum loss predicted in the SAR. The proponent acknowledges that the predicted loss in hectares for a 1000 m buffer is, however, approximately 10% greater than that for the ‘indicative’ port development scenario presented in the SAR (Tables 3-1 and 3-2, Part 7: Supplementary Information, Browse Liquefied Natural Gas Precinct – Strategic Assessment Report, DSD 2011). The ‘indicative port’ development scenario corresponds to one of four conceptual port layout and shipping channel configurations presented in the SAR and only occupies a proportion of the ‘whole’ port development scenario considered to predict the maximum permanent BPPH loss. Further, it should be noted that with the application of a more realistic 500 m buffer based on ongoing Front End Engineering Design (FEED) activities, reliable seabed geotechnical, metocean and bathymetric data and from a more detailed description of the dredging operations anticipated for the construction of the marine facility, the ZoHI would be well within the 1,000 m buffer as presented in the SAR.

The spatial extent of the ZoMI compared to that presented in the SAR will decrease. There will, however, be an increase in the possible extent of the ZoI. It is possible that, at sometimes throughout the dredging campaign, a sediment plume may be visible offshore from Cable Beach, which has the potential to affect the visual amenity of beach users, but there are no environmental impacts associated with this ZoI. Similarly, a visible plume, without accompanying environmental impacts, may sometimes occur off Beagle Bay.

On this basis, it is considered that the proposed increase in dredging volumes to develop the 50 Mtpa proposed Browse LNG Precinct is eligible to be considered under Section 43A of the EP Act.
6. REFERENCES

Bryce, S., Larcombe, P. and Ridd, P.V. 2003. Hydrodynamic and geomorphological controls on suspended sediment transport in mangrove creek systems, a case study, Cocoa Creek, Townsville, Australia. Estuarine, Coastal and Shelf Science 56: 415-431


Environmental Protection Authority (EPA). 2009. Environmental Assessment Guideline No. 3 – Protection of Benthic Primary Producer Habitats in Western Australia’s Marine Environment. Western Australian Environmental Protection Authority, Perth, Western Australia.


